UNDERSTANDING STUDENTS' EXPERIENCES WITH 1:1 COMPUTER-SUPPORTED COLLABORATIVE LEARNING IN A MATHEMATICS CLASSROOM

by

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A dissertation

submitted in partial fulfillment

of the requirements for the degree of

Doctor of Education in Educational Technology

Boise State University

December 2022

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the dissertation submitted by

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Dissertation Title: Understanding Students' Experiences with 1:1 Computer-Supported Collaborative Learning in a Mathematics Classroom

Date of Final Oral Examination: 28 October 2022

The following individuals read and discussed the dissertation submitted by student Oscar Antonio Perales Aguilera, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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DEDICATION

I dedicate this dissertation to “mi familia.” Thank you for instilling in me the notion of “Echale Ganas.” For my wife, Carolina, thank you for your unwavering love, and for being a pillar of strength throughout this journey. You helped make this possible. For my daughter, Olivia, you are the source of my joy and inspiration. For my son, I cannot wait to meet you. Because of them – I am.

ACKNOWLEDGMENTS

First and foremost, I'd like to thank Dr. Uribe-Flórez for her patience, guidance, and understanding throughout my doctoral journey. I also want to thank the other members of my supervisory committee, Profs. Hsu and Trespalacios, for helping me find my voice. I leave Boise State University feeling well and broadly prepared for my professional future.

Thank you to Coach Joshua Sparks for his willingness to collaborate and serve as the dissertation's "fellow teacher." Throughout the process, you greatly aided in shaping and improving my research. Your future is bright, and I look forward to keeping up with your successes.

Lastly, thank you to my coaching family. I'm grateful to Coach Jim Ledford for his unrelenting support and for teaching me the value of family, accountability, and perseverance. You taught and showed me what it means to be a servant leader – in football and in life.

ABSTRACT

There has been a move towards integrating educational technology into K-12 mathematics classrooms. This emphasis has been partly driven by policy, increases in technology resources available, and a need to engage students in their mathematical learning. Most studies on technology integration in mathematics education are focused on teachers' perceptions or students' academic achievement. However, we need to learn how students perceive their learning in this type of environment. This dissertation is a basic qualitative study aimed at understanding the experiences of students with 1:1 computer-supported collaborative learning (CSCL) in an Algebraic Reasoning classroom. The study used the mathematical software, Desmos, as its CSCL system. The school in which this research took place fully implemented a 1:1 student-to-Chromebook program since 2016, and the participants of this study were students in a 1:1 Algebraic Reasoning classroom. The data used in this study were taken from participants' responses to individual semi-structured interviews about their learning experiences with Desmos. Data was analyzed using Kumar et al.'s (2010) framework for effective CSCL systems which encompasses five criterions: (1) Open-ended and guided interactions, (2) interactions that can be stored centrally for meaningful interpretation, (3) predefined collaboration strategies, (4) underlying theories of collaboration represented in the software, and (5) providing active and passive feedback. Results suggest that students' experiences with 1:1 CSCL in Algebraic Reasoning captured all but one them. These elements can inform

educational stakeholders as to how to implement an engaging, innovative, and student-centered 1:1 CSCL mathematics environment.

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ALGEBRAIC REASONING (AR) - Students build on knowledge and skills in algebra 1 by continuing the development of mathematical reasoning related to algebraic understandings and processes through exploration, analysis, and application of functions to deepen a foundation for studies in subsequent mathematics courses (Texas Education Agency [TEA], 2017).

COMPUTER-SUPPORTED COLLABORATIVE LEARNING (CSCL) - Pedagogical approach that uses digital devices such as computers, smartphones, tablets to promote collaboration and student learning. The software system interacts with learners who share and construct subject knowledge that can be monitored and mediated through the software system (Stahl et al., 2006).

COLLABORATIVE LEARNING STRATEGIES - Instructional materials that use cooperation and collaboration components to influence how learners process information. These strategies engage teachers and learners as active participants in the educational process, intended to create a sense of community where knowledge is created in the outside environment to be internalized by each learner (Chung, 1991).

LEARNER TO LEARNER (L2L) INTERACTIONS - Collaborative online interactions between students that take place and are recorded using the CSCL software (Kumar et al., 2010).

LEARNER TO SOFTWARE (L2S) INTERACTIONS **-** Collaborative online interactions between students and digital tools that take place and are recorded in the CSCL software (Kumar et al., 2010).

DESMOS **-** Online graphing calculator software with a suite of classroom activities for use in secondary classrooms with the goal of helping teachers and students maximize mathematical learning with digital tools.

CHAPTER ONE: INTRODUCTION

Integrating technology in mathematics education could empower learners to construct knowledge through computational thinking and innovative design. It has the potential to develop responsible digital citizens with effective communication and collaborative skills (International Society for Technology in Education [ISTE], n.d.). Strategic use of technology in a student-centered learning environment strengthens mathematics teaching and learning and engagement (Dick & Hollebrands, 2011; Kiru et al., 2018; National Council of Teachers of Mathematics [NCTM], 2015; Ozel et al., 2008; Renwick, 2016; Suh et al., 2008). Technology integration strategies in mathematics education could support the learning of skills and knowledge that may affect student performance in state assessments.

Integrating technology is increasingly affecting education and the way students are learning (An & Reigeluth, 2011). Reviews of research on the impact of technology on learning over the last 40 years have found that technology integration, particularly when used to support instruction rather than direct instruction, is beneficial (Tamim et al., 2011). Rather than replacing teaching, technology should enhance it. Literature suggests that technology integration could positively affect students' attitudes toward learning (Hilton, 2018), engagement (Afari et al., 2013; Hilton, 2018), and understanding (Reiten, 2018).

Students in a computer-supported collaborative learning (CSCL) environment with a 1:1 student-to-computer ratio have access to technological devices (e.g., laptops, smartphones, tablets) that can be integrated into the learning process. This approach has the potential to have a significant impact on teaching and learning (Law, 2008) by encouraging knowledge construction and reflective thinking (Jonassen, 2009), and fostering a social climate that reflects the complexity of the real world (Jonassen, 1995; Lin & Liang, 2014).

A potential approach for technology integration is to adopt a 1:1 CSCL environment as an engaging and meaningful anchor for student mathematical engagement and understanding (Delgado et al., 2015). A CSCL environment could foster group learning and collaboration (Abdu et al., 2015; Danielson & Meyer, 2016; Silverman, 1995) by facilitating cohesion and shared responsibility among learners (Oikarinen et al., 2014). This form of collaborative knowledge construction is enabled by learning environments that foster reflective practice through social interactions (Jonassen, 1994, 1995). Thus, a CSCL environment in a mathematics classroom has the potential to provide students with collaborative virtual explorations, real-world applications, and real-time feedback through the medium (Danielson & Meyer, 2016; Kumar et al., 2010).

Underrepresented students in math classrooms could benefit from such an environment. To help educators better recognize the impact of integrating technology as part of the teaching and learning process, it is necessary to understand students' experiences while using the tools. The voices of students who are already at a disadvantage, like retesters, should be acknowledged, especially in technology-enhanced mathematics classrooms. This population are students who passed the algebra 1 course but failed to pass the state algebra 1 exam. Many of the retesting students come from marginalized backgrounds, such as English language learners (ELLs) and students requiring special education services, further widening their achievement gap compared to students in the general population.

As outlined in Table 1, compared to first-time testers, retested students overwhelmingly performed below expectations, with only 30% passing the State of Texas Assessments of Academic Readiness (STAAR) algebra 1 in 2019 compared to 20% in 2021. Many of the retested students who struggled are from certain subgroups (e.g., at-risk, ELLs, special education).

Table 1 **STAAR Algebra 1 Passing Scores in Texas Comparison**

	2019	2021
First Time	84%	72%
Retesters	30%	20%

Note: Adapted from Texas Education Agency [TEA] (2022). Percentages are of students who reached the minimum passing score.

Coronavirus disease (COVID-19) had a significant impact on STAAR algebra 1 exam performance. Because of the pandemic, the 2020 STAAR exams were canceled, leaving a "gap." According to preliminary data analysis from Texas Education Agency (TEA, 2020), STAAR results showed a decrease in academic performance with a larger decline in math than reading. This negative impact of COVID-19 contributed to the achievement gap, in which economically disadvantaged students suffered greater learning loss. According to the report, remote learning appeared to also contribute to this decline (TEA, 2020). With the shift to online administration of STAAR exams, students are expected to receive accommodations like those in the classroom (TEA, 2020). In order to prepare them for success in the 21st century, there is a need to focus on personalized, flexible, and empowered learning that meets the varying needs of all students (TEA, 2018). The goal of this study was to understand students' experiences with 1:1 CSCL in an algebraic reasoning course.

Theoretical Framework

A Computer-supported collaborative learning (CSCL) classroom has the potential to be a social constructivist environment that provides students with multiple means of collaborative interactions via technology (Abdu et al., 2015; Silverman, 1995). It could foster group learning (Abdu et al. 2015, Danielson & Meyer, 2016) through learner to learner (L2L) and learner to software (L2S) interactions (Kumar et al., 2010). A CSCL environment can facilitate cohesion and responsibility, while also reducing students' detachment from classroom discourse (Oikarinen et al., 2014). The ability to participate in an interactive environment where collaboration is encouraged seems to foster and facilitate mathematical learning processes (Danielson & Meyer, 2016; Jonassen, 1994; Oikarinen et al., 2014).

This study adopted the CSCL framework used by Kumar et al. (2010). The framework established five design criteria used to assess a CSCL system. The criteria focused on CSCL interactions (i.e., open-ended, guided), accessibility of previous interactions, predefined collaboration strategies, collaborative theories, and passive or active feedback (Kumar et al., 2010). These are discussed further in Chapter 2 and are listed in Appendix B. In their study, Kumar et al. implemented the CSCL framework as an assessment of a trace-based software system. This tool captured L2L and L2S interactions, facilitated real-time recognition, and analyzed student responses and their collaboration throughout the learning process.

Although a 1:1 CSCL environment has the potential to impact student engagement (Danielson & Meyer, 2016; Oikarinen et al., 2014; Silverman, 1995) and collaboration (Abdu et al., 2015; Jonassen, 1994, 2000), research focused on students' perceptions of their collaborative mathematical experiences within the medium was not found. The basic qualitative study for this dissertation explored students' experiences with a 1:1 CSCL environment in an algebraic reasoning course.

Purpose Statement and Research Questions

The purpose of this qualitative study was to understand students' experiences with 1:1 CSCL in a secondary mathematics class. Using Kumar et al.'s (2010) CSCL framework, the study aimed to answer the central question (CQ): What are students' perceptions of their experiences with a 1:1 CSCL in an algebraic reasoning course?

More specifically, there are two subquestions (SQs) addressing aspects of CSCL.

The SQs are:

SQ1: What are students' perceptions of their interactions with 1:1 CSCL in an algebraic reasoning course?

SQ2: What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

This first SQ places the focus of the study on what happens to student learning during the 1:1 CSCL interactions in mathematics. The emphasis is more about capturing students' nascent thinking about their experiences with the CSCL activities. The second SQ focuses on the collaborative strategies described by students when learning algebra in a 1:1 CSCL environment. SQ2 focus on students' experience as they consider these activities on a metacognitive level, with an emphasis on the collaborative strategies embedded in the CSCL activities. Following the coding of students' responses, data from student interviews were analyzed and identified for emergent themes, and how these themes aligned with the CSCL framework (Kumar et al., 2010).

Significance of the Study

The findings of this study contributed to the existing body of literature regarding students' perceptions of their experiences in a 1:1 CSCL environment. Although this study focused on a specific sample of students (i.e., retesters in my algebraic reasoning classes), it may provide a foundation for further research regarding 1:1 learning environments and mathematics education. Expanding the research base may provide information useful for improving student collaborative learning in secondary mathematics.

Participants in this study had the opportunity to reflect on their experiences within a 1:1 CSCL environment while using Desmos in an algebraic reasoning course. The information provided could be useful for stakeholders in the school system for improving online collaborative learning in mathematics education at the secondary level. The insight into students' experiences provided by the study may be helpful in the planning of professional development opportunities for secondary mathematics teachers implementing a 1:1 CSCL environment in their classrooms.

Methodology Design

A basic qualitative design was the appropriate approach for this study (Merriam, 2009; Merriam & Tisdell, 2015), as it aims to provide breadth and depth on the central phenomenon of exploring students' experiences with 1:1 CSCL in mathematics (Creswell

& Plano-Clark, 2018). The emphasis is on students' perceptions and interpretation of their experiences with their environment (Merriam, 2009; Merriam & Tisdell, 2015).

A nonprobabilistic sampling approach (i.e., volunteer sampling) was used in this study as it allowed the researcher to select individuals living the experience who were available and willing to participate (Creswell & Plano-Clark, 2018). Of the students in the algebraic reasoning sections, a sample of nine students volunteered and were selected to be interviewed to develop an in-depth understanding of the central phenomenon (Creswell & Plano-Clark, 2018).

In this study, data included students' responses to semistructured interviews about their experiences with 1:1 CSCL in algebra. The individual interviews were used to bring context and help understand students' experiences with collaborative learning in an online environment. These semistructured interviews allowed the researcher to ask open-ended questions without response options and to audio record the responses of the participants (Creswell, 2015). This allowed for the flexibility of including additional follow-up questions as needed. The research questions proposed in this study align with Kumar et al.'s (2010) CSCL framework and guided the interview questions. Participant interviews were conducted during the spring 2021 semester. The interview protocol is provided in Appendix A.

Researcher's Role

I, the researcher, am a high school math teacher with nine years' experience and training in using technology for teaching and learning mathematics. Because I am trained in secondary mathematics education and using technology in the classroom, I am knowledgeable about the topic being researched (Saidin & Yaacob, 2016).

Given that the primary researcher is also the teacher on record for the algebraic reasoning course, two primary roles needed to be defined. From the teacher perspective, the researcher implemented 1:1 CSCL strategies by using Desmos as part of the weekly instructional practice. Since the primary researcher is a high school math teacher in the school system being studied, it is important to address the concern of insider bias. This potential bias could invalidate the research, as the teacher is also the researcher. For example, subjects might assume that the teacher/researcher would determine their grade based on their interview question responses and thus would not provide as much in-depth information (Saidin & Yaacob, 2016). This potential issue was addressed by having a fellow teacher conduct the student interviews. Additionally, the interview questions were prestructured and based on the CSCL framework (Kumar et al., 2010). This eliminated the potential for asking leading questions. If clarifications were necessary, the participant was asked to elaborate on an answer by the interviewer.

From the researcher perspective, data were collected and analyzed from students in the researchers' algebraic reasoning courses. Semistructured interviews allowed the interviewer to identify follow-up questions that served as a window into students' experiences with learning math in a 1:1 CSCL environment. The interviewer collected data, but the primary researcher oversaw the data analysis process. The interviews were audio-recorded as a way to avoid potential bias. I gained consent from the necessary parties (i.e., district, administration, parents, students) before conducting this study, and received Institutional Review Board (IRB) approval from Boise State University.

Chapter 1 Summary

This chapter describes the basic qualitative study while providing insight into its significance to the field of student learning in a 1:1 CSCL environment in an algebraic reasoning course. It also describes the purpose of the study, which is to explore students' experiences with 1:1 CSCL in algebra. Kumar et al.'s (2010) CSCL framework guides this research study. The authors provide the five criteria for CSCL environments: open-ended and guided CSCL interactions, observed CSCL interactions can be stored centrally and meaningfully interpreted, predefined collaboration strategies represented in the software, underlying theories of collaboration can be meaningfully interpreted, and the CSCL system provides active and passive feedback.

The study aims at answering the CQ: What are students' perceptions of their experiences with 1:1 CSCL in an algebraic reasoning classroom? The SQs include: (SQ1) What are students' perceptions of their interactions with 1:1 CSCL in an algebraic reasoning course? (SQ2) What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

A basic qualitative approach for this study was chosen. The researcher served the dual role of primary investigator and teacher. Because of this, the researcher needed to distinguish between the two throughout the study. Students interacted within the 1:1 CSCL environment with me as a classroom teacher. From a researcher's standpoint, however, the semistructured interviews were conducted by a fellow teacher to avoid potential insider bias.

The second chapter reviews the literature regarding technology integration in K-12 mathematics classrooms, learning mathematics in a 1:1 CSCL, and students' perceptions of using technology in the mathematics classroom. Chapter 3 describes the methodology of this qualitative study. The findings answering the study's SQs are presented in Chapter 4, including a description of themes from the data analysis. Chapter 5 discusses these findings using the literature on the topic and connects the themes to the theoretical framework to answer the study's CQ, and the implications and recommendations for future research.

CHAPTER TWO: LITERATURE REVIEW

Since the turn of the century, the United States has experienced a steady increase in interest and investment in computer technology for education. This was evident in No Child Left Behind (NCLB)'s goal to improve academic achievement using technology in elementary and secondary schools (United States Department of Education [DOE], 2010). The integration of technology in K-12 classrooms has been a focal point for many districts as they are tasked to meet the demands of rapidly changing demographics, the globalization of the economy, and the technological and cultural changes of the 21st century (Darling-Hammond & Bransford, 2005).

The ISTE standards have stated that a goal of technology integration is to develop students who are prepared to thrive in a constantly evolving landscape (ISTE, n.d.). Empowered learners who construct knowledge through computational thinking and innovative design in a technology-enhanced learning environment may support a student-driven process to learning. Technology integration has the potential to impact student learning (Keengwe et al., 2008; Liu, 2007) and engagement (Renwick, 2016) through social collaboration. This leads to responsible digital citizens with effective communication and collaborative skills (ISTE, n.d.).

To support districts in their pursuit of technology integration, the DOE's (2010) report on technology in education has cited three requisites for effective integration. The first requisite is to provide equitable access to technology for all students. Providing access to technology for all has been a long-term goal that is coming to fruition and continues to evolve based on technological advancements. To promote effective and sustainable integration of technology, schools must provide students with a digital device and reliable internet access that engages students in inquiry and wonder (Barron et al., 2003). The second requisite for effective integration is teacher expertise. Teachers must be able to use and implement digital tools within the curricula to best engage students in collaboration and discourse. The third requisite is to provide teachers with timely access to technical support (DOE, 2010). By providing effective and efficient technical support, teachers are more willing to take the risks needed to explore and integrate technologies in their classroom (Howard, 2013). All these requisites must first be addressed before effective technology integration in the classroom may take place.

The Office of Educational Technology has released a *National Educational Technology Plan* (NETP) that expands on the requisites. It is a national vision plan for learning enabled by technology that serves as a call to action, and it provides a collection of recommendations and real-world examples to educators, administrators, and policymakers (DOE, 2017). One of the goals of this plan is to use technology to transform learning experiences, which would provide greater equity and accessibility to all learners. According to the report, most classrooms in the United States have access to digital tools and broadband, but it acknowledges that those classrooms that do not have it are in communities where the "potential impact is the greatest" (DOE, 2017, p. 1). It is key to note that having access to technology does not equate with learning (Keengwe et al., 2008).

As technology continues to improve, smaller and more portable laptops available at lower costs have increased the access of laptop computers to students at a 1:1 ratio.

Most K-12 teachers now have at least one digital device in the classroom (Delgado et al., 2015). Because of the current presence of devices in the classroom, it is important to identify themes of effective technology integration, specifically in secondary mathematics classrooms and from the students' perspective.

In Maninger and Holden's (2009) study, middle school campuses that provided students with their own digital devices were found to develop a more communicative, collaborative, and supportive school environment. However, the researchers found integration of technology in secondary settings was lagging behind that of other grades. In Barron et al.'s (2003) large-scale study on technology integration, most high schools used computers primarily for research or computer-assisted instruction (CAI), such as Khan Academy and Edgenuity, whereas elementary and middle schools use computers more to promote problem-solving and communication. These are essential 21st century skills for students to compete and succeed in a global society.

When it is carefully designed and applied, technology can accelerate, amplify, and expand the impact of teaching practices, but requires educators to have the knowledge, skills, and confidence to take advantage of a technology-enhanced learning environment (DOE, 2017). These factors significantly influence the integration of technology in the classroom (Drenoyianni & Selwood, 1998; Gorder, 2008; Pierce & Ball, 2009).

Technology is changing education by impacting how K-12 educators integrate digital instructional strategies to help students acquire the skill sets to prepare them for college and a career in the 21st century (Delgado et al., 2015). Technological tools, when used properly, as an instructional strategy could impact student collaboration, engagement, and performance.

Understanding students' experiences with the tools is important for helping educators incorporate technology in the teaching and learning process. The voices of students who are already at a disadvantage, such as retesters, should be acknowledged, especially in technology-enhanced mathematics classrooms. This chapter first presents the theoretical framework, followed by Kumar et al.'s (2010) CSCL framework. The chapter then presents a review of literature on technology integration in K-12 mathematics classrooms, learning mathematics in a 1:1 CSCL environment, and students' perceptions regarding technology integration.

Theoretical Framework

The theoretical framework of this study is the CSCL framework proposed by Kumar et al. (2010). This section begins with social constructivism theory to understand the foundation of sociocollaborative learning and its relation to a CSCL environment. Computer-supported collaborative learning is then explained, and finally Kumar et al.'s (2010) CSCL framework is discussed.

Social Constructivism Theory

Constructivism proposes that learning environments should support multiple representations, knowledge construction, and context-rich activities for students (Jonassen, 1991). Social constructivism theory is based on the idea that people learn from interactions with their environment to internally construct knowledge. This set of assumptions about learning and the processes for supporting it differs from the traditional approach to designing instruction (Jonassen, 1991). It places less of an emphasis on the sequence of instruction and focuses more on the learning environment (Jonassen, 1994). Student learning in this setting is evaluated through knowledge construction in real-world contexts, which require authentic learning tasks with multiple perspectives and viewpoints (Jonassen, 1991). A key component of social constructivism is Vygotsky's (1962) zone of proximal development (ZPD). Vygotsky has categorized tasks into three zones: a) tasks that cannot presently be performed by the learner, b) tasks that can be carried out with outside support (e.g., teacher, classmate), and c) tasks the learner can complete without any assistance. The second category is better known as the ZPD, and it is the space within which learning takes place (McLaren, 2010). As the range of the ZPD expands, more complex tasks are built on the foundation of simpler ones. Vygotsky (1962) has attributed language as the key element to the ZPD's expansion and impact on student learning. Language is used by the facilitator to guide, direct, and correct with the intention to pass the control of the activity from the teacher to the learner. Thus, the collaboration between the learner and the outside source (e.g., teacher, classmate, learning environment) is not to be undervalued in the acquisition of student knowledge (Jonassen, 1995).

Social constructivism theory applied in a classroom requires an environment that allows students to collaborate and interact with others and with tools where meaningful learning is active, reflective, and intentional (Jonassen, 1995). Rather than solely focusing on the acquisition of knowledge, it is the responsibility of teachers to provide learners with as many opportunities to actively process their constructions (McLaren, 2010). Previous studies (Davidson & Worsham, 1992; Vygotsky, 1962) have shown that students are more likely to develop a deep, conceptual understanding of mathematics when they engage in discourse with others. This collaborative environment creates an opportunity for students to "bounce" ideas off each other, making mistakes, correcting mistakes, and learning from each other.

Sociocollaborative Learning

Sociocollaborative learning aims at minimizing the teacher-centered lecturing model in favor of student learning through group collaboration. The underlying assumptions of sociocollaborative learning is that students learn through constructivist ideals, such as active experimentation and reflection discussion in group settings (Silverman, 1995). To accomplish this, teachers need to create a learning environment that is flexible enough to cater to students' strengths, foster exploration, and provide seamless communication between their peers, medium, and teacher (Danielson & Meyer, 2016; Jonassen, 1995; Silverman, 1995).

Technology in this type of socioconstructivist environment is known as CSCL (Abdu et al., 2015; Silverman, 1995) and has the potential to foster student learning (Abdu et al. 2015, Danielson & Meyer, 2016). This approach to learning with technology may engage and support student knowledge construction as learners and technology share cognitive responsibilities (Jonassen, 1995). Here, technology thinks with students instead of thinking for students. Observations in Fonkert's (2010) study have suggested that integrating technology, such as a computer, could enhance communication among students while also increasing their ability to explore concepts and conjecture. The role of such technology in the classroom as a tool, intellectual partner, and simulator of meaningful context facilitates the thinking and knowledge construction of students (Jonassen, 1995). This is consistent with NCTM's (2015) statement that incorporating technology and cooperative learning in the classroom deepens students' learning, experiences, communication, and understanding of mathematics.

There is increasing potential for computers to help teachers create a CSCL environment. In their study, Abdu et al. (2015) arranged students into small groups and developed a learning environment where they facilitated Learning to Learn Together, a framework that focused on building student collaboration within a computer-supported mathematics environment. The researchers have observed that a mathematics classroom that fosters students' problem-solving skills and features a social dimension that encourages group learning positively influenced students' ability to solve mathematical problems together (Abdu et al., 2015). These collaborative learning environments facilitate cohesion and responsibility, while reducing students' detachment from classroom discourse (Oikarinen et al., 2014). The ability to participate in an interactive environment where collaboration is encouraged seems to foster and facilitate the mathematical learning processes (Danielson & Meyer, 2016; Oikarinen et al., 2014). Danielson and Meyer (2016) have identified their principles for CSCL as combining quality provocations (i.e., real-world applications), robust tools to connect students (e.g., virtual manipulatives), and skilled teachers (i.e., facilitators and designer of learning environment), which help students build mathematical understanding, vocabulary, and skill.

Computer-Supported Collaborative Learning Environment

Designing a CSCL environment is worth further exploration as human mental functioning originates during communication and is inherently social (Abramovich & Connell, 2014). The learning environment relates to the sociological, psychological, and pedagogical context of the teaching and learning process that affects students' attitudes and achievements (Lin & Liang, 2014). The interaction between pedagogy and technology in this setting produces exciting new stimuli for student learning (Danielson & Meyer, 2016; Fullan & Langworthy, 2013).

A CSCL environment refers to several uses of technological devices (e.g., laptops, smartphones, tablets) to promote student learning. These mediums can be used in education to provide students with intelligent tutoring systems, CAI, and interactive multimedia learning environments (Lajoie & Naismith, 2012). Even if a classroom has access to digital devices, a classroom that does not implement technology for instructional purposes is not considered a CSCL environment. A CSCL approach can enable the attainment of desired scholastic and educational goals and makes a meaningful impact in the teaching-learning process (Law, 2008). Activities within CSCL should represent the complexity of the real world, promote a social climate (Jonassen, 1995; Lin & Liang, 2014), invite the construction of knowledge, and encourage reflective thinking (Jonassen, 2009).

Collaboration can be defined as the construction of shared understanding through the interaction with others as they are all engaged in completing the same goal (Oikarinen et al., 2015). A CSCL environment is an educational setting in which computers and software are incorporated to aid in the construction and assessment of individual and collaborative learning tasks (Winne et al., 2010). It can foster social, motivational, and cognitive learning across individual, small-group, and large-group settings using tools that increase student interactivity and it can effectively guide collaborative processes

(Gress et al., 2010). A CSCL environment explores the social nature of learning through collaboration among students and students and computers (Kumar et al., 2010).

In these CSCL environments, student work, software interactions, and the creation of learning objects can be tracked (Kumar et al., 2010; Soller, 2004). A CSCL approach to learning differs from the commonly used CAI in that it focuses on the shared interactions between the software system and the student, rather than the computer simply providing students with passive yes or no feedback (Kumar et al., 2010). The software used in the CSCL environment can monitor these interactions and be mediated passively or actively by the software system or teacher. In such 1:1 learning environments, the software system interacts with a select group of students who impart subject knowledge as a byproduct of a collaborative learning strategy, which may be monitored and mediated passively or actively through the software system (Danielson & Meyer, 2016; Kumar et al., 2010). Students can discuss their learning strategies, their understanding, and their challenges with their fellow peers, mediated by a software system (Kumar et al., 2010).

Like a biological organism or geological formation, a CSCL environment is a complex system consisting of multiple independent entities with interconnected functions seeking a common goal via adaptive processes (Margaryan et al., 2011; Ni & Branch, 2008). In their complexity theory, Ni and Branch (2008) have argued that being able to manage these complex situations is a function of study and practice. The more one understands and practices within the environment, the more manageable the system. These systems all have three key attributes in common: (a) independent and complicated entities, (b) variety of entities, and (c) all functions are interrelated and communicate with a common goal (Ni & Branch, 2008). It is not the sum of its parts, but the result of the parts and their interactions (Davis & Simmt, 2003).

A 1:1 CSCL environment is a purposeful, problem-solving systems approach that utilizes tools, techniques, and methods from various knowledge domains (Luppicini, 2005). Complexity theory in mathematics education investigates the computational resources required for effective problem-solving (Burgisser et al., 1997). Like complex systems, mathematics classes are conducive to an adaptive and self-organizing learning environment (Davis & Simmt, 2003). In this environment, the teacher's focus is on establishing a mathematical community conducive to learning and interaction. The suggestion is that complex systems support an individual learner's mathematical understanding (Davis & Simmt, 2003). Thus, engaging a mathematics class in a CSCL setting is a challenging, but worthwhile task if it impacts on their mathematical understanding (Abdu et al., 2015; Pettenati & Cigognini, 2007; Takaci et al., 2015) and attitudes toward the subject (Lopez-Morteo & Lopez, 2007).

Computer-Supported Collaborative Learning Framework

Bruner (1966) has argued that designing an environment that enables learning by doing in which students are actively engaged through exploration and creation is an elemental challenge for teachers. A CSCL setting may be able to support this type of environment (Kay & Goldberg, 1977; Rick & Lamberty, 2005). Students in the classroom can construct digital content that is coupled with other learning activities (e.g., mathematics), which allows learners to share, discuss, and reflect upon their own and shared ideas (Jonassen, 1995; Kumar et al., 2010).

In this study, I used the CSCL framework designed by Kumar et al. (2010) in their review of computing and its role in collaboration. The authors have found that many CSCL tools focused on self-report and content delivery but failed to capture a clear understanding of students' collaborative interactions in real time. Kumar et al. (2010) have argued for a need to utilize CSCL environments to augment solo and shared learning activities with immediate feedback. They have applied their framework to the assessment of a trace-based software system named gStudy (Winne et al., 2006). gStudy is a cross-platform software tool for researching the underlying processes of learning (e.g., individual, and collaborative mathematical discourse). This CSCL tool L2S and L2L interactions, facilitating real-time recognition and analysis of student responses and collaboration throughout the learning process. The purpose of this CSCL framework is to provide multiple collaborative opportunities while capturing all learner activities and the full context of their interactions (Kumar et al., 2010).

Kumar et al. (2010) have highlighted and implemented five-core criteria they deem necessary for advancing CSCL systems. In their CSCL framework, they have first noted that (1) CSCL interactions can be both open-ended (e.g., students explaining their thinking) and guided (e.g., sentence prompts), as they can be shared to everyone in the classroom. Examples of these interactions in an online setting include browsing or posting a response to a prompt (i.e., open-ended). Guided CSCL interactions may include sentence stems or prompts by the software based on student responses. The ability to (2) observe these CSCL interactions by both the students and teacher in real-time interaction, and the ability to store them centrally to interpret is the second criterion. Kumar et al. (2010) have argued that keeping all interactions in one place allows learners and teachers to inspect, share, and compare their interactions with others. The third criterion for Kumar et al.'s (2010) CSCL framework is that (3) predefined collaboration strategies and tactics are represented within the instructional design. These strategies are embedded within the software and are independent from the domain of collaboration. An example of this predefined strategy is Desmos Polygraph. The activity is designed for L2L interactions but requires students to engage in discourse for it to function. The Polygraph activity is discussed further later in this chapter.

The fourth criterion is that (4) underlying theories of collaboration can be represented in CSCL interactions and can be meaningfully interpreted within the theory. Examples of these collaborative interactions include self-, co-, and shared-regulated learning within the CSCL system (Boekaerts et al., 2005; Hadwin et al., 2010; Winne & Hadwin, 1998; Zimmerman, 2000; Zimmerman et al., 1996**).** The fifth criterion is that the (5) CSCL environment needs to provide both active and passive feedback. The authors have argued for feedback as the integral component in a CSCL environment, as it allows learners and teachers to observe the results of interpretations of their thinking to offer appropriate feedback. Table 2 shows a summary and examples of each CSCL framework criterion.

Kumar et al. (2010) have identified a need for a singular platform on which teachers compare the learning practices of many students. They have described a CSCL environment that provides tools and methods that capture solo and shared learning activities on a single platform. gStudy has features that directly scaffold and save learners' responses and collaborations (Winne et al., 2006). This information is then shared back to the learner(s) in the form of real-time feedback. Students can observe the products of their learning and the process of how they learned it, which provides them with opportunities to reflect on their understanding and the understanding of others. Additionally, these computationally formal recordings of learning interactions allow teachers to observe how students learn and interact (i.e., L2S, L2L), thus actively promoting self- and coregulation (Kumar et al., 2010).

Table 2 Computer-Supported Collaborative Learning Framework: Criteria and Examples

Core Criteria

	1	2	3	4	5
Criterion	Open-ended and guided CSCL interactions.	Observed CSCL interactions can be stored centrally and meaningfully interpreted.	Predefined collaboration strategies represented in the software.	Underlying theories of collaboration can be meaningfully interpreted.	CSCL system provides active and passive feedback.
Examples	Open-ended browsing, making posts, annotating. Guided: Sentence stems in chat, real-time prompts from the system.	Google Classroom, Canvas, Desmos, GeoGebra.	Desmos Polygraph activity.	Self-regulated, coregulated, and shared-regulated collaborative learning.	Active feedback: Graphing calculator applications. Passive feedback: Help menus, Google Classroom chat.

Note: Kumar et al. (2010)

Impact of Computer-Supported Collaborative Learning Environments on Student Learning

Several studies have investigated the impact of CSCL environments on student learning. Prinsen et al.'s (2009) study of student communication in a CSCL classroom has shown that students write longer and more elaborate messages to their peers, while other studies (Marjanovic, 1999) have reported student increases in problem-solving, critical thinking, and written communication. In terms of student engagement, CSCL classrooms have been shown to have positive student attitudes toward enjoyment, motivation, and learning (Gomez et al., 2010).

Mathematics education has also benefited from CSCL environments. Studies have shown that a CSCL system, such as computer math-based games, can increase active engagement, decrease off-task behaviors, and increase math performance among students with attention-deficit hyperactivity disorder (DuPaul et al., 2011; Kang & Zentall, 2011). The impact of the CSCL environment on student learning is not exclusive to students with learning disabilities but can benefit all students. For example, Duhon et al.'s (2012) study of students who used a CSCL environment to practice subtraction facts experienced an increase in math performance.

Computer-supported collaborative learning technologies, such as the interaction whiteboard (Hwang et al., 2006; Miller et al., 2004; Torff & Tirotta, 2010), have been found to produce enjoyment in learning math and collaboration when solving problems. An increased motivation to learn (Miller et al., 2004; Torff &Tirotta, 2010) has been evident from students' increased communication and articulation of ideas (Evans et al., 2011; Rick et al., 2011). Furthermore, CSCL classrooms have been shown to increase student interest in advanced math (Starcic & Zajc, 2011) and increase the speed of correctly solving math problems (Segal, 2012). These students have reported higher levels of learning (Hertz-Lazarowitz & Bar-Natan, 2002) and participated more equally when collaborating (Fjermestad, 2004; Janssen et al., 2007). Environments deploying CSCL have also been shown to have higher levels of student satisfaction compared to students in traditional classroom settings (Fjermestad, 2004; Jarvela et al., 2015).

The ability for learners to participate in collaborative knowledge-building activities is a core ability that schools should cultivate to prepare students to flourish in the 21st century (Bereiter, 2002; Roschelle, 2013). This focus on collaboration is evident in the Common Core Standards for Mathematics which targets augmentation and communication practices to develop mathematical proficiency (Common Core State Standards Initiative, n.d.). A CSCL environment is a setting that provides teachers and students with digital tools with the potential to enhance student learning and engagement through collaborative activities within a single platform (Dillenbourg & Evans, 2011). This type of collaborative learning environment, however, requires new classroom norms, as students and teachers are tasked with new roles and responsibilities (Heid et al., 1990). This CSCL environment is designed to support and enhance human interaction and teamwork (Marjanovic, 1999).

Integrating technology in the classroom is not sustainable on its own in significantly changing teachers' practices and students' outcomes (Mishra & Koehler, 2006). These positive effects of technology in learning environments are more of a reflection on how well technology is used instead of on the medium itself (Guerrero et al., 2004; Lowther et al., 2003). Using technology to automate traditional methods of teaching and learning would not make a substantive impact on student learning (Clark, 1983). The teacher should be enhanced and not replaced by the medium. Instead, effective CSCL in a math classroom augments the learning of all students by providing a diverse instructional model, is student-driven, and makes the teaching and learning process more meaningful and rigorous (Ozel et al., 2008).

Technology in K-12 Mathematics

Critical reviews of technology integration in the 21st century K-12 classroom have identified several themes. Harper and Milman's (2016) review of research published on 1:1 technology in K-12 classrooms has identified five themes. The themes include effects on student achievement, changes to classroom environment, classroom uses, effects on learner motivation and engagement, and challenges to classroom integration. Many of the studies reviewed were mixed methods and qualitative. Quantitative studies have focused on the effects on student achievement, learner motivation, and engagement. Mixed methods and qualitative studies have concentrated on the themes of changes to classroom environments, classroom uses of technology, and challenges to integration (Harper & Milman, 2016). Research studies have focused primarily on technology integration in secondary (6th–12th) classrooms and reports on students' experiences are scarce.

Delgado et al.'s (2015) review has focused on the transitions and evolution of technology integration in education, the resources to fund it, and the challenges of using technology in education. Their findings have indicated that the reported ratio of students-to-devices has improved significantly, from 11:1 to 1.7:1. Higher ratios of students per device in some schools were due primarily to limited resources (Delgado et al., 2015). As previously mentioned, providing equitable access to technology for all students is needed for effective technology integration.

The integration of technology to promote mathematical learning experiences in the high school classroom is the focus of this study. The National Council of Teachers of Mathematics (NCTM, 2000) lists technology as one of its six principles of school mathematics. Rather than focusing on just the correctness of an answer, used appropriately, technology could help students develop a deeper understanding of mathematics by emphasizing decision making, reflection, reasoning, and problem-solving (NCTM, 2000). Technology integrated in mathematics classrooms has been investigated by researchers for a number of years. Findings on the effects of technology integration in mathematics have included positive attitudes toward learning (Li et al., 2016; Magen-Nagar & Steinberger, 2017), increased student achievement (Lowther et al., 2003) and conceptual understanding (Reiten, 2018), and a higher engagement in mathematics (Hilton, 2018; Ozel et al., 2008). A shift from a traditional approach to teaching mathematics (i.e., a "sage on the stage"), teachers in technology-enhanced classrooms are provided with the opportunity to serve as facilitators (i.e., a "guide on the side") in a sociocollaborative learning environment (Cicconi, 2014). This learning environment allows students to develop new ways of interacting with peers and software through collaborative strategies (Danielson & Meyer, 2016; Heid et al., 1990; Kumar et al., 2010; Lopez-Morteo & Lopez, 2007).

Additionally, a new genre of real, meaningful, and engaging mathematical problems is made possible using technology, where students no longer rely solely on external proof authorities (i.e., teacher, book), but instead learn to justify their work in a technology-enhanced, sociocollaborative environment (Danielson & Meyer, 2016; Heid et al., 2002), where students can accept greater ownership of their learning. Thus, the challenge for teachers is to design a sociocollaborative, technologically enhanced, mathematics learning environment that engages students in their learning.

Researchers have presented different frameworks for implementing technology in mathematics classrooms. For successful integration, Masalki and Elliot (2005) have identified three main factors. The first is for schools to provide students and teachers with access to the appropriate educational technology. Most districts now support technology integration and provide students and teachers with the necessary tools and resources. The second factor is providing teachers with meaningful and applicable professional development on how to effectively use and integrate technological resources in environments that support learning. This factor is key in not only obtaining teacher buy-in, but also the sustainability of technology implementation. These two factors mirror the technology requisites previously mentioned by the U.S. DOE NETP report (DOE, 2017). Lastly, technology should be integrated within all aspects of the lesson (i.e., curricula, course objectives, and assessment) for effective integration. Teachers must be constantly aware of the role technology plays in each of those aspects of a lesson and adapt accordingly.

Driscoll (2002) has outlined a different framework for the effective use of technology for mathematical learning. The framework is based on the four guidelines that learning is real, active, social, and reflective. For appropriate use of technology in the classroom, teachers need to include mediums that provide real-world context related to current themes (Driscoll, 2002). Learning is active; thus, teachers can implement digital tools that can engage student's cognitive processes (Driscoll, 2002). Furthermore, learning occurs in a social and collaborative environment that provides students with reflection on their thinking and the thinking of others (Driscoll, 2002). Although this framework is for mathematics classrooms, its guidelines hold true for any academic subject.

Technology Tools Used in the Mathematics Classroom

Digital technologies, such as calculators, handheld devices, computer software, internet-based applets, and mobile applications, could be used to support students as they investigate mathematical ideas, develop mathematical conjectures, visualize abstract mathematical concepts, and understand concepts (NCTM, 2000). However, it is not the technologies themselves that lead to student learning, but the strategies the teacher uses to implement them (Keengwe et al., 2008; NCTM, 2015).

Mathematics computer programs, such as Geometer's Sketchpad, GeoGebra, or Desmos, in a mathematics classroom may be used to provide students with dynamic multiple representations of mathematical concepts that support their understanding as they interact with the mathematics in varying ways (Danielson & Meyer, 2016; Lopez-Morteo & Lopez, 2007). The use of these programs can help students make sense of abstract mathematical representations and make algebraic, graphical, and geometric connections among them (NCTM, 2015). However, the extent to which technological tools can be effective depends on the selection of the tool and its implementation in the classroom. In other words, "the effective use of technology in the mathematics classroom depends on the teacher" (NCTM, 2000, p. 25) and their ability to organize and facilitate the learning environment (Lin & Liang, 2014).

Another example of educational technologies prevalent in mathematics classrooms is immediate response devices (IRD). Immediate response devices enable teachers to adapt their teaching to the needs of their students by providing immediate data about their learning (Danielson & Meyer, 2016; Ozel et al., 2008). Immediate response and feedback within a computer-supported learning environment is worth exploring because careful implementation of this enables teachers to integrate quality questioning and more engaging class discussions (Ozel et al., 2008). They can be used for the elicitation of students' initial ideas, formative assessment, instructional decision-making, and a polling device. Thus, a learning environment with the technology that provides this form of real-time feedback in a mathematics classroom is worth exploring further.

A classroom learning environment that offers students a richer range of tools and skills, encourages socialization, increases student engagement, promotes inquiry, and enables equitable treatment of students, helps in the development of responsible independent learners capable of coping better with an information-rich society (Danielson & Meyer, 2016; Magen-Nagar & Steinberg, 2017). Thus, intelligent use of technology in a constructivist environment can augment engagement and cooperation among learners.

Computer-Supported Collaborative Learning Tools in Mathematics Classrooms

There are numerous CSCL tools that could be used to teach and learn mathematics. This section focuses on two popular secondary mathematics programs: GeoGebra and Desmos.

GeoGebra. GeoGebra is a software that gives students real-time, interpretive feedback as they examine functions and draw graphs. Takaci et al. (2014) have investigated collaborative learning in high school calculus students with and without the use of GeoGebra. Based on pretests, posttests, and student interviews, the authors have concluded that learning calculus concepts in a CSCL environment (i.e., GeoGebra) was more efficient than learning in collaborative groups without it. Weinhandl et al. (2020)'s explorative educational study has aimed to identify the design of a learning environment that used GeoGebra. Analysis of their qualitative data of secondary students' responses indicates clear task definition and design, feedback, meaningful context, and a single-source learning environment as critical components for a quality CSCL environment. Meanwhile, Bulut et al. (2015) have studied the effects of GeoGebra on elementary students' achievements with fractions. Compared to participants in a traditional setting, the authors found significant differences between the mean of students' posttest scores in favor of the GeoGebra group. They attributed this to GeoGebra's ability to provide students with multiple representations that enhanced their understanding of fraction concepts.

Desmos. Desmos is a free graphing calculator software that is available online and offline. It can be displayed and downloaded on tablets, laptops, and smartphones as an application. Desmos can also be accessed through any browser. The graphing calculator provides learners with the ability to type an equation or table and point and receive real-time, iterative feedback (i.e., the visual appears in conjunction with the typed expression). Sliders can be created to show the effects of manipulating the coefficients of a function. The software interprets these interactions by adjusting the graph in real time. Another example of this L2S interaction (Kumar et al., 2010) is dragging the cursor to a specific point on the graph, where the system interprets this by revealing the coordinates of the selected point. This type of feedback is a unique experience compared to the typical student experience using a computer, where feedback is given on a student response, usually with hints and indicating whether the response is right or wrong.

The computer in traditional settings thinks for the student instead of thinking with the student. Feedback provided by Desmos allows students to interpret their mistakes for themselves and adjust accordingly (i.e., iterative, and interpretive feedback). Additionally, all these interactive activities can be stored and accessed using a unique class code and school email account by both teachers and students.

Desmos Activities. The majority of the Desmos activities connect students with one another, constantly sharing ideas, asking questions, while challenging each other in an engaging environment (Caniglia et al., 2017; Danielson & Meyer, 2016). During these activities, teachers have access to all these interactions through the teacher dashboard, allowing them to move quickly between views of an individual's work and the whole class. This information helps teachers decide which students are struggling, when to pause the lesson for whole class discussion, and when to display student work and ideas. This is consistent with Kumar et al.'s (2010) notion that an online environment should be capable of recording learner interactions so that they may be interpreted and analyzed to foster classroom discourse and collaboration (Jonassen, 1995). A strong connection exists between the need for classroom mathematical discourse and a CSCL environment (Hegedus et al., 2015).

The principles guiding Desmos for developing these lessons include a) using technology to provide students with feedback as they work, b) support collaboration and discourse by using the network to connect students, and c) provide teachers with real-time information (Danielson & Meyer, 2016). These principles are consistent with Kumar et al.'s (2010) criteria for a CSCL framework in several ways. The first criterion is that CSCL interactions should be both open-ended and guided and available to everyone in the classroom. An example of this is when a student chooses an answer on a Desmos activity, a dialogue box appears and prompts students to “explain their thinking.” This is an example of an open-ended interaction. The next screen in the activity can have a similar L2S interaction, but a sentence prompt is preloaded within the dialogue box to guide student responses (i.e., guided). All these responses can be monitored and displayed in real time on the teacher dashboard. To keep track of student responses for each class, Desmos allows the teacher to create a unique class code for each section that is stored centrally. Students can access their previous responses for any activity simply by using that class code. Although students can access only their data and some peer responses, the teacher has access to all these interactions, a critical criterion for an effective CSCL system (Kumar et al., 2010).

The interactions on Desmos are examples of sociocollaborative learning that can be represented in the software system, which is another criterion of an effective CSCL environment (Kumar et al., 2010). Lastly, the Desmos design principles of using technology to provide students and teachers with real-time feedback are consistent with the need for a CSCL environment to provide students with active and passive feedback (Kumar et al., 2010). An example of active feedback on Desmos is Marbleslide activities. The graph is displayed as the student inputs the equation, and the marbles are released as the student presses the submit button. The marbles then proceed to “slide” on the graph as it tries to hit all the stars.

In recent years, Desmos has been extending its technology by merging it with its pedagogical vision and developing online classroom activities for use in classrooms. The goal is to help teachers and students maximize learning with digital tools (Caniglia et al., 2017; Danielson & Meyer, 2016). These classroom activities allow the teacher to create a social, interactive, and mathematical learning environment cost-free by configuring the activities to meet their curricular and student needs in a variety of topic areas. The Desmos activities featured in this study were chosen due to their alignment with Kumar et al.'s (2010) CSCL framework, as seen in Table 3. Descriptions of the activities featured in this study can be found in the following section. Screenshots of these Desmos activities can also be found in Appendix D.

Table 3 Desmos Activities: Alignment to Kumar et al.'s (2010) CSCL Framework

Criteria	Desmos Activities			
	Marbleslides	Polygraphs	Card Sort	2 Truths & a Lie
CSCL interactions are open-ended and/or guided.	✓	✓	✓	✓
CSCL interactions are observed in real time and are stored centrally.	✓	✓	✓	✓
Predefined collaboration strategies within the CSCL design.	✓	✓	✓	✓
CSCL interactions follow an underlying theory for collaborative learning.	✓	✓	✓	✓
CSCL interactions provide active and/or passive feedback.	✓	✓	✓	✓

Note: Kumar et al. (2010)

Marbleslides. An extension of the graphing calculator, students can engage in a Marbleslides activity where their task is to hit all the stars with a marble that travels along a line. Students receive immediate feedback (i.e., "try again" or "success"). In Marbleslides, students are given a series of graphing challenges in which they would type different equations and restrictions to allow "marbles" to "slide" their way down these lines to collect the given stars (See Appendix D). Students transform lines by manipulating the equations so that the marbles traveling along them go through the stars. Students evaluate their ideas by launching the marbles, while given the opportunity to revise before attempting the next challenge. Similar to the gStudy software's ability to capture learners' interaction in reading activities (Kumar et al., 2010), Desmos reads the equation input data, creates a graph in real time, and captures the real-time learner interactions of students by actively processing whether their graph captures all the stars (i.e., "success") or if adjustments need to be made (i.e., "try again"). Teachers can monitor student success through the teacher dashboard as a "check" appears when a student has successfully captured all the marbles on a screen. The dashboard allows the teacher to "screenshot" various student successes to discuss similarities and differences in the equations used. It is as if students can visualize how Desmos interprets their feedback in an immediate and timely manner. Because of this, students can interpret whether they have communicated to the software exactly what they want to do.

Polygraph. A L2L, predefined collaboration is the Desmos Polygraph activity. Students are randomly paired with another classmate. One chooses a particular graph from 16 displayed on the screen. Their partner then asks yes or no questions that will help him or her eliminate and guess their partner's unique graph. A screenshot of this activity is found in Appendix D. Students are then prompted to explain their thinking and choice of questioning. This activity provides students with an opportunity to communicate with each other via Desmos using informal and formal language. This activity supports collaboration and discourse by using the network to connect students using images and language (Danielson & Meyer, 2016). The Polygraph activity encourages the bridging of informal to formal language, a foundational piece for the understanding of mathematics (Abdu et al., 2015; Oikarinen et al., 2014; Silverman, 1995; Takaci et al., 2015). These predefined collaborations are a key criterion of Kumar et al.'s (2010) CSCL framework and can be found within the other activities chosen for this study (i.e., 2 Truths & a Lie, Marbleslides, Card Sort).

Card Sort. An example of passive feedback on Desmos is when students complete a Card Sort activity. Students are provided with a set of cards via Desmos on a specific topic (e.g., linear, quadratic functions). Students are then to match the cards based on a specific theme (e.g., match graph to corresponding table and equation). This gives them an opportunity to discuss strategies, make mistakes, and learn from them. As students sort and group the corresponding cards accordingly, the teacher dashboard displays in real time whether they have an incorrect match (i.e., red), an incomplete match (i.e., green with missing card/s), or a complete match (i.e., green). A screenshot of a Card Sort activity is found in Appendix D.

2 Truths & a Lie. In 2 Truths & a Lie, students are first presented with a graph of a line and three statements where one of them is false (see Appendix D). Students then explain their reasoning as to why the statement they chose is the lie. Students then build their own graph challenge by manipulating draggable points on the screen. They write three statements about their graphs (i.e., two true, and 1 lie) and then have their peers complete these challenges to find the lie. These graphs are placed in a “class gallery” housed within Desmos in which students can attempt to identify the lie in their peer’s graphs. A student can then go back to their created graph and note all their peer’s interactions with it.

Desmos for Student Learning. Teachers can prompt students to explain their thinking and share and compare graphs of all students to spark classroom discourse. Features, such as the Polygraph activity pairs students at random as one tries to eliminate and guess their partner’s chosen card (e.g., graph, shape) by asking yes or no questions. This provides students with an opportunity to interact with informal and formal academic language, as the guesser identifies the correct object by asking about distinguishing figures (Caniglia et al., 2017). The teacher facilitates academic language growth by allowing students to develop rich informal language that is then captured by the teacher to use later in discussion and formalizing (Caniglia et al., 2017; Danielson & Meyer, 2016). This informal language supports students in preparing to understand and use "official mathematical language" in more meaningful ways than learning experiences that begin with formal mathematical vocabulary (Caniglia et al., 2017; Herbel-Eisenmann, 2002).

Thirty-seven states, including the top three most populated (i.e., California, Florida, Texas), have adopted the Desmos software in their state's mathematical exams. No studies were found that focused on the effect of Desmos on student achievement. Most of the studies found were focused on a particular lesson using the Desmos platform (Ebert, 2014; Kerrigan, 2017). Hegedus et al. (2015) have found that learning mathematics in a dynamic, technology-rich environment engages students with dynamic representations while immersing both teachers and students in meaningful forms of communication (Wilensky & Stroup, 1999), which could positively affect student learning and instructional practice (Hegedus et al., 2015). They found significant gains in student learning and participation for certain ethnic minorities and schools with low SES students.

Learning Mathematics in a 1:1 Computer-Supported Collaborative Learning Environment

It is troubling to find that student disengagement in their mathematical thinking and learning is connected to their attitudes toward mathematics (Larkin & Jorgensen, 2015). Their engagement is an important indicator of student success. Learning environments play a vital role in students' engagement. It is important for educators to identify effective teaching strategies to improve students' engagement and problem-solving competence. A mathematics classroom embedded within a 1:1 CSCL environment presents an excellent opportunity to foster student learning and discourse.

A 1:1 CSCL offers opportunities for innovative and constructivist learning. Designing this type of learning environment for mathematics helps students obtain information through thought-provoking stimuli, while also developing 21st-century skills, such as inquiry and problem-solving (Bower et al., 2010; Danielson & Meyer, 2016; Lin & Liang, 2014). For reasons such as these, schools have now begun to embrace technology as part of their curriculum and have made technology integration in the classroom an integral component in the field of education (Ozel et al., 2008).

Studies have shown that CSCL environments have the potential to engage students in their learning and increase their motivation (Afari et al., 2013; Chipangura & Aldridge, 2017; Donaldson, 2012). A CSCL mathematics classroom provides ways for students to engage in their learning by investigating incorrect answers for deeper meaning and allowing them to resolve a contradiction through interaction with digital resources, which enhances their problem-solving ability (Abramovich & Connell, 2014; Danielson & Meyer, 2016). Teachers and the medium itself can provide students with instantaneous and immediate feedback via a CSCL system, which could impact on student learning and motivation. Providing timely feedback in a CSCL environment is consistent with Attard's (2014) framework for engagement with mathematics. For students to be engaged, teachers must acknowledge students' learning needs and provide timely and constructive feedback. Providing students with opportunities for rich mathematical conversations while challenging them with tasks that have elements of choice and variety embedded within a CSCL activity promotes student-centered learning (Attard, 2014; Danielson & Meyer, 2016; Kopcha, 2010; Liu, 2007).

The teacher remains the critical component in designing and implementing a student-centered CSCL system. In this environment, students need to be able to familiarize themselves with the technology, explore its capabilities, and more importantly, apply their learned knowledge of this medium to specific mathematical tasks (Hollebrands & Okumus, 2018). To accomplish this, teachers must be willing to make a long-term commitment to improving their technological and pedagogical knowledge to effectively implement an effective and innovative CSCL environment (Ertmer et al., 2012; Goos & Bennison, 2008; Pierce & Ball, 2009). Technology is then only a small piece of the puzzle for promoting student engagement and achievement.

Mishra et al. (2013) have argued that a CSCL classroom could provide students with opportunities to investigate in-depth content that transcends disciplines, allows them to solve problems collaboratively, and creates meaningful cooperation while cultivating critical thinking. They have found that, in specific contexts, the designed element of the learning environment could influence the way students manage self-directed learning. The authors have argued that factors, such as aligning technology with learning goals, crossdisciplinary learning experiences, real-world problem-solving, and flexible opportunity, serve as catalysts in fostering an effective CSCL environment (Mishra et al., 2013).

Teaching Strategies in 1:1 Mathematics Classrooms

With information being readily available in an expanding technological society, it is necessary for learning environments to facilitate students' problem-solving skills to sift through information and organize it (Kuo et al., 2012). It is important for educators to identify effective teaching strategies to improve students' engagement and problem-solving competence. A mathematics classroom presents an excellent opportunity to foster these strategies.

A collaborative learning approach in a mathematics classroom, coupled with increasingly challenging tasks, could be a way to promote students' problem-solving activities (Kuo et al., 2012). Group-worthy tasks where each participant is actively involved supports a collaborative learning environment (Cohen, 1994; Fonkert, 2010). Developing positive norm behaviors, such as asking questions, actively listening, and responding appropriately, were deemed necessary for successful group work (Cohen, 1994; Fonkert, 2010).

Digital resources used within a collaborative learning environment may make collaboration and communication more prevalent, as they provide students with virtual manipulations and interactions not necessarily accessible in a traditional mathematics classroom. Fonkert (2010) has noted how Java-based software designed for use with mathematics curriculum (i.e., algebra, geometry, statistics, and discrete mathematics) assists students in making observations by providing a tangible object that can be easily manipulated and by displaying the changes immediately on the screen. Programs, such as Desmos, come to mind. At its core, Desmos is a computer software that can perform the same operations as a graphing calculator. The main difference is that it also serves as a virtual manipulative capable of exploring mathematical concepts at a deeper level (Anabousy et al., 2014; Bulut et al., 2015; Fabian et al., 2018). A 1:1 CSCL environment in mathematics could provide students with opportunities to be more active learners (Fonkert, 2010).

Another teaching strategy commonly used in 1:1 classrooms is game-based learning. Game-based learning is the use of video games as learning tools in the classroom (Bourgonjon et al., 2013). Li (2010) has explored students' learning experiences of learning mathematics through digital game building. Students become game designers and builders as they take ownership of their own mathematical learning. The author has found that learning through technological mediums, such as digital game design, can foster students' knowledge. Because students were constructing mathematical models through game design, their mathematical learning was enhanced due to the game's ability to allow students to reflect and discuss as they engaged with the game. The author has argued that the design of games provides real-world experience, thus enabling students to practice their critical thinking skills (Li, 2010). This mode of technology integration can motivate students, enhance their understanding of concepts, and introduce students to basic computer programming by providing them with choice and a sense of control. Students who participate in environments that support various modes of representation allow them to embed learning within complex and relevant situations where they can be socially interacting with each other while nurturing self-awareness of their learning (Allanson, 2013; Driscoll, 2002). Thus, students' understanding of mathematics is deepened when they experience an ongoing negotiation between their inner ideas and their outer actions (Li, 2010).

Student Engagement in the Computer-Supported Collaborative Learning Mathematics Classroom

An important indicator of student success in mathematics is their engagement. Engagement in mathematics can be defined as the "coming together" of cognitive, emotional, and behavioral engagement that leads to students' enjoyment and valuing of mathematics (Attard & Northcote, 2011). Several studies have shown that students with increased levels of engagement have positive attitudes toward mathematics and high mathematical self-efficacy (Adelson & McCoach, 2011; Eichorn et al., 2019; Linnenbrink & Pintrich, 2003). Many studies have shown that students' attitudes and perceptions toward mathematics are established early in their schooling, which may influence their current engagement and achievement in mathematics (Eccles et al., 1993; Dowker et al., 2012; Hilton, 2018). What is troubling is that many of these attitudes toward mathematics are negative and lead to student disengagement in their mathematical thinking and learning (Larkin & Jorgensen, 2015). Learning environments play a significant role in student engagement (Eichorn et al., 2019).

Several studies have focused on the relationship between the learning environment and student engagement (Chipangura & Aldridge, 2017; Eichhorn et al., 2019; Simon, 1994). Some of these studies focus on the impact that classrooms with CSCL have on student learning. Compared to a traditional classroom setting, students in CSCL mathematics classrooms are more task-focused and invested in their learning process (Chipangura & Aldridge, 2017). A 1:1 CSCL environment that provides students with teacher support, involvement, and task orientation could have a significant impact on student engagement and attitudes toward mathematics (Chipangura & Aldridge, 2017;

Hilton, 2018). Chipangura and Aldridge (2017) have explored whether the student perceptions differ between those in 1:1 CSCL and those in classes that were not CSCL, and the relationship between students' perceptions and student engagement in 1:1 CSCL classrooms. They found significant differences between the two groups, and an increase of students' mathematical engagement in 1:1 a CSCL. Hilton (2018) has investigated students' perceptions of mathematics in a 1:1 iPad classroom and found that, when used properly, it had a positive influence on students' engagement and attitude toward mathematics.

Challenges to Learning in a 1:1 Computer-Supported Collaborative Learning Environment

There are many challenges that arise when learning mathematics in a 1:1 CSCL. One of the main reasons that a rigorous study of group cognition is elusive is because collaborative learning is difficult to facilitate, complex in its design, and adaptable. The regulation of one's own learning is not an easy endeavor, as most learners are not initially equipped to regulate and direct their own learning (Stahl, 2010). This needs to be learned and supported through the CSCL environment designed by the teacher (Hadwin et al., 2010). Another reason for a lack of rigorous study of group cognition is a limited examination of interactive laptops, specifically within mathematics education. Among the few studies that exist, none examined how the CSCL environment influenced students' attitudes toward collaboration activities (Stahl, 2010). Students in CSCL environments sometimes perceive these interactions as being more confusing (Thompson & Coovert, 2003), less productive (Straus, 1997; Straus & McGratch, 1994), and needlessly time-consuming. Thus, simply placing students in a CSCL environment does not guarantee effective collaborative learning (Blumenfel et al., 1996; Kumar et al., 2010; Soller, 2004).

In their study, An and Reigeluth (2011) have brought attention to the need for people who can effectively manage information and technology to solve complex issues quickly and efficiently. Students are growing up with technology embedded into their daily routine, yet there is a lack of research on learner-centered technology integration (LCTI). This model focused on developing 21st-century skills, such as collaboration, higher-order thinking, and problem-solving skills, that are more suited to meet the needs of today's technological society (An & Reigeluth, 2011).

Since a CSCL environment uses technological devices to support student learning, it is a form of LCTI. However, instead of implementing technology in a constructivist environment, teachers tend to use it only for basic and menial tasks, such as word processing and web searching (An & Reigeluth, 2011). They have identified a lack of resources, time, assessment, and inadequate professional development as major barriers to technology integration. This is consistent with the previously mentioned findings. All these causes contribute to the challenges of learning in a 1:1 CSCL environment.

Ertmer (1999) has identified these challenges as first-order barriers, as they deal with external issues. An and Reigeluth (2011) have suggested that effective teacher support requires time for hands-on practice, more effective and meaningful training on technology integration, and the collaboration of all in the educational setting. Looking past the superficial barriers teachers encounter in technology integration, Ertmer (1999) has described these challenges as second-order barriers, for they focused on the fundamental and personal issues that hinder implementation. Grow (1991) has argued that challenges in integration occur due to teachers' unwillingness to alter their natural teaching styles to accommodate students in distinct stages of learning. An effective teacher is not only able to match the learner's stage of self-direction, but helps students advance toward greater self-direction (Grow, 1991).

Overcoming Barriers

Teaching learners to be self-directed is a challenging yet worthwhile endeavor for supporting student learning and discourse. In his paper, Grow (1991) has provided a staged self-directed learning framework that models how teachers can actively equip students to take ownership of their learning. It considers that students have different abilities to be self-directed, teachers must adapt their methods to student needs, and that self-direction can be taught and learned (Grow, 1991). This is the foundation of universal design for learning, which Hunt and Andreasen (2011) have argued provides students with mechanisms to become self-aware of how to "take charge of their learning rather than rely on the teacher to make modifications'' (p. 168). Universal design for learning provides students with multiple means of representing their learning. This is accomplished by using different formats for students to express and engage with mathematical topics (Hunt & Andreasen, 2011; Eichorn et al., 2019). Thus, the implication is that integrating CSCL in a mathematics classroom is a worthwhile endeavor; an inherently social context that can help students take control of their learning in multiple ways should the teacher find ways to overcome the potential challenges of 1:1 integration.

Students' Perceptions Toward Using Technology for Mathematical Learning

Like teachers, students spend several hours in the classroom where different learning situations are derived and are excellent resources for the evaluation of learning in a CSCL environment (Cohn & Fraser, 2016; Magen-Nagar & Steinberger, 2017). Chipangura and Aldridge (2017) have studied the relationships between the learning environment and engagement in multimedia classrooms. The results have indicated that there are significant differences in learning environment perceptions between students in multimedia math classrooms and those who are not in such environments (Chipangura & Aldridge, 2017). Students in the technologically rich environment are more engaged in their learning, and are more task-focused, involved in the learning process, and believe they received appropriate teacher support. Thus, the authors have concluded that student cohesiveness, teacher support, involvement, and task orientation are significant independent predictors of students' perceptions of technology use (Chipangura & Aldridge, 2017).

Magen-Nagar and Steinberger (2017) have studied students' perceptions of a technology-enhanced classroom learning environment. Characteristics, such as student cohesiveness, teacher support, investigation, equity, and differentiation, were among the factors examined that impact on students' perceptions of technology use. These factors are based on Fraser's (1994) characteristics that compose the advanced, innovative, constructivist learning environment. Magen-Nagar and Steinberg (2017) have found that how students perceive the learning environment affects their motivation to learn and their future behavior. They have argued that more positive environments lead to greater students' motivation, more effective learning processes, and higher achievements. These findings are consistent with previous studies (Afari et al., 2013; Dorman, 2009; Lin & Liang, 2014). Schools should consider developing the learning environment component first and then adapting them as best they can to ensure students' successful functioning in the 21st century (Fraser, 2014). Thus, a CSCL environment may feature social, intellectual, and emotional aspects that take time to design but are vitally important in developing a cooperative learning process among students.

Other studies, such as Daher (2008), have focused on students' perceptions of learning math with cell phones and apps. The findings implied that certain aspects (i.e., access, collaborative, communicative, size, and usability) influenced participants' use of digital devices for the learning of mathematics. Daher (2008) has argued that knowing students' perceptions would help teachers in preparing context-appropriate activities for each of the devices. The results indicated that students who used these devices for learning were able to visualize mathematical problems with greater ease, actively engaging students in their learning, and thus helping them solve the problems with more precision (Daher, 2008). The collaboration component through these devices was the most noteworthy influence on student engagement, and by extension, student learning.

Overall, students' perceptions of technology integration are more positive than teachers' perceptions, primarily due to many students having had significant personal computer experience and being more likely to understand the potential effectiveness of using technology (Maninger & Holden, 2009). Students are more motivated to learn the use of technology, often perceiving proficiency as a potential path to academic and career opportunities (Green & O'Brien, 2002; Li, 2007). In studies focused on 1:1 computing, students have been observed to exhibit increased curiosity, excitement, and collaboration in the classroom (Maninger & Holden, 2009). These studies have shown decreased absenteeism and behavior issues as learning becomes more student-centered, self-directed, and contextual (Batane, 2002; Lunt, 2004). This is consistent with several studies that have explored the influence of technology and concluded that technology could motivate students to learn mathematics (Ng & Gunstone, 2002; Nugent et al., 2006; Shyu, 2000). For example, student surveys in Li's (2007) study of secondary students and their views of technology integration in math and science have demonstrated that most of them found the technology useful for learning, citing reasons, such as increased efficiency, motivation, confidence, and preparation for future careers.

Li (2010) explored the effects and students' perceptions of learning mathematics through digital game-building. Students, in that study, became game designers and builders as they took ownership of their own mathematical learning. The authors have found that learning through technological mediums, such as digital game design, can foster students' knowledge (Li, 2010). Because students were constructing mathematical models through game design, their mathematical learning was enhanced due to students' need to reflect and discuss in the design process. The authors have argued that the process provides real-world experience, thus enabling students to practice their critical thinking skills (Li, 2010). This mode of technology integration can motivate students, enhance their understanding of concepts, and introduce students to basic computer programming by providing them with choice and a sense of control. This means that creative thinking and problem-solving present fertile ground for student learning and discourse (Li & Ma, 2010; Shernoff et al., 2003).

Li et al. (2016) have found that the experience with digital game-building forced students to carefully consider how to clearly and precisely present mathematics in meaningful ways. By having to teach other students mathematics topics, the nature of the project drove students to be mindful of audiences and the best ways to express ideas. Students' understanding of mathematics is deepened when they experience an ongoing negotiation between their inner ideas and their outer actions (Li et al., 2016). Therefore, research focused on students' perceptions of the use of technological devices, such as Desmos, in a CSCL mathematics classroom would add to this body of literature and is worth exploring further.

Chapter 2 Summary

The integration of technology in K-12 classrooms has been a focal point for many districts as they are tasked to meet the demands of rapidly changing demographics, the globalization of the economy, and the technological and cultural changes of the 21st century (Darling-Hammond & Bransford, 2005). When it is carefully designed and applied, technology can accelerate, amplify, and expand the impact of teaching practices, but requires educators to have the knowledge and skills to take advantage of a technology-enhanced learning environment (NETP, 2017). These factors influence the integration of technology in the classroom (Drenoyianni & Selwood, 1998; Gorder, 2008; Pierce & Ball, 2009).

The theoretical framework of this study is the CSCL environment framework as presented by Kumar et al. (2010). This framework comprises five design criteria for CSCL environments used by Kumar et al. (2010) in their assessment of a trace-based software system named gStudy (Winne et al., 2006). The first criterion is that CSCL interactions can be both open-ended (e.g., students explaining their thinking) and guided (e.g., sentence prompts). The ability to observe these CSCL interactions by both the students and teacher in real-time interaction, and the ability to store them centrally to interpret, is the second criterion. This is followed by predefined collaboration strategies and tactics that can be represented within the instructional design. Additionally, underlying theories of collaboration (e.g., self-, co-, and shared-regulated learning (Boekaerts et al., 2005; Hadwin et al., 2010; Zimmerman, 2000) can be represented in the CSCL system and can be meaningfully interpreted. Lastly, the CSCL environment needs to be able to provide both active and passive feedback.

Technology is changing education by impacting how K-12 educators integrate digital technological instructional strategies to help students acquire the skill sets to prepare them for college and a career in the 21st century (Delgado et al., 2015). Digital tools, such as Desmos, when used properly as an instructional strategy, could impact student engagement and performance. The literature review focused on technology integration in K-12 mathematics classrooms, learning mathematics in a 1:1 CSCL, and students' perceptions regarding technology integration.

Critical reviews of technology integration in the 21st century K-12 classrooms identified several themes. Delgado et al. (2015) have focused on the transitions and evolution of technology integration in education, the resources to fund it, and the challenges of using technology in education. Harper and Milman's (2016) review of research published on 1:1 technology in K-12 classrooms has identified five themes. The themes identified include effects on student achievement, changes to the classroom environment, classroom uses, effects on learner motivation and engagement, and challenges to classroom integration. Most of the studies reviewed were mixed methods and qualitative.

Technology integrated in mathematics classrooms have been investigated by researchers for a number of years. Findings on the effects of technology integration in mathematics include positive attitudes toward learning (Li, 2010; Magen-Nagar & Steinberger, 2017), increased student achievement (Lowther et al., 2003) and conceptual understanding (Reiten, 2018), and a higher engagement with mathematics (Hilton, 2018; Ozel et al., 2008). In a shift from a traditional approach to teaching mathematics (i.e., a "sage on the stage"), teachers in technology-enhanced classrooms were provided with the opportunity to serve as facilitators (i.e., a "guide on the side"). This allowed students to develop new ways of interacting with peers (Danielson & Meyer, 2016; Heid et al., 1990; Lopez-Morteo & Lopez, 2007) in a more social and collaborative setting.

Mathematics computer programs, such as Geometer's Sketchpad, GeoGebra, and Desmos in a mathematics classroom may be used by teachers to provide students with dynamic multiple representations of mathematical concepts that support their understanding as they interact with the mathematics in varying ways (Danielson & Meyer, 2016; Lopez-Morteo & Lopez, 2007). It can help students make sense of abstract mathematical representations and make algebraic, graphical, and geometric connections among them (NCTM, 2015). However, the extent to which technological tools can achieve these connections depends on the selection of the tool and its implementation in the classroom.

Several studies have focused on the relationship between the learning environment and student engagement (Chipangura & Aldridge, 2017; Eichhorn et al., 2019; Simon, 1994). Compared to a traditional classroom setting, students in CSCL math classrooms are more task-focused and invested in their learning process (Chipangura & Aldridge, 2017). A 1:1 CSCL environment that provides students with teacher support, involvement, and task orientation could have a significant impact on student engagement and attitudes toward mathematics (Chipangura & Aldridge, 2017; Hilton, 2018).

CHAPTER THREE: METHODOLOGY

Many high school students in the United States need to improve their math scores while also demonstrating the skills that this subject area prepares them for, such as problem-solving and collaboration. The mathematical proficiency of American students is below the global average and worse than other developed countries (Organization for Economic Co-operation & Development [OECD], 2019). With digital technology more readily available in the classroom and many state exams shifting toward online administration, teachers are provided with resources that could engage learners. Despite innovations, mathematical literacy and self-efficacy among students remains low (Ramsay, 2014). The integration of technology in mathematics education could empower learners to construct knowledge through computational thinking, innovative design, and cooperation. Strategic use of technology in a student-centered learning environment has been shown to strengthen mathematics teaching, learning (Dick & Hollebrands, 2011; Kiru et al., 2018; Ozel et al., 2008; NCTM, 2015; Suh et al., 2008) and engagement (Renwick, 2016). Moreover, technology-integration strategies that emphasize collaboration could support the learning of skills and knowledge that could then affect student performance on state assessments. However, a need exists for more research to explore students' perceptions of their experiences with technology in a mathematics learning environment.

The purpose of this study was to understand experiences with 1:1 Computer-Supported Collaborative Learning (CSCL) for high school students participating in an algebraic reasoning class. A basic qualitative study approach was selected because it aims to understand students' experiences with 1:1 CSCL learning in mathematics through a general analysis of qualitative data collected in student semistructured interviews (Merriam, 2009; Merriam & Tisdell, 2015). Data from the semistructured student interviews provided an in-depth analysis of the central phenomena. Kumar et al.'s (2010) CSCL model was used as the framework through which the qualitative data were analyzed. The study attempts to fill the gap in research on students' experiences with learning mathematics in an online environment.

This chapter first provides the reader with the background and purpose of the study. With the integration of technology and online learning more prevalent in the classroom, a need exists to explore students' experiences in a CSCL system. This is followed by the presentation of the research questions. The CQ focuses on students' perceptions of their experiences in a CSCL mathematics classroom. To help answer this question, the two SQs focus on different criteria of the CSCL framework. One of the SQs primarily targets students' experiences with CSCL interactions, while the other focuses on the collaborative strategies described by the participants. The research methodology is then presented and explained. The chapter next shifts to presenting the context of the classroom environment involving the CSCL system of the study, Desmos. Background on the demographics of the participants follows. The remaining sections focus on the data collection procedures and how data analysis helps explain the CQ of the study.

Research Questions

The study aimed to answer the central research question: What are students' perceptions of their experiences with 1:1 CSCL in an algebraic reasoning classroom?

This question is addressed intentionally through the lens of Kumar et al.'s (2010) CSCL framework and guided by the following SQs:

SQ1: What are students' perceptions of their interactions with 1:1 CSCL in an algebraic reasoning course?

SQ2: What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

The first SQ focuses the research on what happens to student learning during 1:1 CSCL interactions in mathematics. The emphasis is on capturing students' initial thoughts about their experiences with CSCL activities. The second SQ focuses on students' descriptions of the collaborative strategies for learning algebra in a 1:1 CSCL environment. SQ2 asks them to think about these activities from a metacognitive perspective, with a focus on the collaborative strategies embedded in the CSCL activities. After answering the SQs, the overarching CQ was answered using Kumar et al.'s (2010) CSCL framework.

Research Methodology

A qualitative research approach best served the purpose of understanding students' experiences of learning algebra in a 1:1 CSCL setting because it allows for an in-depth view of their interactions from the participants' perspectives (Creswell & Plano-Clark, 2018). This study utilized a convenience sampling approach that allowed the researcher to select individuals who were available and willing to participate (Creswell, 2015). Of the students in the algebraic reasoning sections, a sample of nine students volunteered and were selected to be interviewed to develop an in-depth understanding of the central phenomenon (Creswell & Plano-Clark, 2018). A sufficient database was collected to develop an in-depth understanding of the central phenomenon—students' experiences with 1:1 CSCL in an algebraic reasoning course.

A basic qualitative study was the appropriate approach selected to answer these questions, as it aims to provide breadth and depth to the central phenomenon of exploring students' experiences with 1:1 CSCL in mathematics (Creswell & Plano-Clark, 2018). The emphasis is on students' perceptions of their experiences with their environment and how they interpret these experiences (Merriam, 2009; Merriam & Tisdell, 2015**)** for mathematical learning**.**

Context—Classroom Environment

In a CSCL environment, the software system interacts with students, displaying subject knowledge as a byproduct of a collaborative learning strategy that can be monitored and mediated (passively or actively) by the platform. The design of these environments concentrates on refining, integrating, and facilitating the student learning process and subject knowledge through collaborative interactions. Teachers receive information on the interactions and students' progress and can offer appropriate feedback (Jonassen, 1995; Kumar et al., 2010).

Designing a CSCL environment that affords multiple collaborative opportunities while simultaneously capturing all learning activities is no easy task. Kumar et al. (2010) have proposed that building a system that captures all L2S and L2L, utilizing design tools to analyze, categorize, and respond in real time, is a way to accomplish this task. A CSCL environment should be able to provide students and teachers with examinable information that documents what collaboration achieved, thus allowing them to use these data to analyze the regulation of individual and group learning (Jonassen, 1995; Winne et al., 2010).

Following Kumar et al.'s (2010) framework for CSCL systems, the researcher incorporated Desmos-created and teacher-created assignments that enabled students to work individually or collaboratively while engaged in algebraic learning (Jonassen, 1994). The Desmos activities chosen for the study followed a constructivist design model as they focused on the social interactions within the 1:1 CSCL environment (Jonassen, 1994, 1995; McLoughlin & Lee, 2010; Young, 2003). The learning environment in the algebraic reasoning classroom, where the study took place, adhered to social constructivism theory based on the idea that we learn from our interactions with the outside environment before knowledge is internally constructed (Jonassen, 1994, 1995). These activities were carried out at least twice a week during the 90-minute class periods. Students interacted with the Desmos activities as a whole class, in groups, or independently, as guided by the teacher.

Additionally, short, interactive, formative assessments on Desmos were given out every two weeks. These assessments were created through the Desmos Activity Builder by the teacher-researcher. The teacher-researcher created the assessments by taking advantage of Desmos features, such as Card Sort, graphing equations, plotting points, and text boxes, where students had multiple ways to explain and justify their thinking. Students received instant feedback through the medium, as set by the teacher. Figure 1 shows an example of this interaction. This is consistent with Kumar et al.'s (2010) framework in that students receive real-time active feedback and are offered opportunities for open-ended interactions between L2S and L2L. The students engaged in sociocollaborative activities within the 1:1 CSCL algebraic reasoning classroom, which could impact on their mathematical understanding (Abdu et al., 2015; Pettenati & Cigognini, 2007; Takaci et al., 2015) and attitudes toward the subject (Lopez-Morteo & Lopez, 2007).

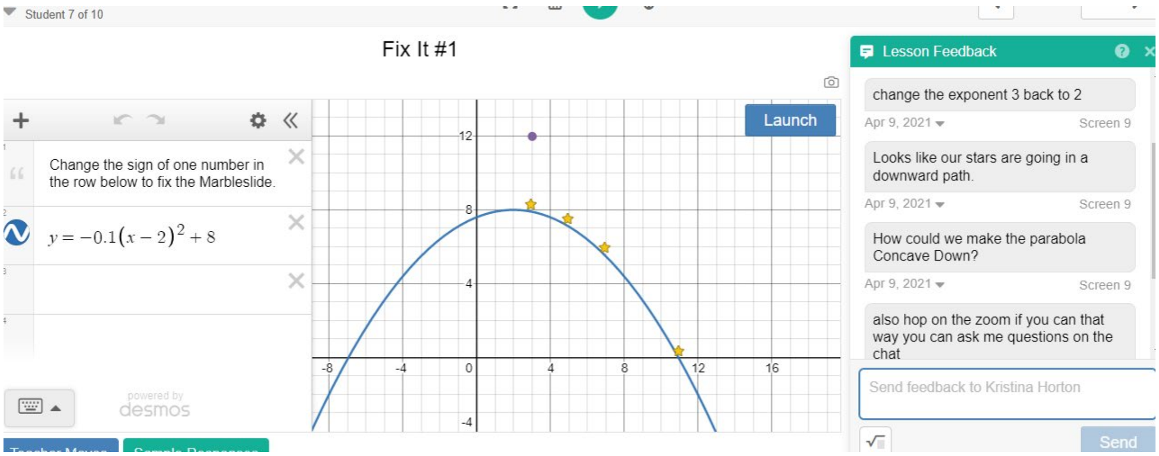


Figure 1 **Example of Teacher Feedback to a Student**

Note: Screenshot of a student screen on a Desmos marbleslide activity.

Participants

Participants in this study were students attending a suburban public high school in North Texas during 2020–2021. One hundred 10–12th grade students were invited to participate in the study, and they were in the primary researcher's algebra reasoning classes during that school year. Students were in these classes after their algebra 1 teachers determined that they needed more of a foundation before moving on to geometry or algebra 2. English language learners (ELLs), general education (GenEd) students, and special education (SpEd) inclusion children, respectively, made up 83%, 27%, and 17% of the class population in these algebraic reasoning portions.

This study was approved by the Boise State University Institutional Review Board (IRB). Anonymity and security of personal information were explained to all participants and their parents or guardians prior to the collection of any data. All identifiable information was removed to protect the participants. All students were informed that they were not going to be impacted in a negative or positive manner with regards to grade or monetary compensations because of their participation in the study. Students were also assured they would not be penalized for lack of participation.

All students willing to participate in the study were selected for the individual interviews. Data from nine, 10–12th grade students in the algebraic reasoning classes were collected through individual interviews. The participants included one female and eight males. Five of the students were general education students, while the remaining were either ELLs, received SpEd services, or both. All were 10th grade students. Table 4 summarizes the demographic information on the participants.

Table 4 10th Grade Participants – Demographic Information

Participant	Demographics			
	Gender	General Education (GEd)	English Language Learner (ELL)	Special Education (SpEd)
Alice	Female	✓		
Beto	Male		✓	✓
Carlos	Male		✓	
Dan	Male	✓		
Edgar (Virtual)	Male		✓	✓
Fabian	Male	✓		
Gabe (Virtual)	Male			✓
Herman	Male	✓		
Isaac	Male	✓		

Note: Participants from my algebraic reasoning classes.

Data Collection

After receiving student assent and parent consent forms, data collection took place during the spring semester of the 2020–21 school year, from participants in an algebraic reasoning course that used Desmos. The Desmos activities followed Kumar et al.'s (2010) framework for effective CSCL systems and were either a Desmos-created activity (i.e., Polygraph, Card Sort, 2 Truths & a Lie, Marbleslides) or a Desmos Activity Builder activity or assessment where L2S collaboration was taking place. The teacher was able to access and present all the students' data and interactions using the Desmos teacher dashboard. See Figure 2 for an example of how it looked. During these two nine-week cycles, activities for the week were chosen based on specific topics covered within the algebraic reasoning unit, in particular function relations, linear, quadratic, and exponential equations.

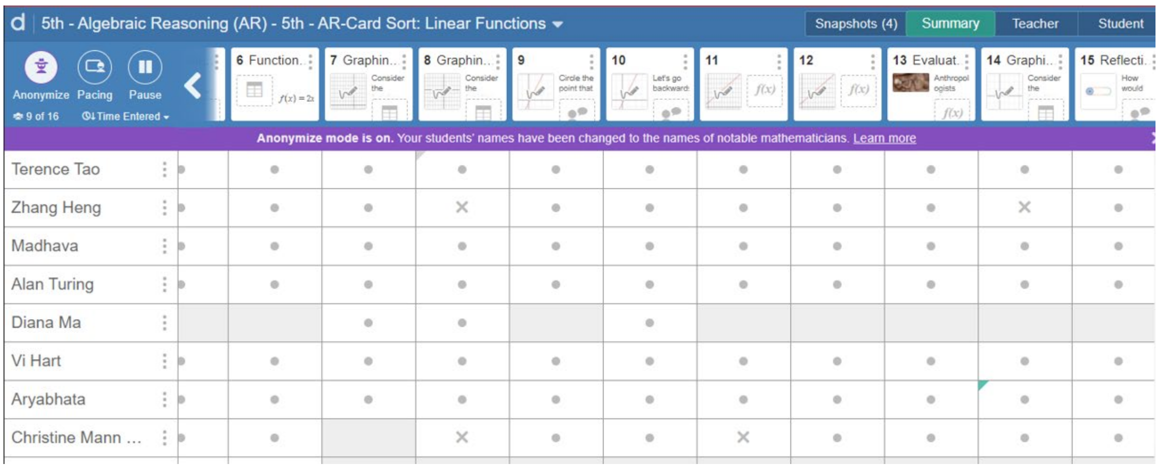


Figure 2 Example of Teacher Dashboard

Note: Screenshot from a Desmos card sort activity.

Data for this study was collected through individual interviews as participants described their experiences in a 1:1 CSCL setting in their algebraic reasoning course. Carrying out the interviews at this time gave participants an opportunity to familiarize themselves with the Desmos platform and its activities from the beginning of the 2020–2021 school year. The interviews allowed the researcher to understand students' experiences in a 1:1 CSCL environment while using Desmos. These semistructured interviews were conducted by a fellow teacher and included open-ended questions without response options, which were listened to and the comments of the participants were recorded. The interview protocol is provided in Appendix A. The fellow teacher was necessary in conducting the interviews because the participants were all students from the primary researcher's algebraic reasoning classes.

The semistructured interviews allowed for flexibility to include additional follow-up questions as needed. In the planning of the study, the interview questions were aligned with the research questions and the CSCL framework as presented in Table 5. However, in the data analysis process, some answers were identified with themes that connect to different criteria of the framework.

Table 5 **Intended Alignment of Research Questions to CSCL Framework**

Research Question	CSCL Framework	Interview Questions
(SQ1): What aspects of CSCL interactions do students talk about when relaying their experiences with 1:1 CSCL in algebraic reasoning course?	● Open-ended and guided CSCL interactions. ● Observed CSCL interactions can be stored centrally and meaningfully interpreted. ● The CSCL system provides active and passive feedback.	IntQ1: What approaches, or tools used by your teacher in the 1:1 environment helped in your learning of algebra? IntQ2: How would you describe your experiences with Desmos while learning algebra (SQ1)? IntQ3: How did Desmos help your understanding of algebra (SQ1)? IntQ4: If so, when did you prefer to use Desmos to learn algebra (SQ1)? IntQ5: What particular activities or tools used by your teacher using Desmos helped you in your learning of algebra (SQ1)?
(SQ2): What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?	● Predefined collaboration strategies represented in the software. ● Underlying theories of collaboration can be meaningfully interpreted.	IntQ6: How would you describe your experiences with Desmos activities, such as Polygraph, Marbleslides, or 2 Truths & a Lie, while learning algebra (SQ2)? IntQ7: How did these collaborative strategies help in your learning of algebra (SQ2)? IntQ8: If so, when did you prefer to collaborate when learning algebra (SQ2)?

Note: Adapted from Kumar et al. (2010).

The student semistructured interviews were conducted in a one-to-one setting based on participant and interviewer availability. Face-to-face participants (seven) were interviewed at the high school they were attending, while virtual students (two) were interviewed on Zoom. Recordings of the interviews were carried out using a districtissued teacher's iPad. The recordings were then transcribed using Google Docs and the Voice Typing tool by the interviewer (i.e., fellow teacher). This was followed by giving each participant an opportunity to review the transcription to allow for clarification and ensure the accuracy of their statements. This form of qualitative validity assesses whether the information obtained is accurate and credible (Lincoln & Guba, 1985). By taking the summaries of the qualitative findings back to participants in the study and asking them whether the transcripts were an accurate reflection of their experiences, the researcher could support the validity of the study (Creswell & Plano-Clark, 2018). These recordings and transcriptions were stored in the interviewer's password-protected drive. Once transcripts were reviewed by each one of the participants, the anonymized transcriptions were given to the primary researcher for analysis. The audio recordings were deleted to protect student identity.

Data Analysis

This study aimed to answer the CQ: How do participants describe their learning experiences with 1:1 CSCL in an AR course? It did so by analyzing participant responses to interview questions aligned with the study's two SQs. In the planning of the study, the interview questions were aligned with the research questions and the CSCL framework as presented in Table 5. Analytical memos were also taken by the researcher at the end of each Desmos activity in this study to summarize and reflect on the day's lesson. This information was recorded on a Google Doc so that the researcher could reference while analyzing participants' responses to the interview questions.

The coding method was carefully considered to generate the findings needed to respond to the research questions posed (Saldaña, 2016). To prioritize and honor participants' voices, in vivo coding was used to identify words or short phrases from students' own language in the data record (Saldaña, 2016). As opposed to descriptive coding, where the focus is on generating a list of general subtopics, in vivo coding derived its codes from the actual language of the participant. This allowed the researcher to analyze the interview transcripts by "attuning yourself to participant perspectives and actions" (Saldaña, 2016, p. 73). From the participants' transcripts, key phrases for each interview question were collected and organized on a Google doc by the primary researcher. In vivo coding gave voice to often marginalized populations, enhancing and deepening educators' understanding of students' views (Saldaña, 2016).

During the first cycle, the in vivo information was used for focused coding to categorize the data based on thematic or conceptual similarities (Saldaña, 2016). Quotation marks of students' similar language were used to track the in vivo codes (e.g., "easy," "simple"). In focused coding, categories with significant or frequent codes emerged from the in vivo process (Onwuegbuzie et al., 2016). This was recorded on a Google sheet. Some codes were merged if they appeared to be similar. Additionally, direct interpretation allowed the researcher to analyze a single instance, pull the data apart, and make meaningful and in-depth connections (Creswell, 2015). From these codes, the themes in participants' responses to the interview questions were generated in the second cycle. The themes were then connected to the 5 criterions of Kumar et al.'s (2010) CSCL framework and helped form the participants' narrative explaining their experiences with CSCL environments, such as Desmos.

After data was analyzed in the two-cycle process to answer the two SQs and identify themes, the primary researcher used Kumar et al.'s (2010) CSCL framework criteria to answer the study's central research question. The discussion is found in Chapter 5. In connecting the themes to the theoretical framework, the researcher established patterns between students' experiences in a 1:1 learning environment to develop naturalistic generalizations that formed the findings and implications of the study. These findings and implications provided a detailed description of the aspects of the study and how they compare with the published literature (Creswell, 2015).

Chapter 3 Summary

High school students in the United States need improvement in mathematics. With an influx of digital technology available in the classroom and an increased need for online learning opportunities due to the pandemic, teachers are provided with resources that could engage learners. However, mathematical literacy and self-efficacy among students continue to decrease (Ramsay, 2014). Technology-enhanced, collaborative learning environments could provide a different approach to teaching mathematics. There is a need for more research exploring students' experiences in a 1:1 CSCL AR classroom. The purpose of this basic qualitative study was to understand the experiences with 1:1 CSCL mathematics of high school students.

A basic qualitative design was appropriate as it aimed to understand students' experiences with 1:1 CSCL learning in mathematics (Merriam, 2009; Merriam & Tisdell, 2015) through a general analysis of qualitative data collected from semistructured interviews. The basic qualitative research design used in this study fit as the emphasis was on students' experiences with their environment and how they interpreted those experiences for learning (Merriam, 2009; Merriam & Tisdell, 2015).

The study involved nine 10th grade students from algebraic reasoning classes at an urban school district in Texas during the 2020–21 school year. The students in the course engaged in sociocollaborative activities within the 1:1 CSCL environment (Jonassen, 1994).

Data collection took place during the spring 2021 academic school year. Students familiarized themselves with the teacher and the CSCL system (i.e., Desmos) during the fall 2020 semester. Student interviews were conducted during the spring 2021 semester by a fellow math teacher. Participant responses were audio-recorded, followed by transcribing and coding to symbolically assign summative attributes to language-based data (Saldaña, 2016).

The following chapter presents the findings from the participant interviews. A brief synopsis of the study process is shown first. This is followed by the findings and how they answered the SQs. The findings associated with each SQ outline the emergent themes, their definitions, and evidence of these themes found in students' responses. These findings were then connected to Kumar et al.'s (2010) CSCL framework. In the remaining sections, Chapter 4 presents the findings from the student data. After the discussion of the findings of the SQs, the CQ is addressed in Chapter 5 using the CSCL framework.

CHAPTER FOUR: FINDINGS

In Chapter 4, I discuss the findings from analyzing participants' responses to questions about their experiences with 1:1 CSCL in an algebraic reasoning course. For the purposes of this study, participants were enrolled in an AR course after it was determined that they needed more of a foundation before progressing to geometry or algebra 2. After receiving consent and assent papers, students were invited to participate in individual interviews on a voluntary basis. Data from nine 10th grade students from the primary researcher's AR classes were collected through individual semistructured interviews.

For the data collection, interview questions were aligned to Kumar et al.'s (2010) CSCL framework as presented in Chapter 3. The student semistructured interviews were conducted in a one-to-one setting based on participant and interviewer availability. A second researcher was necessary for this study because I was the participants' teacher and wanted to ensure my presence did not interfere with their responses. Participant interviews were audio-recorded and transcribed, any student-identifiable data were removed before I received the documents.

The analysis consisted of prioritizing and honoring participants' voice through in vivo coding to help answer the study's CQ: What are students' perceptions of their experiences with 1:1 CSCL in an algebraic reasoning classroom? And the SQs:

SQ1: What are students' perceptions of their interactions with 1:1 CSCL in an algebraic reasoning course?

SQ2: What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

It is important to note that although the interview questions were initially oriented to specific criterions of the CSCL framework and research questions, answers to different interview questions were found to help answer different research questions and connected with other criterions of the framework that were not planned for. The research questions and the theoretical framework criteria were more interconnected than originally intended, and interview questions elicited responses that presented those connections.

The answers to the SQs are presented first as distinct characteristics of students' experiences in a CSCL algebraic reasoning class using in vivo coding. During focus coding, significant or frequent codes emerged from the in vivo process, and then categorized to identify emergent themes (Onwuegbuzie et al., 2016). Table 6 shows how the coding cycles were applied to this study. The emergent themes helped explain students' experiences with CSCL environments in mathematics from the participants' voices.

Table 6 Two Cycle Coding Process

1st Cycle	2nd Cycle	
In Vivo Coding	Code	Emergent themes
"Simplicity of it." "Really easy to understand." "It's easier for me instead of doing things on paper." "I've understood basically everything." "It's really easy for me." "It's a really simple way of learning."	Easy to understand; simple.	Simple
"It's really fun." "I liked learning on [Desmos]." "I liked Desmos." "[Marbleslides] was pretty fun."	Fun; like; enjoyable.	Fun
"Desmos helped a lot." "Really helpful." "Helping me learn like words." "[Desmos] helped me because I got to understand things way better." "[Desmos] has helped me answer future problems." "Really math-friendly."	Helpful; math-friendly.	Helpful

Note: Adapted from Saldaña (2016)

(continued)

Table 6 (continued) *Two Cycle Coding Process*

1st Cycle	2nd Cycle	
In Vivo Coding	Code	Emergent themes
"Calculator on Desmos." "Keyboard part cause…on paper I would have lost most of my work." "Desmos is not on paper [so] I can move things around." "Getting to match the cards." "Getting to type out the equations." "Parabola thing where you can move the lines and stuff manually." "There's a sketch tool on there and the calculator helps you learn better."	Desmos tools and features.	Multifaceted
"I'm a visual learner…I need the visual appearance on how to do things." "[Desmos] puts it in a visual perspective for me and I feel I learn best in that way." "Desmos has images and certain pictures that they show."	Visual	Visual
"[Desmos] was…helping me answer future problems because I knew this other problem [from a previous screen] so I won't make the same mistake." "on paper I would lose most of my work, but on Desmos it's easy to catch up with my work." "It allows us to go back and see what we did along with giving us the tools to kind of visualize everything. So, it's not just plain paper and pencil, see if you can do this."	Stored interactions	Previous interactions are accessible

Note: Adapted from Saldaña (2016)

(continued)

Table 6 (continued) *Two Cycle Coding Process*

1st Cycle	2nd Cycle	
In Vivo Coding	Code	Emergent themes
"It [Desmos] tells you when you're wrong. When you get it right." "Desmos was really giving me that feedback. That was something that nothing else really gave me." "so, Desmos was good. I liked learning on it because it was giving me feedback on, like, what I was doing wrong."	Collaborative interaction; feedback.	Passive feedback
"You can type out the equations…see everything as it happens." "[Desmos] was giving me feedback on what I was doing wrong." "Getting to see all the equations play out; being able to interact with it directly to see how it changes."	Collaborative interaction; feedback; Desmos activity.	Learner to Software interactions
"In algebra, we don't read algebra and it's kind of hard so if you participate and talk to each other and work with each other it's going to be easier and better, and you learn things better and stuff." "Once I found out that it was challenging, I found that by working with someone else to help find a better graph or with learning in school."	Collaborative interaction; feedback; Desmos activity.	Learner to Learner interactions
"Let's say after, like, being stuck on the same [screen] ... after, like, 10–15 minutes, I would ask the teacher [for] help on anything and then he would tell me, and then it all made sense." "If I don't understand it, I ask [the teacher] a question and he helps me understand it." "I would ask the teacher for help on anything [until] it all made sense."	Collaborative interaction; feedback; Desmos activity.	Learner to Teacher interactions

Note: Adapted from Saldaña (2016).

Addressing Research Questions

The main purpose was to understand students' experiences with 1:1 CSCL in a secondary mathematics class. Using Kumar et al.'s (2010) CSCL framework, the study aimed at answering the CQ by first presenting answers to the SQs as distinct characteristics of students' experiences in a CSCL AR class. The CQ is finally answered in Chapter 5 using a combination of the criterions from the CSCL framework identified in the two SQs. Tables are used to highlight aspects of the described experiences.

SQ1 Emergent Themes

To answer the first SQ: What are students' perceptions of their interactions with a 1:1 CSCL in an algebraic reasoning course? in the first cycle, in vivo coding was used on students' responses to identify words or short phrases using their own language by breaking down the data into manageable chunks (Anfara et al., 2002). During the second cycle, focused coding was used to bring meaning and insight to the participant responses to generate themes to answer SQ1 (Saldaña, 2016). These themes were then connected to the CSCL framework and helped form the participants' narrative explaining their experiences with CSCL in an algebraic reasoning classroom. The themes generated from the second cycle are simple, fun, helpful, multifaceted, visual, passive feedback, and previous interactions are accessible. Table 7 includes the themes, their definition, and examples of parts of students' responses. The next paragraphs present descriptions and examples of these themes. Note that the names are fictitious to keep the participants anonymous.

Table 7 Definition of SQ1 Emergent Themes and Student Examples

Emergent themes	Definition	Student response examples
Simple	Students were able to identify the interactions in Desmos to be easy to use for learning algebra.	Alice: What helped most was the simplicity of it because it was really easy to understand and figure things out and answer the questions. Herman: Putting into simple formats and simple ways where you can do the math makes it better for me personally.
Fun	Students' interactions with Desmos were joyful and engaging while learning algebra.	Gabe: Um, tools that we use in face-to-face, we do Desmos. I think that helps a lot. It's really fun and I understand it. Alice: This year especially it's starting to get really interesting and fun [since] I started using Desmos actually.
Helpful	Students' interactions with Desmos were favorable mathematical experiences that were useful in their learning of algebra.	Carlos: Like helping me learn like words and how to use them and how to arrange things.
Multifaceted	Students were able to identify multiple Desmos tools.	Beto: Um, mostly explaining what to do and the calculator on the Desmos ... And the tools that helped me explain the answer.
Visual	Students were able to interact with active and representations of mathematical concepts within Desmos that helped in their learning of algebra.	Herman: What helped is like, I'm a visual learner so for me I need the visual appearance on how to do things. So, it's easier for me instead of doing things on paper and writing it out, that's just my personal opinion.
Previous interactions are accessible	Students were able to store their interactions with Desmos as a scaffolding resource within the Desmos activity that can be accessed at any time.	Edgar: Yeah ... it's all going back to the feedback. Like telling me that I was wrong and then I'll probably [also say] that every time it gave me that check mark that I did something right and let me know that I was going through the right step. It was helping me answer future problems because then I knew this other problem or [screen] so I won't make the same mistake on the other one.
Passive feedback	Students were able to receive graphical and text feedback from Desmos while learning algebra.	Dan: It just puts it ... in a visual perspective for me and I feel like I learn best in that way.

Simple. The first emergent theme identified during the analysis was that students described their learning experiences with CSCL (i.e., Desmos) as "simple." In other words, students described Desmos as clear and easy to use in their algebraic reasoning course. For example, when asked "What approaches, or tools used by your teacher in the

1:1 environment helped in your learning of algebra?", Alice mentioned "What helped most was the simplicity of it because it was really easy to understand and figure things out and answer the questions."

Dan shared a similar sentiment when answering the second interview question, "How would you describe your experiences with Desmos while learning algebra?" He stated "Good, I feel like it's a [really] simple way of learning and it helps a lot." In response to the same question, Herman noted that "Desmos is probably one of the best things we do here at [school]. It's easier than everything else, from going back to last year to now. It's way easier than before." When asked, "When did you prefer to use Desmos to learn algebra?" Herman noted that "once I found out how easy [Desmos] can be and the tool that you use in it." Although the intent of this question (i.e., "When do you…") was to gather information about specific moments within the classroom that students (e.g., small-group, whole group, independently) preferred to use Desmos, the student interpreted the question as when he felt comfortable using the tool.

When responding to the same question, Edgar noted that these strategies "made it pretty easy, because I remember I started algebra last year and we did it with the papers and all that. This year it seems so much easier than what I remember from the first time learning it. I don't know if maybe it was because I already knew a little bit of it but yeah." When speaking with Herman, the fellow teacher asked a follow-up question asking whether there were any topics that "y'all did where Desmos was more helpful?" Herman mentioned, "Probably this one that we're doing now where we are using algebra tiles. That's probably the easiest part of it." He is referring to using Desmos to present virtual algebra tiles, as seen in Figure 3. What Herman was describing coincides with our quadratics unit in which students used digital algebra tiles on Desmos to help them understand binomial expansion and factoring of quadratic equations.

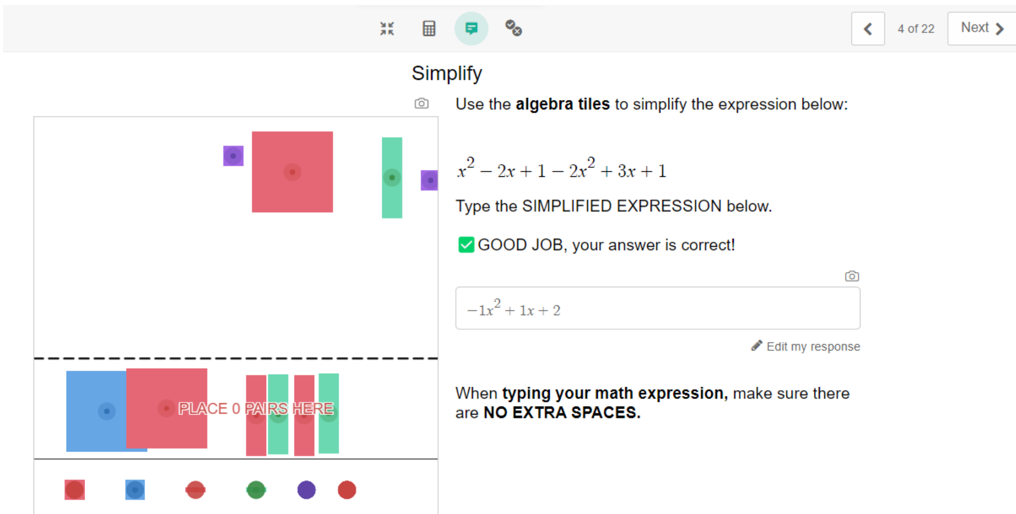


Figure 3 Algebra Tile Activity and Software Feedback

Note: Screenshot of a student's Desmos activity screen.

Fun. The second emergent theme was that the CSCL interactions with Desmos while learning mathematics can be "fun." In other words, students found their interactions with Desmos to be joyful and engaging while learning algebra. While working through Desmos activities like the Marbleslides, students indicated they enjoyed using Desmos in their learning of algebra. In her response to the first interview question regarding tools and approaches that helped in the learning of algebra in a 1:1 setting, Gabe mentioned using Desmos as "It's really fun and I understand it." In his response to the interview question "what particular activities/tools used by your teacher using Desmos helped you in your learning of algebra?" Alice specifically mentions the Marbleslide activity, "the one with the balls where you type out the equations and you have to get all the stars. That one was pretty fun." This response is like Isaac's answer to the interview question "How would you describe your experience with Desmos activities learning algebra? He mentioned that “Marbleslides are pretty much my favorite because he [the teacher] said as long as you can get all the stars, then you can go on so there are no strict rules.” In her response to the interview question “when did you prefer to collaborate or work together when learning algebra?” Alice noted that “Last year I started getting used to learning algebra. This year, especially, it’s starting to get really interesting and fun, so I started using Desmos, actually.”

Helpful. The third emergent theme was “helpful.” In other words, students’ interactions with Desmos were favorable mathematical experiences that were useful in their learning of algebra. Students expressed that the interactions with Demos helped develop mathematical knowledge. For example, Carlos made a particular mention of academic language in her response to the interview question, “How did Desmos help your understanding of algebra?,” to which Carlos responded with, “helping me learn [words] and how to use them and how to arrange things.”

Regarding students’ experiences with Desmos while learning algebra, Dan described it as “Good, I feel like it’s a really simple way of learning and it helps a lot.” This is a similar response to Gabe’s when asked about what approaches or tools used helped in her learning of algebra. He stated that “we do Desmos ... I think that helps a lot.”

What made Desmos “helpful” can be found in the following students’ responses. When answering the interview question, “How did Desmos help your understanding of algebra?” Herman responded, “Putting [the content] into simple formats and simple ways where you can do the math makes it better for me personally.” This sentiment is mirrored by Isaac’s response to the same question. “It allows us to go back and see what we did, along with giving us the tools to kind of visualize everything. So, it's not just plain paper and pencil. See if you can do this."

Multifaceted. The next emergent theme from answering SQ1 was that students' CSCL interactions were "multifaceted." In other words, students were able to identify multiple Desmos tools. This provided them with multiple opportunities to capture their thinking. For example, Beto's follow-up response to the first interview question:

Teacher: "Our first question says what approaches or tools used by your teacher in the 1:1 environment helped in your learning of algebra?"

Beto: "Um, mostly explaining what to do and the calculator on the Desmos."

Teacher: "Good, so that Desmos calculator helped you a lot?"

Beto: "Yeah. and the tools that helped me explain the answer."

In this situation, Beto is referring to two Desmos features. The first is a built-in scientific calculator that students can access at any time during an activity. An example of this calculator can be found in Figure 4 during a teacher created Desmos activity. The calculator would display dually with the Desmos screen and would compute number operations instantly. It would also capture student computations, which was helpful in keeping track of student thinking. The "tools that helped me explain my answer" that Beto could be referring to are found in activities that feature sketch components (i.e., 2 Truths & a Lie) and a text box for students to explain their thinking (i.e., Polygraph, Card Sort, Marbleslides, 2 Truths & a Lie).

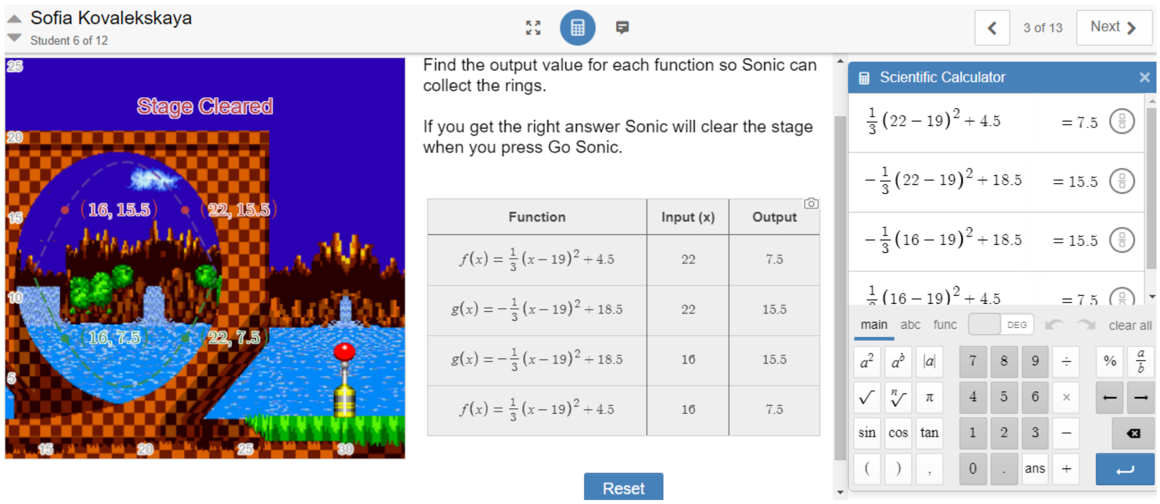


Figure 4 **Example of Built-In Desmos Calculator in an Activity**

Note: Screenshot of a student's Desmos activity screen.

Herman described the "multifacetedness" of Desmos. When responding to the question, "What particular activities/tools used by your teacher…helped you in your learning of algebra?", Herman noted, "He has these little handheld algebra tiles that he uses to explain stuff and there's a sketch tool that you can use on there and the calculator helps you learn better. There're all kinds of stuff on there."

Visual. The next emergent theme from answering SQ1 was that students described their CSCL interactions via Desmos as "visual." In other words, students mentioned visual representations of mathematical concepts that Desmos provides. In his response to the first interview question about what approaches/tools were used in the 1:1 environment, Herman stated, "What helped is ... I'm a visual learner so for me I need the visual appearance on how to do things. So, it's easier for me instead of doing things on paper and writing it out."

An example of the "visual" theme can be found in Alice's response to the interview question, "How would you describe your experiences with Desmos while learning algebra?" She specifically made a comment about the "visual" feedback she was receiving when stating that "you can type out the equations and see everything as it happens. So, it's really easy to understand."

Additionally, throughout his interview, Dan kept mentioning the "visual" aspect of Desmos. "It just puts it ... in a visual perspective for me and I feel like I learn best in that way." When asked if there were certain times or topics, he felt were better for using Desmos, Dan commented, "Yeah, when we were learning about parabolas and graphs" because you can "move the lines and stuff manually. I think that helped."

Isaac shared a similar sentiment. When asked "Were there any topics where you were like 'Desmos is perfect for this'?," Isaac responded, "Definitely parabolas because I had no idea what they were. My stepdad said they were going to be dreadful, but they were actually pretty good." When answering the interview question "What particular activities/tools used by your teacher using Desmos helped your learning of algebra?," Isaac commented, "it's just visualizing the parabola as you are able to adjust the numbers that really gave me a better understanding of how everything would move."

Previous Interactions are Accessible. The next emergent theme was that previous interactions were accessible. This refers to students being able to store their interactions with Desmos as a scaffolding resource within the Desmos activity that can be accessed at any time. If students are logging in using their school-issued Google accounts, they can go back at any time and view their previous interactions. When responding to the interview question, "Were there any tools or activities in Desmos that helped your learning?," Edgar responded with, "Yeah, it all [goes] back to the feedback. Like telling me that I was wrong ... and also ... every time it gave me that check mark that

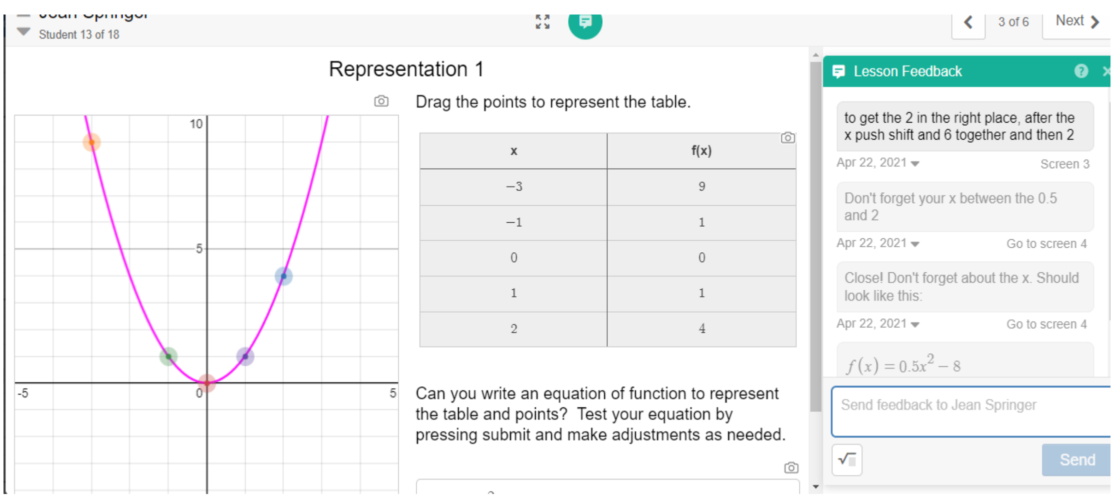
I did something right and let me know that I was going through the right step. It was helping me answer future problems because then I knew this other problem or screen, so I won't make the same mistake on the other one." In this example, Edgar is describing his process as he works through a Desmos activity. He can go back to a previous screen and review his work to help him on the current screen. Edgar knows that because he received a "check mark" on the previous screen, he was able to successfully complete the task. For example, on a Marbleslide activity, students receive a check mark indicating that they have completed a specific screen challenge.

Another example is Beto's description of the "keyboard part" of Desmos when asked about how Desmos helped in his understanding of algebra. The student mentioned that "on paper I would lose most of my work, but on Desmos it's easy to catch up with my work." This description brings attention to students being able to access and interact with the CSCL content. Isaac echoed a similar sentiment when he responded to the same question, noting that "It allows us to go back and see what we did along with giving us the tools to kind of visualize everything. So, it's not just plain paper and pencil. See if you can do this."

Passive Feedback. The next emergent theme was connected to the passive feedback students received from their learning. Activity components, such as sketch tools, graphs, and textbox, provide students with the L2S interaction opportunities. These interactions were interpreted by either the software or teacher, which then provides feedback to help understand student thinking. Compared to active feedback, the difference is that in passive feedback, there is a slight delay between student input and the software and teacher interpretation before feedback is given. A mention of this type of “passive” feedback was noted in Fabian’s response to the interview question. In his response to the question, “How would you describe your experiences with Desmos while learning algebra?,” Fabian pointed out that the feedback is what he found helpful on Desmos as he expressed, “It [Desmos] tells you when you’re wrong. When you get it right.” In his response to the same question, Edgar talked about the passive feedback he was receiving:

> so, Desmos was good. I liked learning on it because it was giving me feedback on, like, what I was doing wrong. Let’s say after, like, being stuck on the same [screen] ... after, like, 10–15 minutes, I would ask the teacher [for] help on anything and then he would tell me, and then it all made sense.

When asking for help, students would write in our classroom zoom chat their questions and the teacher would respond via Desmos’ feedback feature as seen in Figure 5.



x	f(x)
−3	9
−1	1
0	0
1	1
2	4

Figure 1 Teacher Feedback Interaction on Desmos

Note: Screenshot of a student’s Desmos activity screen.

Connecting SQ1 Findings to CSCL Framework

In this section, I am connecting the themes described before to the CSCL framework. As a result of this analysis, students focused on the following criteria of the framework: (1) open-ended or guided CSCL interactions, (2) observed CSCL interactions can be stored centrally and meaningfully interpreted, and (3) the CSCL system provided students with active and passive feedback. Table 8 is an overview of the relation between the CSCL framework and the emergent themes for SQ1.

Table 8 Connection Between CSCL Framework and SQ1 Emergent Themes

CSCL framework criteria	Emergent themes
(1) Open-ended or guided CSCL interactions.	• Simple • Fun • Multifaceted • Helpful
(2) Observed CSCL interactions can be stored centrally and meaningfully interpreted.	• Helpful • Previous interactions are accessible
(5) CSCL system provides students with active and passive feedback.	• Visual • Passive feedback.

Kumar et al.'s (2010) first framework criterion is open-ended and guided CSCL interactions. In other words, the system offers students free browsing of content, making posts, sharing content, and chatting without constraints (i.e., open-ended). The CSCL system also offers guided collaborative opportunities, such as sentence stems, real-time prompts from the system based on students' self- and coregulatory activities (i.e., guided). Using Desmos as the CSCL system for this study, examples of open-ended and guided CSCL interactions in activities are the Marbleslides, Polygraph, and 2 Truths & a Lie activities. The focus of SQ1 was on the aspects of CSCL interactions students described in their experiences with Desmos. Participants identified these open-ended and guided interactions via Desmos as “simple,” “fun,” “multifaceted,” and “helpful” when learning algebra.

The second CSCL framework criterion is that the observed CSCL interactions can be stored centrally and meaningfully interpreted (Kumar et al., 2010). The work and interactivity that students engaged in through the software could be monitored and measured. All Desmos activities are stored within the access code created on the platform by the teacher. During the data analysis, it was clear that students talked about the capability of Desmos to centrally store their data, and participants made several mentions of being able to access their previous interactions as “helpful” to their learning of algebra. Within the activity, students mentioned that they were able to go back to any previous screen they interacted with if necessary. This analysis speaks to the identified theme that participants’ previous interactions were accessible.

The fifth CSCL framework criterion of providing active and passive feedback was also found in the analysis of data. The “visual” and “passive” themes identified as part of how students talk about their experiences with Desmos related to this component. The “visual” aspects of Desmos were a significant theme identified by the students as being able to manipulate equations and see how it impacted their graphs in real time is the foundation of the Marbleslides activities. In terms of the “passive” theme, students can receive feedback either from the software or the teacher based on their interactions with static images (e.g., sketching on graphs, algebra tiles, etc.).

Subquestion 1 Summary

This section reports the findings associated with SQ1, “What aspects of CSCL interactions do students talk about when relaying their experiences with 1:1 CSCL in an algebraic reasoning course?" Students' responses are analyzed first to identify themes to answer the question, and then these themes are connected to the CSCL framework criteria. Findings from the initial process, the themes are simple, fun, helpful, multifaceted, visual, previous interactions are accessible, and passive.

The themes aligned with three criterions of Kumar et al.'s (2010) CSCL framework as students described their classroom experiences with Desmos. The first criteria was open-ended and guided CSCL interactions. The themes identified were that these CSCL interactions were "simple," "fun," "multifaceted," and "helpful." Students described using Desmos as simple and easy to use in their algebraic reasoning course. These open-ended and guided interactions on Desmos gave students the ability to expand on their answers or responses by providing multiple ways for them to represent their thinking, which students identified as helping them to explain their thinking.

The second framework criterion of CSCL interactions can be stored centrally and meaningfully interpreted was also observed. The themes identified were that students' "previous interactions were accessible" and "helpful" in their learning of algebra. All the interactions and student work within Desmos could be stored within each student activity and could be accessed by students. Because students were able to continue to interact with previous screens within the activities, they found it helpful in their learning of algebra, which made their interactions fun and attainable.

The emergent themes identified from student responses were that their interactions were "visual" and "passive", consistent with the fifth CSCL framework criterion. In other words, students identified Desmos as a tool that can provide them with immediate, timely feedback that is active (e.g., inputting and equation that Desmos graphs simultaneously) and passive (e.g., student "explain your thinking" text boxes). As opposed to waiting to receive feedback from a scored paper, students were able to explain their thinking and receive immediate and timely feedback within Desmos. Students found these multiple means of feedback helped them internalize mathematics in a way that was intuitive in their comprehension. The "visual" aspects of the feedback provided within Desmos were found to be a critical component of participants' experiences with learning algebra in a 1:1 CSCL setting.

Subquestion 2 Emergent Themes

To answer the second SQ: What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course? participants' responses were initially coded following the same two-cycle coding process described for SQ1 and then analyzed to identify themes that answered the question. These themes were then connected to the CSCL framework. According to Kumar et al. (2010), a CSCL system design affords multiple collaborative opportunities that capture all learner activities within the full context of their learning environment. These collaborative strategies are based on L2S and L2L interactions, which can be analyzed, categorized, and interpreted in real time. After initial coding, the themes identified from participants' responses were related to L2S, L2L collaborative interactions. However, a third theme also emerged of learner to teacher (L2T) interactions. Table 9 includes the themes, their definition, and examples of parts of students' responses. The next paragraphs present descriptions and examples of these themes.

Table 9 Definitions and Student Response Examples of the Emergent Themes Related to Subquestion 2

Emergent themes	Definition	Student response examples
L2S Interaction	Students were able to work in conjunction with the Desmos software (L2S) when exploring algebra to produce and share mathematical reasoning.	Isaac: It allows you to do things in your own way. So, you can make things as complex, complicated or as simple as you want. But, just allowing you to use the creativity along with math which really helped me because I am all about creativity and the imagination stuff.
L2L Interaction	Students were able to work in conjunction with other students within Desmos while learning algebra to produce and share mathematical reasoning.	Gabe: So, if you participate and talk to each other and work with each other it's going to be easier and better, and you learn things better and stuff.
L2T Interactions	Students were able to work in conjunction with the teacher within Desmos while learning algebra to produce and share mathematical reasoning.	Gabe: "I understand it sometimes. If I don't understand it, I ask [the teacher through Desmos] a question and he helps me understand it."

Note: Learner to Software (L2S), Learner to Learner (L2L), Learner to Teacher (L2T)

Learner to Software (L2S) Collaborative Interactions. The first theme emerging from the analysis is a collaborative strategy students identified based on a L2S interaction. Students worked in conjunction with the Desmos software (i.e., L2S) when exploring algebra to produce and share their mathematical reasoning. Students were asked about Desmos activities that featured collaborative strategies. For example, when answering the interview question "How would you describe your experience with

Desmos activities, such as Polygraph, Marbleslides, or 2 Truths & a Lie while learning algebra?", Isaac specifically talked about the Marbleslides activities. He described them as "pretty much my favorite because [the teacher] said as long as you can get all the stars, then you can go on so there are no strict rules." Isaac expanded on his response by noting that Marbleslides "allows you to use all the formulas that you have already known to understand more, and it just gives you creativity." Since the challenge and equation input is all on a single screen, students can type and modify their equation and simultaneously see how the equation changes as they type it. This is an example of a L2S interaction where the student inputs information into the platform, then the software interprets this input to provide immediate feedback in the form of a graph. This is a similar sentiment to what Alice stated when answering the question about what activities and tools in Desmos helped in her learning of algebra. She responded "again getting to type out the equations … the one with the [marbles] where you type out the equations and you have to get all the stars. That was pretty fun."

This sentiment is echoed by Dan's response to the interview question, "How did these collaborative strategies help in your learning of algebra?" In his statement, the student stated that "they've just helped me understand better ... visually being able to work with it myself." In working "with himself" the main interactions within the platform are between the student and the Desmos software, as it interprets students' input in a visual manner. All these activities (i.e., Polygraph, Marbleslides, Card Sort, 2 Truths & a Lie) have a visual element. However, Marbleslides and Card Sort specifically feature L2S interactions, which is what Dan is referring to when he said, "being able to work with it myself."

Learner to Learner Collaborative Interaction. A L2L interaction was also identified by the researcher as another collaborative strategy when talking about students' experiences with CSCL. The theme refers to students being able to work in conjunction with other students within Desmos while learning algebra in the Algebraic Reasoning course. The Desmos Polygraph activity was talked about by students and connected to this theme. Gabe's response to the interview question "When did you prefer to collaborate when learning algebra?" supports this claim:

> Because in algebra we don't read algebra and it's kind of hard, so if you participate and talk to each other and work with each other it's going to be easier and better, and you learn things better and stuff.

Success dependent upon peer-to-peer collaboration was only in a Desmos Polygraph activity. One student (i.e., guesser) must be able to communicate his or her questions in a way that can be understood by their partner (i.e., picker). The partner responds, prompting the guesser to interpret this into eliminating options until the correct, chosen graph by the picker remains. This is what Gabe was referring to as "going to be easier and better" when you "talk" and "work with each other." Figure 6 shows an example of this L2L interaction on a Polygraph activity.

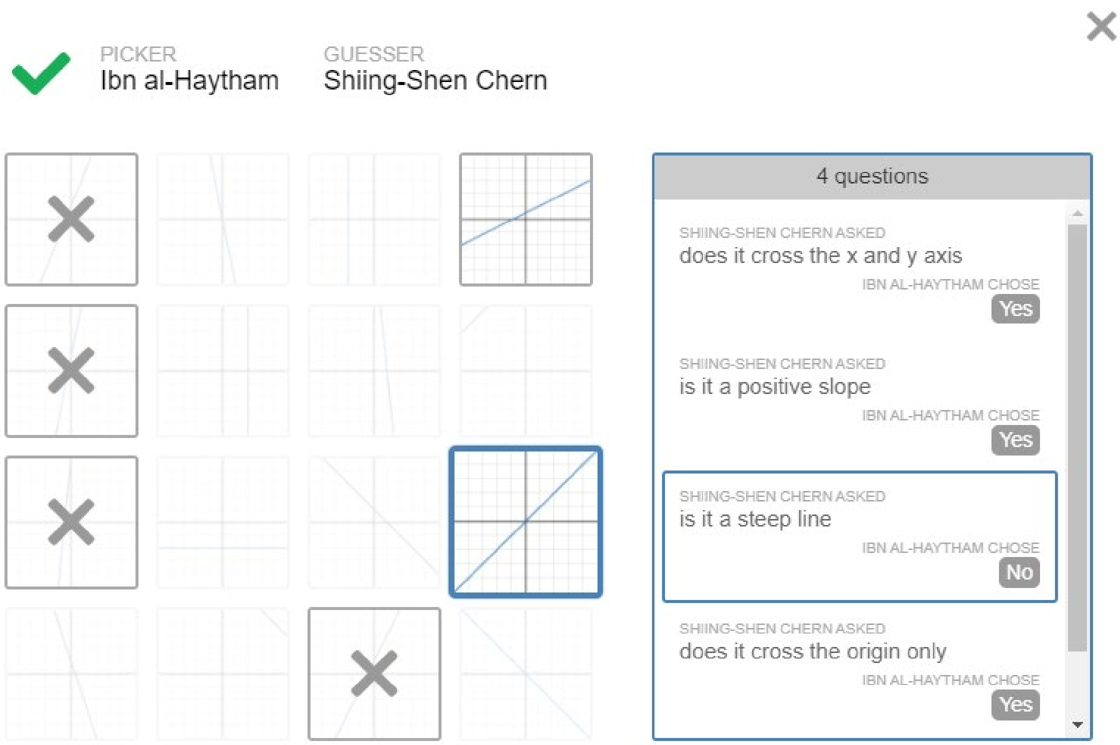


Figure 2 Example of Learner to Learner Interaction on Desmos Polygraph

Note: Screenshot of a student's activity screen engaged in a Polygraph activity with another student.

In this response, Gabe is referring to the coregulated learning experience of a Polygraph activity as it is the only activity where students could actually "talk to each other" and "work with each other." He acknowledges that algebra is "kind of hard" but that when participating in a coregulated learning activity on Desmos (i.e., Polygraph) it makes the mathematical concepts "easier," and he can "learn things better and stuff." As Gabe described in his response to the interview question about how Desmos helped his learning of algebra, these collaborative interactions were "like a game" (i.e., "Guess Who?").

There were, however, some students who struggled with some of the collaborative interactions with peers. For example, when responding to the question, “How would you describe your experience with Desmos activities?,” Herman referred to the Polygraph activities. As Herman noted, “In my experience, I kind of struggled on it. It’s not as easy, well Polygraph isn’t easy for me. It’s cool, but I struggled on it.” When the interviewer asked a follow-up question about what made Polygraph a bit more challenging, Herman responded that “putting stuff together to me is a bit more difficult.” The student struggled at times initiating the questioning for their partner (i.e., “putting stuff together”). Figure 7 shows an example of this type of struggle during a Polygraph activity. As Herman noted, “You have to have an understanding of what to put together and how stuff works in algebra.” It is difficult to “fake through” a Polygraph activity as student output is dependent upon the quality and engagement of the L2L interaction. A need is created in this situation. A need to be able to communicate effectively and understand what your partner is asking or saying. As Herman concluded, “Once I found that [Polygraph] was challenging, I found that working with someone else [helps] find a better graph or with learning in school.”

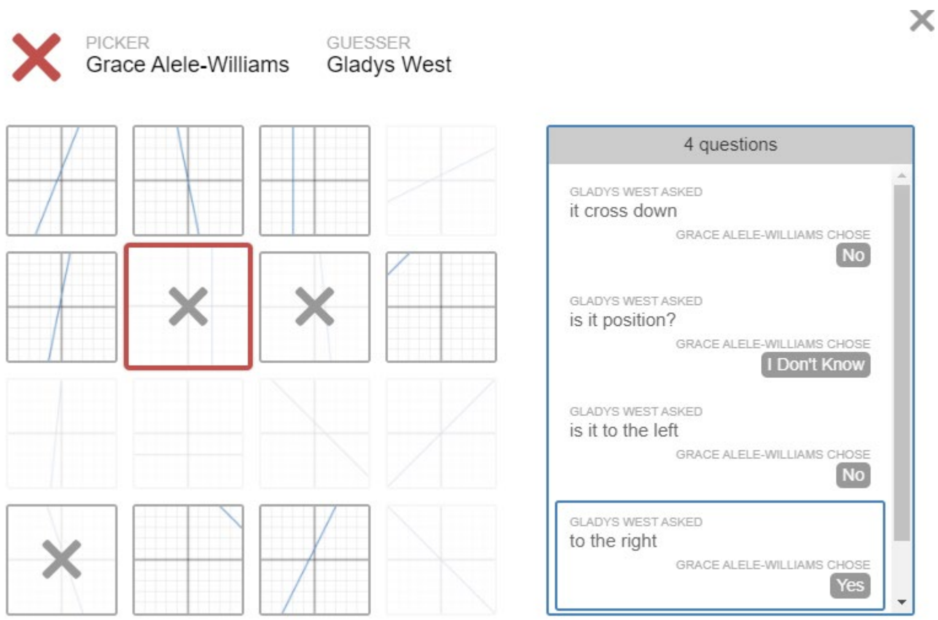


Figure 7 Example of a Polygraph Fail

Note: Screenshot of a failed interaction between two students in a Polygraph activity.

2 Truths & a Lie was another activity described by students that is identified as a L2L collaborative interaction. In this activity, students are first presented with a graph of a line and three statements where one of them is false (i.e., a "lie"). Students then explain their reasoning as to why the statement they chose is the lie by using the provided text box of sketch tools. The activity concludes by students building their own graph challenge, creating three statements, and then having their peers complete these challenges. As Isaac recalled, "if you understand it and [see] it you can figure out what is wrong with and what could be a thing about it." The "it" the student refers to is interpreting the graph created by a fellow peer, identifying the false statement, and explaining their reasoning. Figure 8 shows an example of this L2L collaborative interaction.

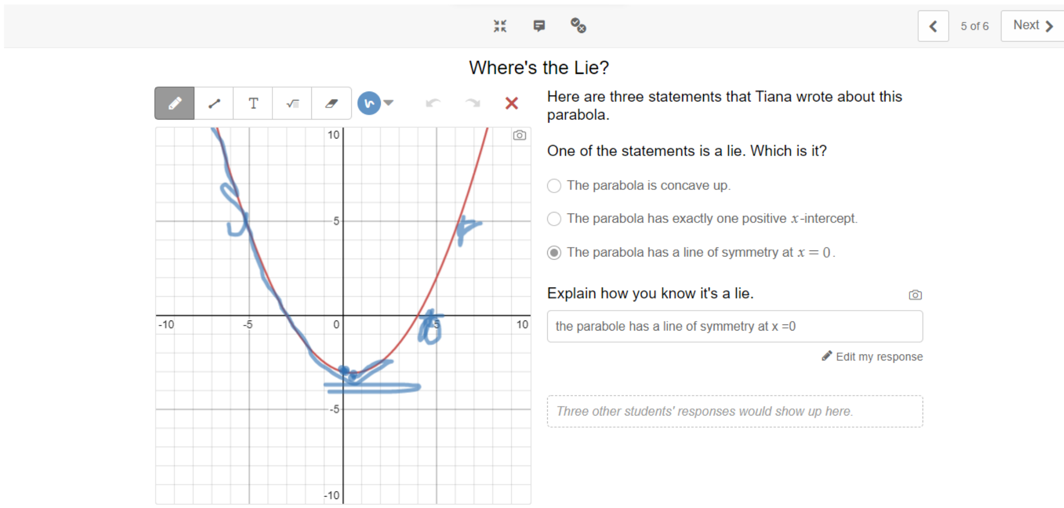


Figure 3 Example of Learner to Learner Interaction on the Desmos 2 Truths & a Lie Activity

Note. A screenshot of a student interacting with a challenge problem created by another student during the 2 Truths & 1 Lie activity.

Learner to Teacher Collaborative Interaction. The third emergent theme identified relates to their L2T interactions. In other words, students were able to work in conjunction with the teacher within Desmos while learning algebra to produce and share mathematical reasoning. When describing his experiences with Desmos, Gabe reflected that “I understand it sometimes. If I don’t understand it, I ask [the teacher through chat] a question and he helps me understand it.” So even if the interactions she is having with Desmos do not make sense, Gabe was able to ask for help, and the teacher would interact with Desmos to provide clarification that would guide his thinking. He also mentioned how open-ended discussions as a class helped solidify his understanding when answering the third interview question, “How did Desmos help your understanding of algebra?,” Gabe replied, “It helped me because I got to understand things way better and the way he teaches, we follow-up. Like the whole class follows up using Desmos.” This response echoes the importance of having multiple forms of collaborative interactions within the learning environment, and how technology itself is not enough. During Desmos activities, the teacher monitored student actions and would at times pause and discuss as a whole class (i.e., "The way he teaches we follow-up. Like the whole class follows up using Desmos") when needed.

Connecting Subquestion 2 Findings to the Computer-Supported Collaborative Learning Framework

Aligning the analysis of students' responses related to interactions to the CSCL framework, it was found that the emergent themes connected to the third criterion of the framework: the predefined collaboration strategies represented in the software. Table 10 is an overview of the relation between the CSCL framework and the emergent themes for SQ2.

Table 10 Connection Between CSCL Framework and SQ2 Emergent Themes

CSCL framework criteria	Emergent themes
(3) Predefined collaboration strategies represented in the software.	• L2S interactions • L2L interactions • L2T interactions.

Note: Kumar et al. (2010). Learner to Software (L2S), Learner to Learner (L2L), and Learner to Teacher (L2T).

One of Kumar et al.'s (2010) framework criterion is the presence of predefined collaboration strategies within the platform. In this study, the Desmos activities students engaged in featured these collaborative strategies. For example, Polygraph and 2 Truths & a Lie featured L2L collaborative interactions. Students interacted with other students asking and responding to each other's questions (i.e., Polygraph), or would create a mathematical situation or challenge that peers could interact with (i.e., 2 Truths & a Lie). Marbleslides and Card Sort, on the other hand, engaged students with more L2S collaborative interactions. Participants would interact with a particular component within the activity and Desmos would immediately respond based on their input. Both L2L and L2S are discussed in Kumar et al.'s (2010) study. However, the data from this research showed that students discussed another type of interaction—L2T. These interactions occurred at the teacher's discretion and were based on the flow of the class. In other words, the teacher would provide the whole class feedback and direction based on student interactions within Desmos and the pace of the lesson. Participants relied on L2T interactions when L2S and L2L interactions were insufficient, and they needed more guidance.

Subquestion 2 Summary

This section reports on the students' responses to the SQ, "What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?" SQ2 initially aligned with the third and fourth criteria of Kumar et al.'s (2010) CSCL framework as students described their classroom experiences with Desmos. The themes that emerged from the data analysis (i.e., L2S, L2L, and L2T) focused on predefined collaboration strategies that occurred within the software. At a metacognitive level, these predefined collaboration strategies refer to self-regulated (i.e., L2S), coregulated (i.e., L2L), and shared-regulated (i.e., L2T) learning within the CSCL system (Desmos).

Chapter 4 Summary

This chapter discussed the findings from analyzing participant responses of their experiences with 1:1 CSCL in an algebraic reasoning course. These students were placed in my algebraic reasoning class because they were identified by their algebra 1 teachers as needing more of a foundation before moving into geometry or algebra 2. The criteria for selecting participants for the individual interviews was based on students' willingness to be a part of the study. Data from nine 10th grade students in these classes was collected through individual semistructured interviews completed by a secondary researcher.

For the data collection, interview questions were aligned to Kumar et al.'s (2010) CSCL framework. The students' semistructured interviews were conducted in a one-to-one setting based on participant and interviewer availability. I did not conduct the interviews as I am also the participants' AR teacher and wanted to ensure my presence did not interfere with their responses. Participant interviews were audio-recorded, transcribed, and removed any student identifiable data before being presented to me.

The analysis consisted of prioritizing and honoring participants' voices through in vivo coding to answer the study's CQ: How do participants describe their learning experiences with 1:1 CSCL in an algebraic reasoning course? The answers to the SQs were initially coded to present distinct characteristics of students' experiences in a CSCL algebraic reasoning class. This information was used for focused coding, which I used to identify emergent themes. These emergent themes helped form the participants' narratives, explaining their experiences with CSCL environments like Desmos.

To answer the SQ1: What aspects of CSCL interactions do students talk about when relaying their experiences with 1:1 CSCL in an algebraic reasoning course? students' responses were analyzed first to identify themes to answer the question, and then these themes were connected to the CSCL framework criteria. From the initial process, the themes were identified as: "simple," "fun," "helpful," "multifaceted," “visual,” “previous interactions are accessible,” and “passive.” As a result of this analysis, it was found that students focused on the following criteria of Kumar et al.’s (2010) framework: (1) open-ended or guided CSCL interactions, (2) observed CSCL interactions can be stored centrally and meaningfully interpreted, and (5) the CSCL system provides students with active and passive feedback.

To answer the SQ2: What are students’ perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course? students’ responses were analyzed first to identify themes to answer the question, and then these themes were connected to the CSCL framework criteria. From the initial process, the themes identified were: L2S, L2L, and L2T collaborative interactions. Aligning the analysis of students’ responses related to interactions with the CSCL framework, it was found that the emergent themes connected to the following criterion: (3) Predefined collaboration strategies represented in the software. Additionally, a L2T collaborative interaction was identified from this study and not previously mentioned in Kumar et al.’s (2010) study. The CQ was answered using a combination of the key emergent themes identified in the two SQs that are discussed further in the following chapter. After the discussion of the findings of the SQs, the CQ is addressed using the CSCL framework of this study.

CHAPTER FIVE: DISCUSSION

The use of a CSCL environment in a mathematics classroom is considered as a thought-provoking stimulus that develops 21st-century skills, such as inquiry, collaboration, and problem-solving (Bower et al., 2010; Danielson & Meyer, 2016; Lin & Liang, 2014). These abilities are necessary for success in the modern world, especially when students transition from high school to college, the workforce, and adulthood. It is a form of technology integration with the potential of engaging students in their learning and increasing their motivation (Afari et al., 2013; Chipangura & Aldridge, 2017; Donaldson, 2012). However, students' perspectives of their experiences within this type of environment are lacking. This study contributes to the increased understanding of students' experiences with 1:1 CSCL in an algebraic reasoning classroom and makes suggestions about implementing these types of programs (e.g., Desmos) as a teaching tool. Overall, the students who participated in this study reported that their experiences with Desmos were helpful, and provided visual representation of the content and timely, interpretive feedback while learning algebra.

This chapter is organized into five sections. The [1] first section is a summary of the study that includes a discussion of the problem, setting the context of the study and participants. That is followed by [2] a discussion of major findings of each SQ and the CQ. Each of those discussions presents a conclusive statement about each research question. Then, [3] the implications of the study are presented. It includes my personal reflections as teacher and researcher about the meaning of the findings. It is followed by

[4] a discussion of the ethical considerations and the limitations and delimitations of the study. The chapter concludes with [5] a section on suggestions for future research.

Summary of Study

A basic qualitative study, as outlined by Merriam and Tisdell (2015), was conducted to establish an understanding of students' experiences with 1:1 CSCL in an algebraic reasoning (AR) course. Participants' perceptions of their experiences in this environment were examined through their responses in semistructured interviews.

The participants were nine students enrolled in an algebraic reasoning course with a 1:1 CSCL environment that used the Desmos platform. The participants were students attending a large (2,000+ students) suburban public high school in North Texas. These students were willing to participate in the study and met the requirements of having to repeat the STAAR test and taking the algebraic reasoning course during the study's 2020–2021 academic year.

To establish an understanding of participants' experiences, Kumar et al.'s (2010) CSCL framework was used to generate a CQ and two SQs. The SQs were generated to address specific aspects of the CSCL framework.

CQ: What are students' perceptions of their experiences with 1:1 CSCL in an algebraic reasoning classroom?

SQs:

SQ1: What are students' perceptions of their interactions with 1:1 CSCL in an algebraic reasoning course?

SQ2: What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

The first SQ focuses the research on what happens to student learning during 1:1 CSCL interactions in mathematics. The emphasis is on capturing students' initial thoughts about their experiences with CSCL activities. The second SQ focuses on students' descriptions of the collaborative strategies for learning algebra in a 1:1 CSCL environment. SQ2 asks them to think about these activities from a metacognitive perspective, with a focus on the collaborative strategies embedded in the CSCL activities. After analyzing students' data, the researcher identified emergent themes, presented a narrative of their experiences in such an environment, and recognized how these themes align with the CSCL framework (Kumar et al., 2010).

Discussion of Findings

The information in this section is divided into three sections. The first two sections are a discussion of the findings related to the two SQs and their connection to previous studies. The third is a discussion on how these findings answer the CQ in relation to the CSCL framework.

Discussion of Findings for Subquestion 1

Analyzing the coding of the data revealed that students discussed the following identified aspects of CSCL interactions: simple, fun, helpful, multifaceted, visual, previous interactions are accessible, and passive feedback.

Simple. The most common way students talked about their CSCL interactions in Desmos was that they were "simple." The integration of a CSCL environment in their algebraic reasoning class was perceived as unobtrusive to their mathematical learning experiences. Once students had a foundational understanding of how Desmos works, they engaged in the activities with ease. The interactions students' experienced emphasized decision-making, reflection, and problem-solving, which contributed to their feelings of "simplicity" and mathematical understanding (NCTM, 2000). A simple, minimalist instruction approach in the form of content delivery and interaction was important because it gave students more time to focus on their mathematical cognitive abilities by reducing time on knowledge search, engaging them in justification of thinking, and stimulating innovative ideas and ways of learning math (Danielson & Meyer, 2016; Silverman, 1995). These results are consistent with other studies that have examined students' views on the use of various technologies for mathematical learning (Fabian et al., 2018; Zulnaidi & Samri, 2017). Most studies on student perspectives on math learning with technology do not separate the activity from the medium. Participants in Lai et al.'s (2012) study found technology to be simple and enjoyable, but it was unclear whether students were referring to the device or the learning strategy within the digital platform. In this study, participants found the interactions with the Desmos tool to be "simple."

Fun. All participants found their interactions with Desmos to be "fun." The main activity students found enjoyable was Marbleslides. This activity presented them with challenges that could be completed in varying ways, dependent upon students' knowledge level of functions. Like a game, students interacted at their level, which impacted their positive attitude toward learning (Li et al., 2016; Magen-Nagar & Steinberger, 2017).

Students engaged in mathematics both cognitively and emotionally, which led to students enjoying, having "fun," and valuing their mathematical learning (Attard & Northcote, 2011). This is supported by studies that show students with increased levels of engagement have positive attitudes toward mathematics and high mathematical self-efficacy (Adelson & McCoach, 2011; Eichhorn et al., 2019; Linnenbrink & Pintrich, 2003). Students in CSCL mathematics classrooms are more task-focused and invested in their learning (Chipangura & Aldridge, 2017). This is because the learning environment impacts on students' motivation to learn (Magen-Nagar & Steinberg, 2017). Thus more "fun" CSCL interactions led to greater students' motivation, more effective learning processes, and higher achievements (Afari et al., 2013; Dorman, 2009; Lin & Liang, 2014).

These findings are consistent with those of other studies that have looked at students' perceptions of learning mathematics through technology. In Yimer and Feza's (2020) study of students' perspectives of CSCL of calculus using the GeoGebra software, the authors have discovered that participants found the environment enjoyable and interesting. The authors have argued in their study that learning mathematics in such a technologically enhanced environment would benefit its learners in the construction of conceptual knowledge, positively impacting their attitudes toward mathematics. In a similar study using GeoGebra for mathematics education, Wassie and Zergaw's (2019) findings have contributed on students' enjoyment to students becoming more responsible for their own learning when they are actively engaged in the CSCL environment.

Helpful. Along with participants' interactions being "simple" and "fun," they described their experiences with Desmos as "helpful" in their learning of algebra. The integration of technology to promote mathematical learning experiences in the classroom, when used appropriately, could help students develop a deeper mathematical understanding through the emphasis on decision-making, reflection, reasoning, and problem-solving (NCTM, 2000). In their study, Mishra et al. (2013) have found that the designed element of the CSCL environment can influence the way students manage self-directed learning. These interactions allowed students to solve problems collaboratively, creating meaningful cooperation while cultivating learners' critical thinking (Mishra et al., 2013). In Zulnaidi and Samri's (2017) study on the effectiveness of using the GeoGebra software to build students procedural and conceptual knowledge, the authors have also claimed this type of learning environment was helpful. The authors have argued that GeoGebra significantly enhanced students' conceptual knowledge because it helps them see the concepts and relate it to their own understanding.

It is important to note that these results contradict previous research that has claimed students in CSCL environments frequently perceive these interactions as confusing (Thompson & Coovert, 2003) and less productive (Straus, 1997; Straus & McGratch, 1994). However, a well-established CSCL environment that is facilitated by the teacher has the potential of engaging students in their learning, increasing their motivation, and helping them in their understanding of algebra (Afari et al., 2013; Chipangura & Aldridge, 2017; Donaldson, 2012).

Multifaceted. One of the ways participants found their Desmos interactions helpful was the multifaceted opportunities they had to show and explain their thinking. This learning environment allowed students to develop new ways of interacting with peers and software through collaborative interactions and strategies (Danielson & Meyer, 2016; Heid et al., 1990; Kumar et al., 2010; Lopez-Morteo & Lopez, 2007). This is consistent with NCTM's (2015) statement that incorporating multiple learning opportunities in the classroom deepens students' learning, experiences, communication, and understanding of mathematics. An example of providing multiple collaborative interactions is found in Anabousy et al.'s (2014) study on middle school students working with technology to learn about algebraic concepts. The properties of the technological tool, which included graphic, algebraic, and verbal representations, were attributed to these students' success. The findings of the authors suggest that it is critical to provide students with opportunities to interact with algebraic concepts using these representations for them to develop a conceptual understanding of the topic.

Providing students with opportunities for rich mathematical conversations while challenging them with tasks that have elements of choice and variety embedded within a CSCL activity promoted a sociocollaborative, student-centered learning approach to learning algebra (Attard, 2014; Danielson & Meyer, 2016; Kopcha, 2010; Liu, 2007). This is supported by researchers who have argued that a CSCL mathematics classroom provides multiple ways for students to engage in their learning through various interactions that enhance their problem-solving ability (Abramovich & Connell, 2014; Danielson & Meyer, 2016). At the elementary level, Bulut et al. (2015) have also explored the effects of a technology-enhanced environment on third-grade students' academic achievement in fractions. Their findings have revealed that participants who engage in dynamic activities on the digital platform had access to multiple representations of fractions, which improved their understanding of the concept.

Visual. Participants described their CSCL interactions as "visual." Learning mathematics in a dynamic, technology-rich environment engages students with dynamic representations while immersing them in meaningful forms of communication (Wilensky & Stroup, 1999). These virtual representations assisted students in making observations by providing a “tangible” object that could be manipulated and by displaying these changes immediately on the screen (Fonkert, 2010). Comparable results were found in Wassie and Zergaw’s (2019) study of using GeoGebra in mathematics education. According to the authors, integrating algebraic concepts in a visualizing manner was critical in developing students’ mathematical abilities. The results of Zulnaidi and Samri’s (2017) study on GeoGebra used to improve students’ mathematical knowledge are likewise consistent with this assertion. They have concluded that such a setting may be advantageous for students since it makes information clearer through the use of appealing photos, images, and graphics, all of which are beneficial for students’ conceptual knowledge development.

Additionally, this visually interactive CSCL environment can positively affect student learning and instructional practice, especially among largely marginalized populations (Hegedus et al., 2015). These assertions are similar to those found in other educational technology research. Li and Ma (2010) have discovered in their review of current research on the impact of computer technology on mathematics education in K-12 classrooms that this type of learning environment has larger effects on the mathematics achievement of marginalized students, and that these effects are greater when collaborative interactions occurred. This is consistent with the findings of this study, as most participants fall into these categories.

Previous Interactions are Accessible. Being able to access prior work within the Desmos activity was another theme found in the analysis. Students enrolled in the AR course could access any of the Desmos activities they completed throughout the semester if they had internet access. Participants described this to be helpful in their learning of algebra in a CSCL environment. Having the ability to go back within the activity to a previous example was helpful in increasing student achievement (Lowther et al., 2003), conceptual understanding (Reiten, 2018), and a higher engagement in mathematics (Hilton, 2018; Ozel et al., 2008).

Having CSCL interactions that are recorded by the software and accessible to students are helpful in learning by fostering classroom discourse and collaboration (Jonassen, 1995). This was especially true in L2L activities, like Polygraph, where students collaborated with each other as they worked through the learning of algebra. Thus, a strong connection exists between the need for classroom discourse and a CSCL environment where students can access, review, and reflect on their interactions (Hegedus et al., 2015). Similar claims about students being able to access their interactions and work in a CSCL environment were found in Weinhandl et al.'s (2020) study of using GeoGebra for learning mathematics. The authors discovered that participants emphasized the need for constant availability of information, implying that they wished the materials could be accessed at any time and that it remained available after the tasks were completed.

Passive Feedback. In many students' responses, a major theme identified was "feedback" as a key component when using Desmos. It is troubling to find that student disengagement in their mathematical thinking and learning is connected to their attitudes toward mathematics (Larkin & Jorgensen, 2015). Their engagement is an important indicator of student success. Learning environments that provide multiple forms of feedback (Kumar et al., 2010) play a significant role in student engagement. Providing timely feedback in a CSCL environment significantly impacts the quality of a student learning experience (Attard, 2014). Careful implementation of immediate response and passive feedback within a CSCL environment can enable teachers to integrate quality questioning and more engaging class discussions (Ozel et al., 2008).

Weinhandl et al. (2020) reached a similar conclusion about the importance of feedback. The authors have identified feedback as a crucial component for successful implementation of a technology-enhanced environment in their study of utilizing GeoGebra for mathematics education. Their findings have suggested that feedback is critical to the development of mathematical competencies, as students could work independently and receive "just in time" information from the software. This type of technology-supported feedback should strengthen students' confidence (Weinhandl et al., 2020).

Discussion of Findings for Subquestion 1 Summary

The analysis of the coded data indicated that in response to SQ1, participants talked about CSCL interactions that were overwhelmingly positive ("simple," "fun," "helpful," and "visual"). Part of the reason participants perceived such ease in use of the Desmos software was because all their interactions were stored within the software platform, which allowed them to access their work at any time. Specific characteristics, such as "multifaceted" and "passive feedback," were also identified. Depending on the context of the Desmos activity, the interactions gave students options to show their thinking in multiple ways while also receiving visual and passive feedback. Previous research on CSCL environments in mathematics education supports these findings. The next section discusses the findings for SQ2.

Discussion of Findings for Subquestion 2

In the data analysis process, it was found that students discussed the collaborative strategies based on different types of interactions: L2S, L2L, & L2T. All of these are connected to social constructivist theory as students collaborate and interact with tools and with others throughout the learning experience (Kumar et al., 2010). The identified themes indicate that the environment in the classrooms provided interactions that are active, reflective, and intentional for students (Jonassen, 1995). When these types of interactions occur, technology in a CSCL environment can foster student learning (Abdu et al. 2015, Danielson & Meyer, 2016).

Learner to Software Interactions. In a L2S collaborative interaction, students may engage and support student knowledge construction, as learners and technology share cognitive responsibilities (Jonassen, 1995). Students experience an ongoing negotiation between their inner ideas and outer actions (i.e., interaction with Desmos) that deepens their understanding of algebra (Allanson, 2013; Driscoll, 2002). Technology that can think "with" students as opposed to "for." Digital resources within a L2S interaction made collaboration and communication more prevalent through virtual manipulations that are not necessarily accessible in a traditional mathematics classroom (Fonkert, 2010). Some of these L2S activities (e.g., Marbleslides) had game-based learning elements as students "built" their own equations for the marbles to slide down and collect all the stars. Students took ownership of their own mathematical learning and fostered their knowledge (Bourgonjon et al., 2013; Li, 2010). The Marbleslides activity provided students with a L2S authentic experience that enabled them to practice their critical thinking skills while providing choice and a sense of control (Li, 2010). A similar conclusion about the role of L2S interactions was made by Zulnaidi and Samri's (2017) study of GeoGebra's effectiveness on student learning. The authors have argued that students interacting with the environment (e.g., GeoGebra) helped them in their learning process by relating their mathematical ideas to the software's interpretation. This form of technology-supported feedback allowed students to work at their own pace while also strengthening their confidence (Weinhandl et al., 2020).

Learner to Learner Interactions. In a L2L collaborative interaction, students are more likely to develop a deep conceptual understanding of mathematics when they are engaged in discourse with others (Davidson & Worsham, 1992; Vygotsky, 1962). Students in an L2L interaction can "bounce" ideas off each other, make mistakes, correct mistakes, and learn from each other. The underlying assumption of this form of sociocollaborative learning is that students learn through constructivist ideals (e.g., active engagement, reflection) in group settings (Silverman, 1995). Because students interact with their peers, they enhance their communication while increasing their ability to explore concepts and make conjectures (Fonkert, 2010). They can discuss their learning strategies, understanding, and challenges with their fellow peers, mediated by a software system (Kumar et al., 2010). Some of these activities connected students with one another, sharing ideas, asking questions of each other (Caniglia et al., 2017; Danielson & Meyer, 2016).

The need to provide students with opportunities for L2L interactions was an argument made by Anabousy et al.'s (2014) study of middle school students using GeoGebra to learn algebraic concepts. They have argued that, of the three representations identified (i.e., algebraic, graphic, and verbal), students being able to verbalize their thinking has been ignored by mathematics educators. The authors have concluded that verbal representation needs to be an interface of the technology tool, as it would help students overcome their mathematical difficulties.

Activities, such as the Polygraph, provided students with an opportunity to interact with informal and formal academic language (Caniglia et al., 2017). This type of interaction was group worthy as each participant was actively involved in supporting a collaborative learning environment (Cohen, 1994; Fonkert, 2010). The Polygraph activity supports the use of informal language in preparation for understanding and using mathematical language in meaningful learning experiences (Caniglia et al., 2017; Herbel-Eisenmann, 2002).

Participants found L2L interactions to be more challenging, as knowing how to communicate effectively is more difficult. If not facilitated and monitored properly by the teacher, these L2L interactions can be more confusing to students (Thompson & Coovert, 2003) and less productive (Straus, 1997; Strass & McGratch, 1994) if students are not engaged properly with the activity. However, as mentioned above, implementing a properly collaborative learning approach can promote their understanding and problem-solving ability (Kuo et al., 2012).

Learner to Teacher Interactions. A L2T collaborative interaction was a theme identified in the study that was not previously discussed in Kumar et al.'s (2010) CSCL framework. Simply placing students in a CSCL environment does not guarantee effective collaborative learning (Blumenfel et al., 1996; Kumar et al., 2010; Soller, 2004). The teacher serves an integral role in the CSCL environment.

From this study, it was found that the teacher can help facilitate mathematical learning through the software by capturing student thinking that can be used later for classroom discussion and formative feedback (Caniglia et al., 2017; Danielson & Meyer, 2016). A CSCL environment immerses both teachers and students in meaningful forms of communication (Wilensky & Stroup, 1999) that positively affect student learning and instructional practice (Hegedus et al., 2015).

Discussion of Findings for Subquestion 2 Summary

The analysis of the coded data indicated that in response to SQ2, students talked about collaborative strategies that involved interactions between L2S, L2L, and L2T through the Desmos platform. Technology in a CSCL environment (Abdu et al., 2015; Silverman, 1995) can foster student learning (Abdu et al., 2015; Danielson & Meyer, 2016). It creates a learning environment that caters to students' strengths, fosters exploration, and provides seamless communication between students, medium, and teacher (Danielson & Meyer, 2016; Jonassen, 1995; Silverman, 1995). The information in the remaining section discusses how Kumar et al.'s (2010) CSCL framework helps answer the CQ of this study.

Central Question—Discussion of Findings

How do participants describe their learning experiences with 1:1 CSCL in an algebraic reasoning course?

To answer the CQ, during the data analysis, I identified four of the five criterions of the Kumar et al.'s (2010) CSCL framework: (1) open-ended and guided CSCL interactions, (2) observed CSCL interactions can be stored centrally and meaningfully interpreted, (3) predefined collaboration strategies represented within the instructional design, and (5) the CSCL system provides students with active or passive feedback. The fourth criterion is that underlying theories of collaboration can be represented and meaningfully interpreted in the CSCL system. Even though the Desmos activities all possessed qualities of self-, co-, and shared-regulated learning, these were not mentioned directly by the participants.

When describing their learning experiences with 1:1 CSCL in an algebraic classroom, participants noted the interactions were both open-ended and guided through Desmos, one of the criterions of the CSCL framework. Students described these CSCL interactions as “simple,” “fun,” “helpful,” and “multifaceted.” Providing students with opportunities for rich mathematical conversations with these themes and interactions within the CSCL environment promoted student-centered learning (Attard, 2014; Danielson & Meyer, 2016; Kopcha, 2010; Liu, 2007).

According to Li and Ma’s (2010) review of literature on the impact of computer technology on mathematics education, elementary school students outperform secondary school students in terms of mathematics achievement. For example, Bulut et al. (2015) have examined the effects of GeoGebra on third-grade students’ achievement in fractions. Their findings revealed that participants who engaged in mathematical learning via the digital platform had access to multiple fraction representations, which improved their mathematics achievement when compared to those in a traditional setting. It would be interesting to see what would happen if a high-quality CSCL environment for mathematics was introduced at a younger grade level, and how this would affect secondary students’ attitudes toward and perceptions of mathematics (Eccles et al., 1993;

Dowker et al., 2012), and their engagement and achievement in the subject (Hilton, 2018).

Student data also showed participants observing the second criterion: How their CSCL interactions on Desmos were accessible and stored within the platform. The ability to easily recall previous interactions by students to show and track their thinking was "helpful" in learning algebra. This engaged students and gave them ownership of constructing and enjoying their learning (Gomez et al. 2010). The software provided students with different formats to express and engage with the mathematical topics that were simple to access (Hunt & Andreasen, 2011; Eichhorn et al., 2019). These are examples of the importance of a CSCL environment that can store all CSCL interactions centrally and accessibly for students (Kumar et al., 2010).

The fifth framework criterion, the CSCL environment provides students with active and passive feedback, was found in the analysis of participant data. Participants identified the "visual" and "passive" feedback they received as being positive experiences while using Desmos for algebraic learning. These types of timely feedback can promote positive attitudes toward mathematics and high mathematical self-efficacy (Adelson & McCoach, 2011; Eichhorn et al., 2019; Linnenbrink & Pintrich, 2003). Within the data, many participants described the ability to input an equation, while Desmos simultaneously interpreted and output a visual graph. Students were able to visualize their interactions in an immediate and timely manner. The Desmos software assisted students in making observations by providing a tangible object that could be easily manipulated while displaying the changes immediately on the screen (Fonkert, 2010). It provided students with mechanisms to become self-aware of how to take ownership of their learning rather than relying on the teacher to make modifications (Hunt & Andreasen, 2011). Students were able to construct an understanding of whether they have communicated to the software their intended result. Receiving “visual” and “passive” feedback helped them make sense of abstract mathematical representations and make visual connections among them by actively engaging them in their learning to solve problems with more precision (Daher, 2008; NCTM, 2015)

The fourth criterion of the CSCL framework also identified in the data was that predefined collaboration strategies were represented within the instructional design. These collaborative activities were identified in L2S, L2L, and in the newly emergent L2T interactions. These type of predefined collaboration strategies (e.g., Marbleslides, Polygraph) may support student cohesiveness, teacher support, involvement, investigation, and differentiation which could be significant predictors of students' positive attitudes toward using Desmos in a CSCL environment (Chipangura & Aldridge, 2017; Magen-Nagar & Steinberger, 2017).

Marbleslides was regularly mentioned by many of the participants as an activity that stood out for them. From the participants' descriptions, the challenge aspect in a nonrestricted, safe, virtual environment where mistakes can be made and corrected until the desired outcome is achieved was a contributing factor to its helpfulness in understanding algebra. In this L2S interaction, there is “low-floor, but high-ceiling” capability in the Marbleslides activity as the software adapts to the interactions and knowledge level of the learner.

In L2L interactions, coregulated learning was identified when students described their experiences with the Polygraph activity. This activity provided students with a group-worthy task where each participant was actively involved in the learning process (Cohen, 1994; Fonkert, 2010). Students noted the importance of communicating with their peers to correctly guess their partner's graph. Students had to write their messages on Desmos and then the statement was interpreted by their peers to provide the proper response. This increased their communication and articulation of ideas (Evans et al., 2011; Rick et al., 2011). This reliance on each other's ability to discourse helped students improve their critical thinking and written communication (Marjanovic, 1999) and motivation to learn (Miller et al., 2004; Torff & Tirotta, 2010).

As noted by the L2T collaborative interaction described by the participants, the interactions between the students and teacher were critical in their positive experiences with the CSCL environment. Examples of L2T interactions were found within all the Desmos activities used in this study. Without proper teacher facilitation, at some point L2S and L2L interactions are limiting factors that can cause confusion in student learning (Straus, 1997; Straus & McGratch, 1994; Thompson & Coovert, 2003). When students get lost or confused within these types of interactions, having a teacher who is monitoring these interactions and providing appropriate and timely feedback can help guarantee an effective collaborative learning environment (Blumenfel et al., 1996; Kumar et al., 2010; Soller, 2004).

In a L2T interaction, the teacher was critical in the designing and implementation of the CSCL mathematical environment. Students were not initially equipped to use Desmos to regulate their own learning (Stahl, 2010). This needed to be learned and supported through the CSCL environment designed by the teacher (Hadwin et al., 2010). The teacher was responsible for familiarizing students with the Desmos software, exploring its capabilities, and applying their learning knowledge to specific mathematical tasks (Hollebrands & Okumus, 2018).

The L2S, L2L, and L2T interactions perceived by the participants connected to Kumar et al.'s (2010) CSCL framework because they involved predefined collaborative activities (e.g., Polygraph, Marbleslides, 2 Truths & a Lie, etc.) that were sociocollaborative in nature and helped in students' algebraic understanding. These are all examples of elements supporting the implementation of social constructivism as students collaborate and interact with tools and with others. This form of meaningful learning is active, reflective, and intentional for students (Jonassen, 1995).

Central Question—Discussion Summary

Kumar et al.'s (2010) framework was connected to how students perceived their experiences using Desmos in the algebraic reasoning course. In the study, participants described how Desmos provided them with open-ended and guided interactions (e.g., Polygraph, Marbleslides) that honored the student voice and guided student thinking. The software contained all student interactions within the platform, and it was accessible to students. Participants being able to access previous work within a singular area (i.e., the Desmos platform) was described as "helpful" by many of the participants. In a CSCL environment, it is best to keep all necessary information in a centralized location, as opposed to switching between multiple digital platforms throughout an activity (Kumar et al., 2010). The activities used throughout the study (e.g., Polygraph, Marbleslides, 2 Truths & a Lie, Card Sort) all featured predefined collaboration strategies that focused on self- (i.e., L2S), co- (i.e., L2L), and shared-regulated learning (i.e., L2T) (Kumar et al., 2010). Having students interact with mathematics in multiple ways in a CSCL environment supported their understanding (Danielson & Meyer, 2016; Lopez-Morteo & Lopez, 2007).

Meanwhile, the fifth CSCL framework criterion of providing active and passive feedback was the most identifiable theme in this study. Participants noted the importance of these types of feedback. Their understanding was deepened when they experienced an ongoing negotiation between their inner ideas and their outer interactions (Li et al., 2016). It allowed for more creative thinking and problem-solving in a CSCL environment that provided plenty of opportunities for student learning and discourse (Li, 2010; Shernoff et al., 2003). Furthermore, the identification of the L2T theme was also found to be critical for students' positive experiences with a 1:1 CSCL mathematics environment.

Implications

The study has implications for schools and teachers seeking to implement CSCL environments in mathematics. The main implication is students can be active learners (Fonkert, 2010) by having 1:1 CSCL as their central method for engaging their cognitive processes (Driscoll, 2002). The findings suggest that when students can experience multiple opportunities to engage with mathematics and technology, like a CSCL environment, they can perceive abstract mathematical representations and make connections between them (NCTM, 2015). Insight into participants' experiences provided by the study may be helpful in preparing context-appropriate activities that promote mathematical discourse (Daher, 2008). Additionally, this information can be used in the planning of professional development opportunities into 1:1 CSCL for teachers. Given that Texas, the state in which the study took place, is in the process of shifting to online administration of all STAAR tests, the study may provide policymakers with research on students' experiences with math in an online environment, which could impact districts' approaches to online learning. With many districts struggling to engage math students within an online environment, this study presents options that can be considered. The findings suggest that with proper teacher facilitation, a CSCL environment can be a simple, engaging, innovative, and formative learning experience for students that provides multiple ways of interacting with the software and other learners. Using programs like Desmos is shown by research to have the potential to be supportive of a technology-enhanced, sociocollaborative environment (Danielson & Meyer, 2016; Heid et al., 2002) where students can reflect on their thinking and the thinking of others (Driscoll, 2002), as found in this study. However, it is important to note that the teacher remains the critical component in designing and implementing a student-centered CSCL system. They must be able to organize and facilitate the conditions conducive for learning (Lin & Liang, 2014). Teachers are responsible for familiarizing students with the online environment, providing opportunities to explore its capabilities, and providing purposeful questioning and feedback to their mathematical tasks (Hollebrands & Okumus, 2018; Kumar et al., 2010). It is not the technologies themselves but how teachers incorporate the technologies in their teaching that make a significant impact on student learning (Keengwe et al., 2008; NCTM, 2015). Additionally, as found in the study, teachers need to make sure to interact with students within the CSCL environment. In this study, those interactions were found valuable for student engagement and comprehension.

As discussed before, there are multiple CSCL framework criteria that were identified by students as important pieces in their experience. A classroom learning environment that offers students a rich range of tools, encourages socialization, and enables equitable treatment of students helps in engagement and the development of independent learners with the 21st century skills to cope with an information-rich society (Danielson & Meyer, 2016; Magen-Nagar & Steinberg, 2017). Teachers need to be intentional in their facilitation of a CSCL environment. Due to these collaborative interactions occurring within the CSCL system, new classroom norms for students and teachers need to be established to create an effective learning environment (Heid et al., 1990). From the data, shared-regulated learning was discussed by participants when a L2S or L2L interaction was confusing for them, and required clarification or guidance from the teacher (i.e., L2T). The L2T interaction was an emergent theme that was not previously discussed in Kumar et al.'s (2010) framework but was talked about by participants in this study.

Assumptions of the Study

The assumption is that all participants answered to the best of their ability. Anonymity and security of personal information was explained to all participants and their parents or guardians prior to the collection of qualitative data. All personally identifiable information was changed to protect the students, and before the data was shared with the school system or university. The semistructured interviews were conducted in a one-to-one setting, where the interviewee felt comfortable enough to respond freely and honestly. Participants of this study were not impacted in a negative or positive manner with regards to grade or monetary compensations. Furthermore, students were not penalized for lack of participation.

Because this study focused on a specific group of students (i.e., algebra 1 retesters in an AR course), one must be wary of generalizing the findings for all students in a secondary mathematics classroom. Other factors, such as language and internet availability at home and school, could impact students' experiences in a 1:1 CSCL environment. The findings of this study are not meant to suggest that a 1:1 learning environment leads to higher achievement scores. Instead, the study aimed to provide insight into a 1:1 CSCL's significance to the field of student learning and engagement in a secondary mathematics classroom.

Ethical Considerations

Potential ethical issues could arise since the primary researcher was also the lead teacher in the study. Students were given the opportunity to review the findings from the student interviews. This ensured that the researcher presented an accurate depiction of what the participants wanted to say. Before collecting data, obtaining administrative consent and ethics clearance was necessary. Students participating in the study (a) had access to their own Chromebook; (b) had access to a wireless network at home/school; and (c) used the laptops to complete academic tasks.

The leading researcher of the study served the role of classroom instructor and facilitator, and the research site was the leading researcher's classroom. Additionally, permissions were obtained from Boise State University, Richardson ISD, Berkner High School, student participants, and parental consent. Since participants were from the researcher's classroom, a fellow math teacher conducted the interviews. The researcher protected the anonymity of the participants by having the interviewer mask participants' names and assigning them pseudonyms (i.e., Alice, Beto, etc.). Since participants were students of the leading researcher, having another teacher conduct the interviews kept the participants anonymous and prevented coercion and biased responses. Participant interviews were audio-recorded, transcribed, and cleaned from any identifiable information by the secondary researcher prior to the lead researcher having access to the data. This was done to protect the students' anonymity and confidentiality of personal information.

Limitations and Delimitations

There are some limitations and delimitations to consider in this study. This section presents limitations related to the group, limitations related to the researcher, and delimitations in the use of a 1:1 CSCL environment in mathematics education.

Limitations. The purpose of this study was to understand students' experiences with 1:1 CSCL in an AR course. The main assumption is that all participants answered honestly and to the best of their ability. From these participants, only a general understanding can be made. The group was self-selected from my three sections of the AR course. The group was representative of over 100 students at the high school enrolled in AR for the 2020–2021 school year. Since the course was designed for students who failed the STAAR algebra 1 exam but passed the algebra 1 course, the students in the class represented the students achieving lower than average.

The second limitation of the research is that I served the dual role of teacher and researcher that created some concerns about validity and trustworthiness of the study. To avoid bias in participants' results, a fellow teacher conducted the interviews, recorded, transcribed, and removed identifiable data before I received a copy of these documents. Participants understanding what the questions were asking was certainly an issue in the interactions between the interviewer and some of the participants. Because I was not the one conducting the interviews, there were multiple times while analyzing participant responses that did not fully answer the question or lacked clarification. The interviewer did what I asked him to do—ask the scripted question and ask follow-up questions if necessary. However, the secondary researcher missed opportunities to ask clarifying questions or ask for details on students' responses. Additionally, because the audio recordings were deleted before I received the transcribed response, I was unable to review them for clarification. This would have been helpful, as I had an insight into students' thinking and whether their statements were answering the questions. Furthermore, as the teacher in the 1:1 CSCL environment, I have extensive background knowledge on the subject (i.e., algebra) and the medium (i.e., Desmos) used for instruction. The fellow teacher was also a mathematics teacher but teaching algebra 1 during that time. It is important to note that data was collected in the spring of 2021 and analyzed during fall 2021. I left the school district of study, changing roles from teacher to instructional coach in fall 2021. In March 2022 I was hired by Desmos as a curricular solutions specialist. Data analysis and findings were not impacted by these new roles as the data analysis was completed before the starting the new job.

One more limitation to note is how the COVID-19 pandemic impacted the research. School at the start of the 2020–2021 school year began fully virtual. At the time of data collection in the spring 2021 semester, classes were hybrid. This meant students and parents who were comfortable attending face-to-face could do so. Only a small portion of my students chose this option, which made L2L interactions much more difficult to manage. Most participants in the study were from my face-to-face students. It would be interesting to consider what the results of the study would have been had all my students been face-to-face. Furthermore, the findings of this study focused on students' experiences in the classroom and are not meant to suggest any relationship between a 1:1 learning environment and achievement scores. Instead, the study aims to provide insight into a 1:1 CSCL's significance to the field of student learning in a secondary mathematics classroom.

Delimitations. The study was completed in a secondary school in Texas, and its findings are not intended to be generalized. This study focused on a specific group of students (i.e., algebra 1 retesters in an algebraic reasoning course using Desmos) in one classroom and during the 2020–2021 school year. Findings are only connected to their experiences, and not to experiences of all students in a secondary mathematics classroom.

Another delimitation concerns the CSCL environment. The software used in this study was Desmos. Students' responses and experiences described were about this platform. The CSCL environment was heavily student-centered. How a teacher uses Desmos, or any other math software, might change students' experiences. Most students talked about Desmos being "helpful" to their understanding in many ways. This may not necessarily be a standard feature of CSCL environments but instead a practice that is representative of the AR classes. The CSCL environment captured in this study was specifically for secondary students and their experiences are insufficient to generalize to the elementary level.

Recommendations for Future Research

A CSCL environment could foster group learning and collaboration (Abdu et al., 2015; Danielson & Meyer, 2016; Silverman, 1995) by facilitating cohesion and shared responsibility among learners (Oikarinen et al., 2014). This form of collaborative knowledge construction (Jonassen, 1995) is enabled by learning environments that foster reflective practice through social interactions (Jonassen, 1994).

A CSCL classroom environment has the potential to be a constructivist environment that provides students with multiple means of collaborative interactions via technology (Abdu et al., 2015; Silverman, 1995). It could foster group learning (Abdu et al. 2015, Danielson & Meyer, 2016) through L2L and L2S interactions (Kumar et al., 2010) that are facilitated through L2T interactions. Environments using CSCL have the capability to facilitate cohesion and responsibility, while also reducing students' detachment from classroom discourse (Oikarinen et al., 2014). The ability to participate in an interactive environment where collaboration is encouraged seems to foster and facilitate the mathematical learning processes (Danielson & Meyer, 2016; Jonassen, 1994; Oikarinen et al., 2014). Understanding students' experiences in a CSCL environment could provide information about their learning processes.

High school students in the United States need to improve their scores, as their achievement is well below other developed countries (DOE, 2010) in mathematics. The integration of technology in classrooms, especially during the pandemic, is a focal point for many districts. With state testing shifting toward being fully online, a need also exists in providing students with a technology-enhanced learning environment to practice and hone their algebraic skills. Thus, a CSCL environment in a mathematics classroom has the potential to provide students with collaborative virtual explorations, real-world applications, and real-time feedback through the medium (Danielson & Meyer, 2016; Kumar et al., 2010). This study was designed to understand students' experiences with

1:1 CSCL in an AR course. Kumar et al.'s (2010) CSCL framework was the lens used to understand their experiences.

A CSCL environment like Desmos may be a strategy that helps address the issues listed above. Future research could investigate how students talked about their Desmos experiences, and how those experiences were related to their achievement on the state algebra I exam. This would explore whether students using a CSCL environment that is guided by Kumar et al.'s (2010) framework criteria have any perceived impact on their mathematical achievement.

Since a limitation to this study was the dual role of teacher and researcher, future studies could investigate teachers' experiences with facilitating a 1:1 CSCL environment in mathematics. This study could be expanded within K-12 mathematics. Additional research could investigate other mathematics courses (e.g., geometry, calculus) and other grade levels (e.g., elementary, middle school) in capturing students' experiences with 1:1 CSCL. Furthermore, a similar study could be conducted but focused on teacher's experiences. It could consider how mathematics teachers perceive the experience of using Desmos to support the teaching and learning process in their classrooms.

Conclusion

The purpose of this study was to understand students' experiences with 1:1 CSCL in an algebraic reasoning classroom. The foundation for understanding these experiences was through Kumar et al.'s (2010) CSCL framework for effective systems. Of the five criterions proposed by the authors, the findings show that students used four of them to describe their experiences. When working with the Desmos CSCL platform in their AR class, participants described positive experiences with predefined collaborative strategies, which featured open-ended and guided interactions that could be easily observed and accessed by students and teachers. Participants also described the framework element of providing them with active and passive feedback that was timely, interpretative, and intentional.

The fourth criterion of the CSCL framework focused on underlying theories of collaboration represented in the software system. Although Desmos featured activities that were self-regulated, coregulated, and shared-regulated learning experiences, these were a reflection on the design of the software and not clearly identified as perceived by students during the data analysis process.

As a group, students discussed using Desmos in a 1:1 CSCL environment in positive terms. The main points students discussed in their experience reflected the themes of simplicity, engagement, helpfulness, multiple representations, and interpretive feedback. Participants also discussed different collaborative strategies used within the Desmos CSCL environment. These included the ones identified in Kumar et al.'s (2010) study, which were L2S and L2L interactions. However, the student data also revealed an emergent theme—L2T interactions as being critical in their positive experiences with 1:1 CSCL in algebra. Thus, ensuring that students have a pleasant CSCL experience while studying mathematics is a function of the collaborative interactions facilitated by the teacher, not the 1:1 technology environment itself.

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APPENDIX A: INTERVIEW QUESTION DOCUMENT

Project: Understanding students' experiences with 1:1 computer-supported collaborative learning in a mathematics classroom

Time of Interview:

Date:

Place:

Interviewer:

Interviewee:

Position of Interviewee:

Knowing that student availability may be a factor, the interview questions will be short, open-ended, and focused on obtaining students' reflections on their experience with 1:1 in a mathematics classroom. Follow up questions based on students' responses may also be recorded. This interview data will help in answering the study's central question (CQ): How do participants describe their learning experiences with 1:1 CSCL in an Algebraic Reasoning course? The sub-questions will help explain the CQ further include: (SQ1) What aspects of CSCL interactions do students talk about when relaying their experiences with 1:1 CSCL in Algebraic Reasoning course? (SQ2) What are students' perceptions of collaborative strategies embedded in a 1:1 CSCL environment in an algebraic reasoning course?

Interview Questions:

1. What approaches or tools used by your teacher (i.e., CSCL interactions) in the 1:1 environment helped in your learning of algebra (SQ1)?
2. How would you describe your experiences with Desmos while learning algebra (SQ1)?

3. How did Desmos help your understanding of algebra (SQ1)?
4. If so, when did you prefer to use Desmos to learn algebra (SQ1)?
5. What particular activities or tools used by your teacher using Desmos helped you in your learning of algebra (SQ1)?
6. How would you describe your experiences with Desmos activities such as polygraph, marbleslides, or 2 truths & a lie while learning algebra? (SQ2)?
7. How did these collaborative strategies help in your learning of algebra (SQ2)?
8. If so, when did you prefer to collaborate when learning algebra (SQ2)?

APPENDIX B: CSCL FRAMEWORK

Kumar et al.'s (2010) five design criteria for a CSCL framework:

1. CSCL interactions can be both open-ended (e.g., students explaining their thinking) and guided (e.g., sentence prompts), as they are both shared to everyone in the classroom.
2. The ability to observe these CSCL interactions by both the students and teacher in real time interaction, as well as the ability to store them centrally in order to interpret.
3. Predefined collaboration strategies and tactics can be represented within the instructional design.
4. Underlying theories of collaboration can be represented in the software system and CSCL interactions can be meaningfully interpreted as belonging to specific parts of the theory.
5. CSCL environment needs to be able to provide both active and passive feedback.

APPENDIX C: LINEAR FUNCTION DESMOS ACTIVITIES

Desmos Activity	Students will be able to...	Description	Relation to CSCL Framework
Polygraph: Lines	● Identify key features of lines. ● Use informal/formal language to describe linear features to peers. ● Increase vocabulary relevant to lines.	Students are paired with a classmate to play polygraph activity. One student chooses a line; the partner asks yes/no questions in order to narrow a field of suspects down to one. In between rounds, students answer questions focused on vocabulary and strategy.	(A) CSCL interactions are both open-ended and guided. (B) All polygraph interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the polygraph game between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. L2S interactions an example of self-regulated learning. Sharing these interactions are an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.
Marbleslides: Lines	● Explore properties of linear function. ● Explore the effects of changing slope on the graph. ● Explore the effects of changing the y-intercept on the graph. ● Explore the effects of domain and	Students transform lines by manipulating the linear equations so that the marbles traveling along them go through the stars. Students evaluate their ideas by launching the marbles, while given the opportunity to revise before attempting the next challenge.	(A) CSCL interactions are open-ended as students manipulate the equations freely to complete the challenge of collecting all stars with sliding marbles. (B) All marbleslides interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the marbleslides activity is the L2S interactions as student input their equations and view how it impacts their graphs

	range restriction on the graph.		instantaneously. (D) L2S interactions an example of self-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides passive (L2S) feedback.
Card Sort: Linear Functions	• Identify the equations and their correspondi ng graph and table.	Students notice and use properties of linear functions to make groups of three (e.g., equation, graph, table). Students are later asked to make conjectures about their peers' different groupings and ask corresponding questions.	(A) CSCL interactions are both open-ended and guided. (B) All card sort interactions are stored and accessed through the Desmos teacher dashboard. (D) L2L interactions an example of co-regulated learning. L2S interactions an example of self-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.

Two Truths and a Lie: Lines	• Identify key features of lines. • Use informal/formal language to describe linear features to peers. • Increase vocabulary relevant to lines.	Students practice their understanding of features and vocabulary of linear equations by creating a line, writing 2 true and 1 false statement about it, and having a peer separate fact from fiction.	(A) CSCL interactions are both open-ended and guided. (B) All interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the activity between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides active (L2L) feedback.

APPENDIX D: QUADRATIC FUNCTION DESMOS ACTIVITIES

Desmos Activity	Students will be able to...	Description	Relation to CSCL Framework
Polygraph: Parabolas	• Identify key features of parabolas. • Use informal/formal language to describe parabolic features to peers. • Increase vocabulary relevant to parabolas.	Students are paired with a classmate to play polygraph activity. One student chooses a parabola; the partner asks yes/no questions to narrow a field of suspects down to one. In between rounds, students answer questions focused on vocabulary and strategy.	(A) CSCL interactions are both open-ended and guided. (B) All polygraph interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the polygraph game between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. L2S interactions an example of self-regulated learning. Sharing these interactions are an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.
Polygraph: Parabolas, Part 2	• Identify key features of parabolas. • Use informal/formal language to describe parabolic features to peers. • Increase vocabulary relevant to parabolas.	This activity follows up on Polygraph: Parabolas, using the discussions (and students' informal language) in that activity to develop academic vocabulary related to the graphs of quadratic functions.	(A) CSCL interactions are both open-ended and guided. (B) All polygraph interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the polygraph game between L2S is an example of a predefined collaboration strategy. (D) L2S interactions an

			example of self-regulated learning. Sharing these interactions are an example of shared-regulated learning. (E) The activity provides both (L2L) and (L2S) active feedback.
Match My Parabola	• Identify key features of parabolas. • Explore and apply properties of quadratic equations • Increase vocabulary relevant to parabolas.	In this activity, students work through a series of scaffolded quadratic graphing challenges to develop their proficiency with standard, vertex, factored, and other quadratic function forms.	(A) CSCL interactions are both open-ended and guided. (B) All interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the activity between L2S is an example of a predefined collaboration strategy. (D) L2S interactions an example of self-regulated learning. Sharing these interactions are an example of shared-regulated learning. (E) The activity provides both (L2L) and (L2S) active feedback.
Card Sort: Parabolas	• Identify the quadratic equations and match the cards based on their characteristics.	There are many strategies for determining the shape of a graph given its equation. In this activity, students will find the shape of a parabola by using its form to reveal its characteristics. The	(A) CSCL interactions are both open-ended and guided. (B) All card sort interactions are stored and accessed through the Desmos teacher dashboard. (D) L2L interactions an example of co-regulated learning. L2S

		activity begins with a review of both the characteristics and forms of a parabola. Later, students will determine characteristics of the graph of a parabola given either in standard form, vertex form, or intercept form.	interactions an example of self-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.
Marbleslides: Parabolas	● Explore properties of quadratic functions. ● Explore the effects of changing the coefficients on the graph. ● Explore the effects of domain and range restriction on the graph.	Students transform lines by manipulating the quadratic equations so that the marbles traveling along them go through the stars. Students evaluate their ideas by launching the marbles, while given the opportunity to revise before attempting the next challenge.	(A) CSCL interactions are open-ended as students manipulate the equations freely to complete the challenge of collecting all stars with sliding marbles. (B) All marbleslides interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the marbleslides activity is the L2S interactions as student input their equations and view how it impacts their graphs instantaneously. (D) L2S interactions an example of self-regulated learning. Sharing these interactions an example of shared-regulated learning. (E) The activity provides passive (L2S) feedback.
Two Truths and a Lie: Parabolas	● Identify key features of parabolas.	Students practice their understanding of features and	(A) CSCL interactions are both open-ended and guided.

	• Use informal/formal language to describe linear features to peers. • Increase vocabulary relevant to lines.	vocabulary of a parabola by creating a parabola, writing 2 true and 1 false statement about it, and having a peer separate fact from fiction.	(B) All interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the activity between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides active (L2L) feedback.

APPENDIX E: EXPONENTIAL FUNCTION DESMOS ACTIVITIES

Polygraph: Exponentials	• Identify key features of exponential graphs. • Use informal/formal language to describe parabolic features to peers. • Increase vocabulary relevant to parabolas.	Students are paired with a classmate to play polygraph activity. One student chooses an exponential graph; the partner asks yes/no questions to narrow a field of suspects down to one. In between rounds, students answer questions focused on vocabulary and strategy.	(A) CSCL interactions are both open-ended and guided. (B) All polygraph interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the polygraph game between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. L2S interactions an example of self-regulated learning. Sharing these interactions are an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.
Marbleslides: Exponentials	• Explore properties of exponential functions. • Explore the effects of changing the coefficients on the graph. • Explore the effects of domain and range restriction on the graph.	Students transform lines by manipulating the exponential equations so that the marbles traveling along them go through the stars. Students evaluate their ideas by launching the marbles, while given the opportunity to revise before attempting the next	(A) CSCL interactions are open-ended as students manipulate the equations freely to complete the challenge of collecting all stars with sliding marbles. (B) All marbleslides interactions are stored and accessed through the Desmos teacher dashboard.

		challenge.	(C) The nature of the marbleslides activity is the L2S interactions as students input their equations and view how it impacts their graphs instantaneously. (D) L2S interactions an example of self-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides passive (L2S) feedback.
Card Sort: Exponentials	• Identify the exponential equations and match the cards based on their characteristics.	There are many strategies for determining the shape of a graph given its equation. In this activity, students will find the shape of an exponential graph by using its form to reveal its characteristics. The activity begins with a review of both the characteristics and forms of an exponential graph. Later, students will determine characteristics of the graph of an exponential.	(A) CSCL interactions are both open-ended and guided. (B) All card sort interactions are stored and accessed through the Desmos teacher dashboard. (D) L2L interactions an example of co-regulated learning. L2S interactions an example of self-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides both active (L2L) and passive (L2S) feedback.

Two Truths and a Lie: Exponentials	• Identify key features of an exponential graph. • Use informal/formal language to describe exponential features to peers. • Increase vocabulary relevant to exponential graphs	Students practice their understanding of features and vocabulary of a parabola by creating an exponential graph, writing 2 true and 1 false statement about it, and having a peer separate fact from fiction.	(A) CSCL interactions are both open-ended and guided. (B) All interactions are stored and accessed through the Desmos teacher dashboard. (C) The nature of the activity between the two students is an example of a predefined collaboration strategy. (D) L2L interactions an example of co-regulated learning. Sharing these interactions is an example of shared-regulated learning. (E) The activity provides active (L2L) feedback.

APPENDIX F: SCREENSHOTS OF DESMOS ACTIVITIES

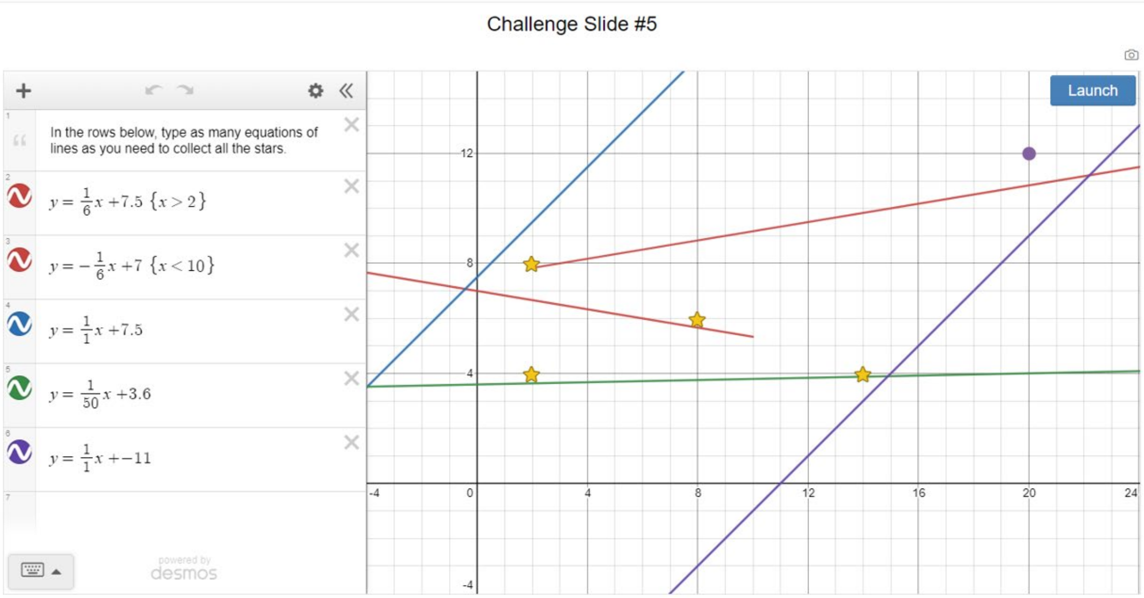

Figure F1 Marbleslides

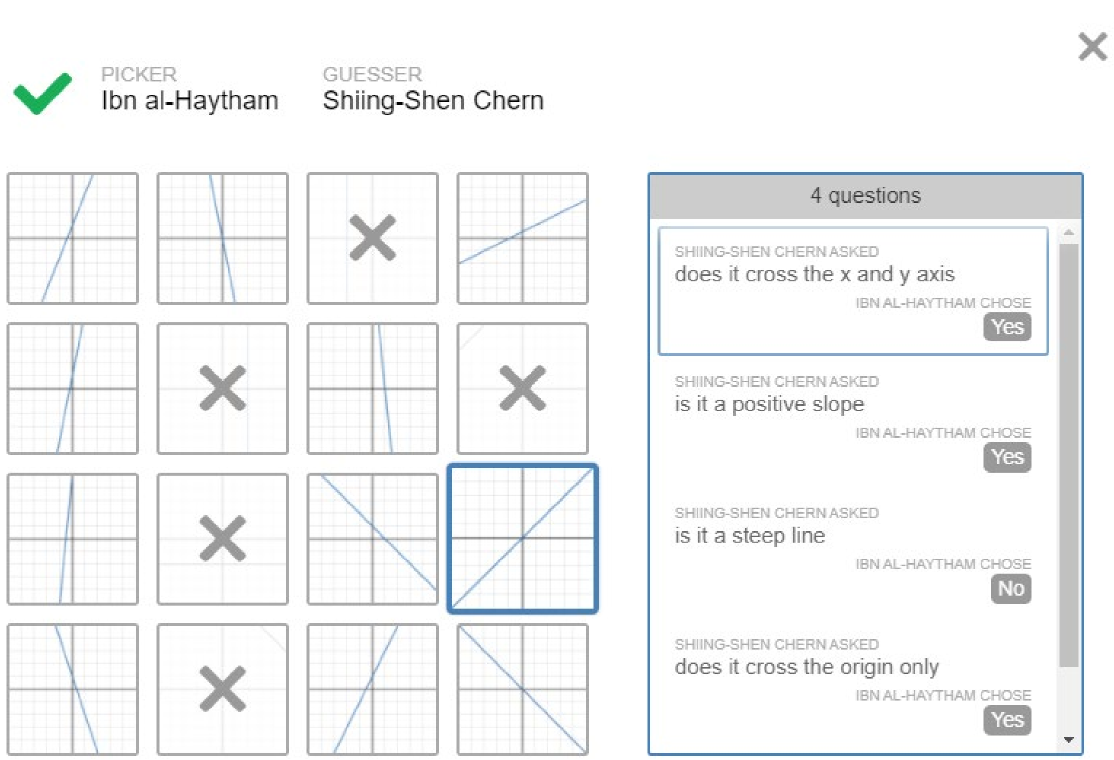

Figure F2 Polygraph

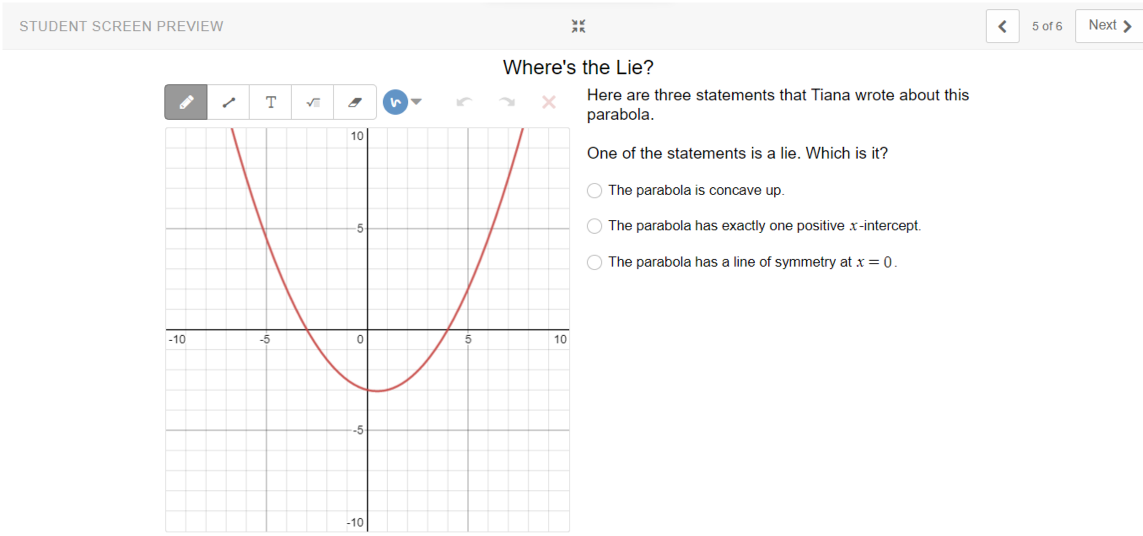

Figure F3 2 Truths & 1 Lie student screen

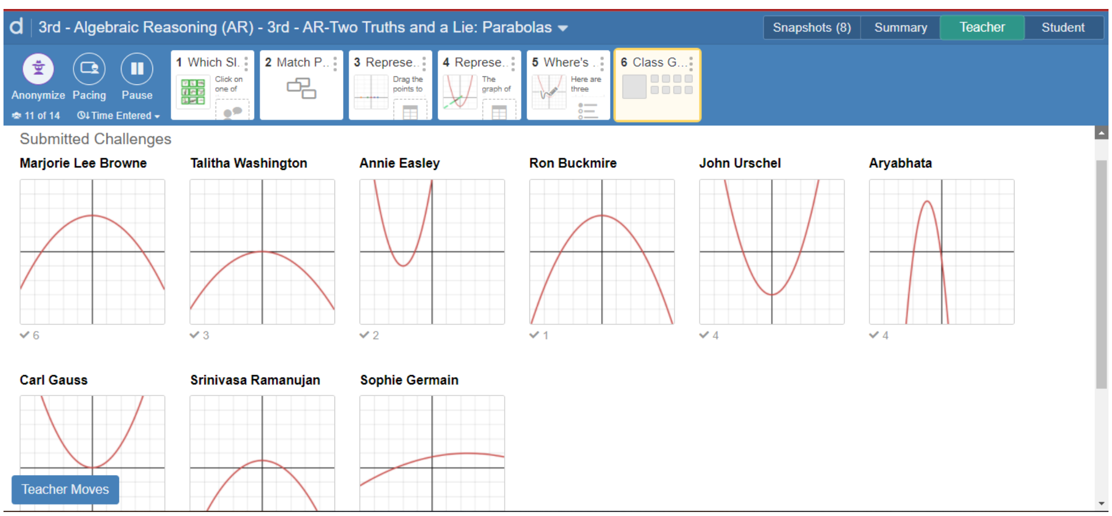

Figure F4 2 Truths & 1 Lie teacher screen

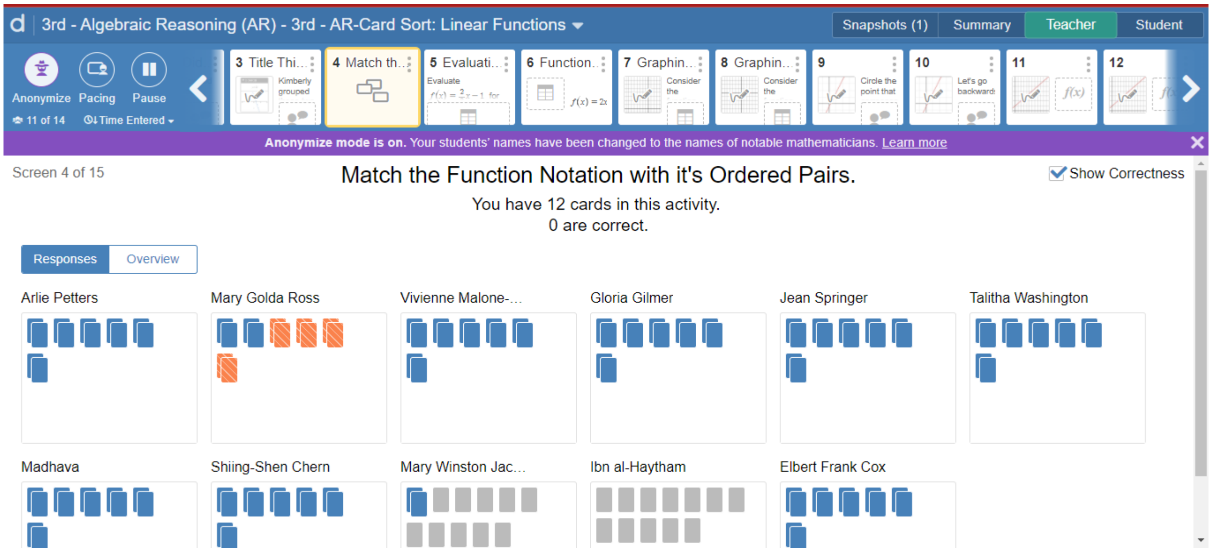

Figure F5 Card Sort