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"Sometimes It's Just Too Much Screen Time": The Case of Sarah

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ABSTRACT
Use of math apps in elementary schools is increasing, with most research focusing on achievement-related outcomes. Given that motivation is an essential mediator of student success, research on the relationship between the use of elementary math apps and motivation is needed. This paper focuses on the case of Sarah, drawn from a 5-month-long, exploratory multiple-case study of a technology-rich third-grade math classroom that routinely used math apps during instruction. Using self-determination theory and expectancy-value theory to guide the operationalization of motivation, the findings suggest that math apps are strongly associated with students' enjoyment of math and their sense of connection. In Sarah's case, math apps shifted from an enjoyable technology to one that left her stressed and frustrated. Additionally, findings illustrate that motivation related to math app use can change over a relatively short period of use. This study on math apps shows that implementing new technology in elementary classrooms often yields unintended consequences. This study contributes to understanding how educational technology can both support and undermine elementary students' motivation, underscoring the importance of examining its full range of impacts.
KEYWORDS: Elementary Education, Mathematics, Motivation, Technology

Sarah, with long hair that hung past her shoulders, wore a tortoise-colored headband that complemented her long, golden-brown hair. Often wearing a lavender shirt that matched the color of her new braces, Sarah was an introverted third grader who preferred quietly reading a book in the corner to group work, that is, unless she was paired with Madison or Chloe, her two best friends. Sarah could be withdrawn and inward-focused compared to her peers, who were often boisterous and spirited, especially during free time and group work. While Sarah was quick to retreat to a reserved, independent activity, she was also not afraid to voice her opinion when she felt confident.

Sarah's classroom, like many across the nation, has turned to mathematics applications in recent years. Many districts, schools, and classrooms turned to math apps like these as a cost-effective solution during the pandemic. However, with growing class sizes, a shortage of teachers, limited funding, and a continued need to make-up COVID learning losses (Darling-Hammond et al., 2023; Nguyen et al., 2024), the use of math apps has continued to proliferate in K-12 schools because of their potential to personalize learning and offer teachers the ability to work with small

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groups or individual students (Outhwaite et al., 2023). In fact, Swartz (2026) provides an upper-bound estimate of 1.31 billion users worldwide who use K-12 math apps. What is relatively unknown is the full impact of math apps beyond achievement (e.g., motivation, math identity, etc.). With recent research showing that standardized test scores fall with increased screentime (Horvath, 2025), this study adds to an emerging body of literature that cautions the use of educational technology.

The case of Sarah comes from a 5-month exploratory multiple-case study of a technology-rich third-grade math classroom that routinely used math apps during instruction. As Sarah alluded to in her quote, there may be drawbacks to using math apps. In this article, I examine the relationship between math app use and motivation by looking at math app use through Sarah's eyes and answering the following questions:

(1) What is the relationship between math apps and Sarah's motivation in mathematics?

(2) What shifts, if any, did Sarah's motivation experience over the course of a semester of math app use?

Literature Review

Math Apps

In the last decade, math apps have gained significant traction worldwide, with math apps such as DreamBox, Zearn, and IXL becoming widely utilized. In a recent study, Swartz (2026) estimated that there are 608 million users of math apps devoted entirely to math and 683 million users of learning apps with math and additional content. Research on math apps can be divided into several broad categories: research on achievement and learning (Griffith et al., 2020; Outhwaite et al., 2019), research on affect-related factors (e.g., math identity, motivation, anxiety) (Fadda et al., 2022; Swartz, 2024a; Swartz, 2025), research on the design and features of math apps (Alam & Dubé, 2022), and research related to the context and implementation of math apps by teachers (Montazami et al., 2022; Swartz, 2024b).

Most research on math apps has focused on learning outcomes and achievement (Griffith et al., 2020; Kim et al., 2021). A 2020 meta-analysis of 35 studies on learning apps found evidence that math apps benefit students' math learning (Griffith et al., 2020). Most notably, Griffith et al. (2020) found that children benefited the most from apps on interactive touchscreen devices that supported "active, repeated, and varied practice of [math] skills" (p. 10). Another meta-analysis by Kim et al. (2021) found a positive, relatively large effect size for students using apps compared with those who did not. However, Kim et al. also found a moderating variable: whether the study used a researcher-designed or standardized outcome to measure math learning gains. In other words, when achievement was measured with a standardized outcome measure, such as a state math exam, they found math learning gains were moderate; however, when achievement was measured with a researcher-designed assessment, they found math learning gains from math apps to be significantly higher. While research on math apps and learning has demonstrated that they enhance students' learning gains, there is inconsistency in how researchers operationalize learning. This inconsistent and often narrow view of mathematical achievement makes the overall finding that math apps help increase learning less valuable and less significant. I will now examine research on the mathematical app related to the construct on which this article focuses.

Math Apps and Motivation

Research on K-12 math apps and motivation has consistently found that apps generally increase students' motivation in mathematics (Fadda et al., 2022; Kay & Lauricella, 2018). While most research indicates that math app use increases students' motivation, some studies have also shown that students are equally motivated to engage in non-app math (Swartz, 2025). Research on motivation in mathematics has varied in the instruments and theories used to measure motivation, the mathematics content/grade level, and the mathematics application used. Several studies used attention, relevance, confidence, and satisfaction to examine motivation (Bai et al., 2012; Kim et al., 2017), while other research has utilized value and enjoyment as factors to explain motivation (Mavridis et al., 2017; Sun-Lin & Chiou, 2019).

Specific to this study, which utilizes self-determination theory's (SDT's) basic psychological needs (autonomy, competence, relatedness) to guide the operationalization of motivation, research utilizing SDT and math apps can be separated into two categories: research utilizing SDT's basic psychological needs (i.e., which basic needs are met through math app use?) and research utilizing SDT's taxonomy of motivation as intrinsic, extrinsic, and amotivation (absence of self-determined motivation). Examining research math apps and the basic needs, a Chilean study of third and fourth graders using an online math platform, MatematicaST, found that multiple-try feedback (allowing students multiple attempts and providing hints after each attempt) was shown to more positively support male students' autonomy, while both genders had similar levels of competence as a result of the feedback (Cubillos et al., 2024). Another study found that the math app Decimal Point, which focused on decimal operations, promoted both autonomy and perceived competence among fifth- and sixth-grade students (Hou et al., 2022). Students' autonomy was supported through the choice of which game to play and when to stop playing a game, while their competence was supported through the game display of the user's skill mastery. Researchers examining the online math platform, First In Math, which focuses on a range of K–8 math content, found the app supported autonomy through choice among different types of games (skill-based challenges, adaptive difficulty levels, etc.) as well as competence through goal setting and skill progression features of the app (Pan et al., 2026). Examining the dearth of research on math apps and SDT's basic needs, a commonality emerges: apps have been primarily shown to support autonomy (through game choice) and competence (through displays of mastery).

Research utilizing SDT's taxonomy of motivation as intrinsic, extrinsic, and amotivation has found that math apps increase students' intrinsic and extrinsic motivation (Kassa et al., 2025; van Roy et al., 2019). In a study using quantitative measures of intrinsic and extrinsic motivation, researchers found that students who used GeoGebra exhibited higher intrinsic and extrinsic motivation to learn geometry than those who did not use the app (Kassa et al., 2025). Moreover, students who used GeoGebra also demonstrated greater enjoyment of learning mathematics. Two studies also found that gamification elements, such as rewards and immersive storylines, could serve as extrinsic motivators, whereas earning badges through mastery could be intrinsically motivating (van Roy et al., 2019). Across studies examining math apps through the lens of extrinsic and intrinsic motivation, math apps were most often associated with extrinsic motivation.

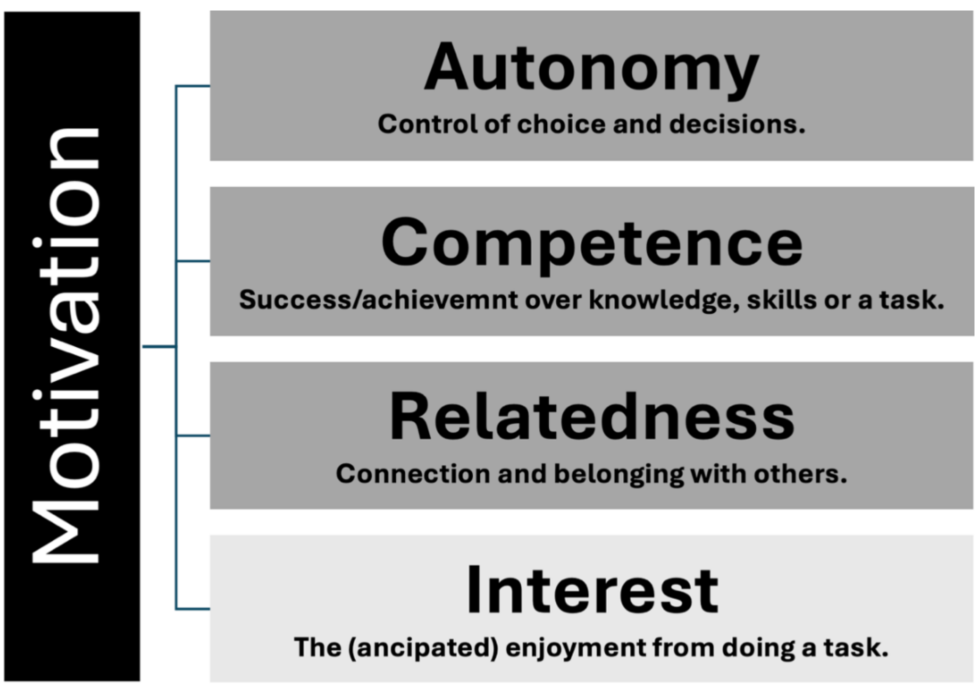
Given the lack of qualitative research on math apps and elementary students' motivation, there is a need to examine these phenomena qualitatively to better elucidate the nuanced relationship among math apps, their features, and students' motivation. Moreover, the limited qualitative research on math apps and motivation has focused on niche apps not used on a global scale. Not only does this study utilize qualitative methods, but the math apps used in this study, Reflex, Frax, Prodigy, and Boddle, account for an estimated 70 million users worldwide (Swartz, 2026).

Theoretical Frameworks

Motivation is a robust construct that has a long and rich history of theory and practice. My working hypothesis is that math apps, a key part of many students' learning environment, impact how students relate to mathematics and to their classmates. As such, I hold the view that motivation is situated—that is, motivation is a product of being, learning, and interacting within one's environment. This view of motivation is consistent with self-determination theory (SDT), which I use to guide my operationalization of motivation. SDT rests on the understanding that all human beings share three basic psychological needs: competence, social relatedness, and autonomy (Deci & Ryan, 2000). Autonomy refers to control over one's choices and decisions, competence refers to demonstrated success in knowledge, skills, or tasks, and relatedness refers to the feeling of connection and belonging with others.

Additionally, I include the interest task value from expectancy-value theory (Eccles et al., 1983), as results from my pilot study indicated that this essential component of students' motivation was missing from my initial operationalization of SDT. Eccles (2005) defines interest as "the enjoyment one gains from the task or the anticipated enjoyment one expects to experience while doing the task" (p. 111). Figure 1 shows the four components I use to guide my operationalization of motivation: autonomy, competence, and relatedness from SDT (darker shading) and interest from EVT (lighter shading).

Figure 1
Theoretical Framework Components of Motivation



Methods

Research Design

This study employed an exploratory case study design. Creswell (1998) notes several key components of a case study, including the identification, boundedness, and utilization of extensive and multiple sources of data, which require many hours in the setting of the case. Each case was an individual student who engaged with math apps as part of their mathematics learning and instruction time. Specifically, I wanted to learn how their motivation was related to the math apps they used. The cases were bounded as I studied students from one school (and one classroom) and focused on their interactions with technology during math instruction over the span of one semester. I used extensive, multiple sources of information in data collection to provide a detailed, in-depth picture of each student or case. In all, I spent over 75 hours observing the classroom and describing the environment over the span of data collection. In understanding the relationship between math app use and motivation, the boundaries between phenomenon (motivation) and context (use of math apps) were not clearly evident, which Yin (2009) cites as a defining component of a case study.

Context & Participants

This paper is part of a larger, multiple-case study design, designed to identify and explore the relationship between math apps and students' mathematics identities and motivation in mathematics. While the larger project consisted of five cases, or five third-grade students, who engaged with math apps as part of their mathematics learning and instruction time, in this paper, the analyses are from a series of interviews, surveys, and observation notes with one third-grade student, Sarah.

I have chosen to focus on Sarah as a revealing case (Yin, 2009) because Sarah makes the boundary between the phenomenon (motivation) and context (use of math apps) unusually clear, and her use of math apps relates to the entire phenomenon (all the theoretical components of motivation; see Figure 1). Additionally, Stake (1995) describes an instrumental case as one that enhances understanding of a phenomenon. With an instrumental case, the focus is on the phenomenon and context, not the case itself. However, Stake notes that "some cases would do a better job than others" (p. 4). In this report, Sarah was chosen not as a representation that generalizes all students' motivation with math apps, but rather, her case provides a clear view of how a student's motivation can interact with their use of math apps. Exploring how an elementary student's motivation interacts with their math app use is both innovative and still needs further explanation.

Sarah described herself as female and Caucasian, and institutionally, her school labeled her as being gifted and talented. At the time of data collection, Hope Elementary School, located in the Southern United States, had a minority student enrollment of 41%, and over 70% of the school's students scored at or above the proficient level on the state math test.

Data Collection & Analysis

Data collection incorporated surveys, interviews, observations, and analytic memoing to address the research questions. A repeated survey measuring changes from a semester of math app use was administered at the beginning and end of the semester, utilizing items from van der Kaap-Deeder et al.'s (2015) Basic Psychological Need Satisfaction and Frustration Scale, which were adapted as necessary to align with the context of elementary mathematics, and open-ended questions. Weekly open-ended surveys were given after "regular math time" (math instruction without technology) and "math app math time" to capture the nuances and distinctions in students' motivation related to the two types of math time. In addition to observational field notes and surveys, each case study student participated in two semi-structured, individual interviews (Rubin & Rubin, 2011).

The surveys were analyzed by utilizing a meta-matrix (Miles & Huberman, 1994) for each case, which organized their responses to each question to examine changes in responses. The interviews were analyzed using thematic analysis (Braun & Clarke, 2012) as well as using a priori codes (Miles et al., 2014). Figure 2 shows the analytic steps taken to code the interviews.

Drawing on the three basic needs outlined by self-determination theory (Deci & Ryan, 2000) and the interest task value from expectancy-value theory (Eccles et al., 1983), I used autonomy (A), competence (C), relatedness (R), and interest (I) to create eight a priori codes: A, C, R, I, A_T, C_T, R_T, and I_T where T stands for technology. The unit of analysis for all of the codes listed above was a turn of talk or an utterance (Johnstone & Andrus, 2024). After applying the a priori motivation codes, I analyzed all instances of each a priori code and utilized thematic analysis to create subcodes that described interest (e.g., "Math is exciting/fun" and "Math is not exciting/fun"), competence related to math apps (e.g., "Good at math" and "Math app math is helpful for learning math"), and each of the a priori codes for motivation.

After creating a codebook with definitions and examples of each a priori code (i.e., each component of motivation), I coded each interview using these codes. Then, I reviewed the coded interviews and modified the codebook as needed. After training a motivation subject matter expert to serve as a secondary coder, the secondary and primary coders independently coded a randomly selected representative 15% section of each interview, discussed discrepancies, and updated the codebook as needed. Then, an additional randomly selected 15% section of each interview was independently coded, and from this, interrater reliability was calculated. Interrater reliability was calculated with Cohen's Kappa. Using Landis and Koch's (1977) interpretation of Cohen's Kappa, the motivation coding reflected substantial agreement ($\kappa = 0.66$).

Figure 2

Overview of Interview Coding Procedure

Step in coding procedure	What was done
Step 1	Coded all interviews with a priori codes (A, C, R, I, A_T, C_T, R_T, I_T)
Step 2	Developed subcodebook utilizing thematic analysis on a priori coded segment
Step 3	Used subcodebook to code all interview transcripts
Step 4	Analyzed coded interviews and made alterations to the subcodebook as needed
Step 5	Trained secondary coder (expert in motivation) on a random representative 15% of each interview and reconciled subcodebook as needed
Step 6	Independently coded 15% of each interview and calculated reliability coefficient

Each motivation component was described in terms of value and experience. For value, I considered responses to questions about autonomy, relatedness, and competence, recording whether students responded negatively, affirmatively, or mixed. Responses like “Yes” or “Mm-hmm” were coded as affirmative, while “No” or “I don’t think so” were negative. When responses were unclear, I used the actual response as the label. I did not ask questions about the value or importance of interest motivation, so that was always marked as N/A. The study was approved by Texas State University’s IRB (protocol #8854), and all participants provided assent and their legal guardians provided informed consent.

Results

To organize the results of Sarah’s motivation and experience with math apps over the course of a semester, I will begin by presenting her motivation at two time points.

Start of Semester (January)

Sarah was a mathematically gifted student, recognized as gifted both institutionally and by her teacher, Ms. Care. She was a student whose mathematical ability was intertwined with her enduring confidence that she was good at math. Often scoring the highest in her class, math was a subject Sarah excelled at, and this achievement fueled her love for the subject. Sarah preferred doing math with close friends or alone as opposed to being paired with “loud” and rowdy peers. While Sarah enjoyed the gamified nature of the math apps her class used, she felt learning math necessitated some feeling of work and that math should not be purely fun.

Autonomy. In January, at the start of the semester, Sarah indicated autonomy was somewhat important to her. She responded, “Not always,” to the question, “Is it important to have control and freedom over how you learn math?” Sarah placed some value on autonomy when learning regular math, saying, “I don’t mind if I have the choice or not. I like hard math problems.” In digging deeper to see why Sarah valued not having autonomy, that is, why Sarah placed importance on not having the perceived freedom to control her math learning, she described the importance of being challenged and the growth that comes from being assigned problems, as opposed to choosing problems for herself. Sarah felt that if given the choice of which math problems she wanted to do, she would likely choose the easier problems. She felt it was important to be given math problems outside of one’s comfort zone and shared, “If you only do the math facts you know that you would choose, you’re never going to learn anything, and a teacher will challenge you.” For Sarah, a more structured approach to learning promoted growth that might otherwise be limited if a student (i.e., herself) had both the freedom and inclination to select less challenging problems.

Sarah felt that regular math and math app math offered similar levels of autonomy and believed that math apps generally did not offer much autonomy because they “just give you a math fact, and you have to solve it whether you like it or not.” Since autonomy was not a motivating factor when Sarah engaged with math, she did not seem to perceive the features of math apps that allowed students to control aspects of their learning, such as the ability to control a game character’s path and the ability to choose which type of game to play, as of value to her experience of math.

Competence. Sarah valued feeling competent, and this was an important component of motivation for her. She responded, “Yes” to the question, “Is it important to know you’ll do good on a math activity before you start it?” Feeling confident in her ability was important to Sarah, but she also valued challenging questions “because if you only do the math facts you know that you would choose, you're never going to learn anything." Sarah felt that it was not always important to know she would do well on math problems prior to starting them because she might not completely know how to approach every new question her teacher gave her, or know if she would be successful.

Sarah experienced competence regularly and felt she was good at math. Much of the enjoyment Sarah experienced from doing math was tightly tied to her competence in math. This was true for both regular math and math app math: feeling competent, in general, about how she would do on a math activity was crucial for Sarah. Experiencing competence led to increased effort and, ultimately, success. Sarah described the cycle and relationship between competence, effort, and success in the interview excerpt below:

> Interviewer: Is it important to know that you'll do good on a math activity before you start something in math?
> Sarah: Sometimes yes, because you'll try harder and then you will get it right. It's like a chain reaction. But usually, even if you don't think you can do it, as long as you just try to do it.
> Interviewer: Okay. I like the word you said, chain reaction. And how does that chain reaction work? What's the first thing, and how does it work?
> Sarah: If you feel confident, then you're probably going to try harder. Then you'll get it right, and you'll feel, and you'll still be confident, and it goes in a circle.

For Sarah, her effort on math assignments and activities was often directly related to her sense of competence. Sarah's competence seemed to support her effort and, eventually, success in solving math problems. She felt that even if you think, "I'm not sure I can do this," if you are confident in yourself (i.e., see yourself as competent), you will at least "just try" or maybe "try harder" and then "you will get it right." Out of a positive sense of competence came effort, which led to success. This success was a part of the enjoyment Sarah experienced when doing math. The cycle Sarah describes in the interview excerpt above can be summed up by the following "chain reaction": competence → effort → success (success leads back to competence) → enjoyment.

Relatedness. Sarah placed little value on the relatedness component of motivation. When asked if it was important to feel close and connected with her friends and peers when doing math, Sarah responded, "Not really when you're doing math. Not in math. Not really."

While relatedness and feeling connected to classmates in math were not something Sarah experienced often or felt was important, she described math apps as offering a little bit more interaction with peers than regular math. Her reasoning was that students usually talked more with each other during math app time. It was not that the math apps themselves offered more opportunity for relatedness, but rather the environment in which math apps were usually utilized offered more time to talk and connect with classmates. Overall, Sarah placed little value on relatedness and described minimal experiences of relatedness with both regular math and math app math.

Interest. Sarah responded with a 5 (Completely true) to the statement "I enjoy learning math" on the survey she completed at the beginning of the semester, supporting the notion that she experienced a high amount of joy when learning math. She gave several reasons why math was fun, noting the joy she experienced when solving problems as well as the enjoyment tied to the success she experienced. In several instances of the interview, when asked to describe how she felt about math, Sarah would say, "I like math. It's fun!" or "It's just fun!" In these moments, when probed about her enjoyment, Sarah had trouble articulating exactly why math was fun, but she felt and knew from an instinctual place that math brought her joy. In other instances, Sarah explained that she experienced enjoyment "partially because I'm good at it." Part of Sarah's enjoyment of math was tied to her success and sense of competence.

Sarah also firmly felt that math app math was extremely fun. However, Sarah acknowledged that while the enjoyment she experienced with math apps was greater than that of regular math, this enjoyment was problematic. She stated, “Math apps just kind of make it [math] too fun when math is supposed to [be] work. I kind of like, I like work.” For Sarah, many things about math apps were enjoyable: the ability to customize characters’ outfits, the ability to buy items for the virtual room in which her game character resided, and the animations and sounds the game made as she solved problems. At one point during the first interview, she pulled off her headphones while playing Reflex and said, “This sounds really funny.” The sounds and ways that the game characters from Reflex were interacting with her were too fun not to show me.

There appeared to be a limit on “fun” when it came to math. Perhaps it was harder for Sarah to differentiate doing math from playing a game, and that distinction was much clearer when doing regular math. Or perhaps hard work was ingrained in Sarah’s conception of learning math, and work was a little less fun or enjoyable when compared to her experience of math on apps. Either way, there was an apparent conflict with the amount of fun Sarah experienced on math apps and her perception of doing or learning math. In one instance of describing the overwhelming fun of playing on math apps, Sarah said, “It’s [math apps] really fun, but sometimes it’s just too much screen time.” Sarah felt conflicted with the amount of fun she experienced on math apps.

End of Semester (May)

At the end of the semester, Sarah had been mathematically changed. While she was still a confident third grader whose love and enjoyment of math bubbled out of her, she experienced subtle shifts in her motivation. Perhaps there had been no better way to illustrate who Sarah had been mathematically in May of 2024 or what had changed in who Sarah had been mathematically over the four months from January to May than to examine her feelings toward the same timing feature in Reflex. Sarah had gone from viewing Reflex’s timing feature as making her “more motivated because I know I have to answer this question right now” to feeling “stressed and frustrated” by the timer.

Autonomy. In May, Sarah placed some value on the motivational component of autonomy (she answered, “It depends” to the question “Is it important to have autonomy over how you learn math?”). Sarah valued being able to draw and work out problems on paper compared to clicking or typing in answers to problems on math apps. In other words, Sarah valued solving problems on paper because it provided more autonomy through choosing what she could write on the paper in her own words. Sarah also felt that having the freedom to choose how she learned math was nice, “because then it’s easier. I don’t have to like do all the hard stuff that’s really tricky.” Sarah also valued autonomy because it allowed her to skip the harder math she might not want to do.

Sarah indicated that regular math offered greater autonomy than math app math. She appreciated the individualized support of her teacher with paper and pencil activities, support that Sarah felt she did not experience on math apps. She described the difference in autonomy and said, “I think like math on paper, you can, like, you can draw out problems, and you can ask for help. With the computer, it’s just programmed to do a certain thing. It won’t really let you change the problem or do anything.” Sarah felt there was a lack of flexibility and freedom experienced when doing math app math, something she did not experience when doing regular math. In addition, Sarah responded with a 4 to the statement “I feel free to choose which math activities I do” on the survey at the end of the semester, supporting the notion that not only did Sarah place a moderate value on autonomy, but she also experienced a moderate amount of autonomy in her math learning, though less autonomy on the apps compared to regular classroom activities.

Competence. Sarah placed some value on competence, as seen in her response of "Sometimes" to the question, "Is it important to know you're going to do good on a math activity before you start that activity?" For Sarah, it was only sometimes important to feel like you would succeed in math. In further clarifying this, Sarah indicated it was "not really" important to do well on math app math because some problems on the apps might be much harder than other problems. "[Math apps have] different problems [where] some problems are harder. Just because one [problem] is really tricky, that doesn't mean the next one will be." For Sarah, the difficulty of problems on math apps varied greatly, likely affecting the confidence she had in her answers. Perhaps this was why she placed less importance on competence, rating it as only sometimes important. She also felt that Reflex was helpful for learning because it "forces you to, well, it doesn't really force you, but it makes you learn." Whether Sarah encountered a difficult problem on a math app she did not know how to solve, or if she was given easy problems that could be done quickly, Sarah believed that learning was taking place on Reflex. And because the content was more challenging and less predictable, she was less certain about whether she would be successful (or not) when approaching math.

Sarah experienced competence regularly and felt she was "really good" at math. Much of the competence Sarah experienced was related to the role her mindset played in her ability to master and achieve in mathematics. Sarah said, "When you're like just freaked out, it's really, it's a lot harder to concentrate on the math. If you really think you're going to do good, sometimes you'll work a little harder." Sarah felt that her ability to master and achieve an activity in math influenced her decision to put effort forth and try that activity. Commenting on this, she said, "It's kind of hard to do something that you're not very good at." When asked if she would have less motivation to attempt a math activity she knew she might struggle with, Sarah replied in the affirmative. At the same time, Sarah was okay with making some mistakes, saying, "I usually get like one or two [math problems/facts] wrong on [math] papers." For Sarah, these mistakes were okay because "if you get like one bad grade on one paper, she's [the teacher] not going to really do anything."

Relatedness. In May, Sarah expressed that she valued the motivation component of relatedness; that is, Sarah valued feeling connected to classmates who are important to her. When asked if it was "important to feel close with your friends and people in your class when you're doing math," Sarah replied, "Yeah." She described why it was important, saying, "If you're in a group, it's hard to work with people that you're not really good friends with because sometimes you'll just like fight over what the answer is or they'll skip ahead when you're still working on a problem." For Sarah, group work in math, which she enjoyed more than any other kind of math, was only successful when relatedness was experienced. To Sarah, relatedness was, in part, a connection with friends, not just people in general. She desired connection and group work with specific classmates she called "good friends."

While apps like Prodigy and Boddle allowed students to battle other students online, this opportunity for relatedness was not the same as the connection Sarah experienced in regular math. She explained, "If we're in a group, we're actually talking to each other face-to-face, but in Prodigy, they're just like yelling at each other because they're, if you're battling each other." The kind of interaction math apps allowed was not the relatedness Sarah valued, with math app interaction often leading to a chaotic environment in which students disagreed and yelled at one another. After a semester of using math apps, Sarah realized face-to-face interaction and social and emotional connection were more important to her than connection through the screen of a laptop.

The importance and value Sarah placed on face-to-face human interaction with classmates led her to describe tradeoffs and concessions she was willing to make in order to experience connection with her peers. She said, "I really like group work. Sometimes it's easier to do other things alone, but it's more fun to do a lot of things with other people." Even though group work could be more challenging than individual work, Sarah enjoyed the experience of doing math in a community with others and was willing to deal with the additional struggles related to group work. Sarah experienced greater relatedness with regular math than with math app math. In ranking the participation structures of learning math, Sarah said, "I'd rather do group [work], or I'd usually prefer group work. But if we can't do group work, I like individual work over math apps." Group work and feeling connected with classmates when learning became valued by the end of the semester for Sarah.

Interest. After four months of regularly utilizing her laptop to engage in math apps, Sarah said, "I love the all no computer [days]" since she felt that math apps are "not that much fun." In providing reasons as to why math apps were no longer as fun as they once were, Sarah felt a major reason was that her classmates often had behavior issues when on their computers playing math apps. This would routinely lead to Ms. Care, her teacher, sending the class back to their desks to work independently. During one observation in late April, I observed an episode of Sarah's class getting off task because several students could not resist playing on math apps instead of doing a group activity. The group activity involved solving math problems to get hints to search for keys hidden throughout the school.

> After recess, so many students were off task and playing the math app Boddle instead of doing the assigned "escape room" math activity that the classroom teacher stopped the activity early. It seems like math apps have caused "fun" paper and pencil math games to no longer produce the same enjoyment and dopamine they might have for other students and/or these students before they used math apps so much. (Field note, April 29, 2024)

Being punished for her classmates' disruptive behavior (e.g., missing some of lunch, ending fun "regular math" activities) was frustrating for Sarah. This bad behavior seemed to occur more often with math apps or as a result of students using math apps when they were not allowed to. Sarah said, "A lot of people are just stuck on their computers, and it causes problems, and sometimes it delays us getting in line to go to lunch or something. And so, I just, I don't like screens that much."

Another key aspect of math apps related to diminished/less enjoyment for Sarah was the timing mechanism on many apps. For example, Reflex had a timer counting down as students attempted math facts, or students would be challenged to complete as many facts as possible in a set time. Describing the timer on Reflex, Sarah said, "Reflex is a little harder than the other math apps because it's timed, and the multiplication, it's a lot of facts you have to memorize and get right really quickly." When asked if she liked this timing feature, Sarah replied, "No, some people need longer to do math." The timing mechanism on many apps caused Sarah to experience diminished enjoyment with math app math.

With regular math, Sarah experienced enjoyment that primarily came from doing something she genuinely enjoyed. Throughout the second interview in May, Sarah would say, "I like math!" when asked to describe her feelings and emotions toward math. Moreover, when she was asked what, in particular, she found enjoyable about math, Sarah replied, "I don't know. I like solving problems, and I'm good at it, which makes it like a little more [fun]." Overall, Sarah experienced a more stable and enduring enjoyment with regular math, but found math app math to be considerably less enjoyable than regular math toward the end of the year.

Changes in Motivation

Examining changes in Sarah's motivation (Figure 3), there is an increase in relatedness from low to high and a change in the interest comparison between regular math and math app math.

More subtle changes were observed with the value of competence decreasing for Sarah, as well as changes in how she experienced both autonomy and relatedness. I will now unpack the largest changes in Sarah's motivation.

Figure 3
Changes in Sarah's Motivation

		Interview 1 (Jan)	Interview 2 (May)
Response to Value of Motivation Component	Autonomy	"Not always"	"It depends"
	Competence	+	"Sometimes"
	Relatedness	–	+
	Interest	N/A	N/A
Experience (Regular Math vs Math app Math)	Autonomy	S	R
	Competence	S	S
	Relatedness	S	R
	Interest	A	R

Note: For the value of the motivation component, "–" = negative response and "+" = affirmative response. For the comparison of each student's experience of regular math and math app math, R = regular math offers more experiences of the motivation component, A = math app math offers more experiences, and S = similar experiences.

Relatedness. Relatedness was a motivational component that Sarah valued more at the end of the semester than at the beginning. In January, Sarah felt it was "not really" that important to feel close and connected with her friends and peers when doing math. By the end of the semester, Sarah valued feeling connected to classmates and seemed to differentiate opportunities for connection in regular math and math app math based on the quality of interaction. While math apps like Prodigy and Boddle allowed students to experience relatedness by battling other students online, the quality of interaction via math apps had a low value for Sarah, and she expressed a high value and enjoyment in interacting face-to-face with her peers.

Interest. Perhaps the most evident shift in Sarah's motivation related to math app math and regular math came when she reversed the order of which type of math she enjoyed more. While the interest and enjoyment Sarah felt when doing math was consistently high throughout the semester, Sarah started the semester holding the view that math app math was more enjoyable than regular math. Sarah acknowledged that while the enjoyment she experienced with math apps was greater than that of regular math, this enjoyment was problematic because there was not enough "work," which I interpret as Sarah problematizing the gamified nature of some of the apps. By the end of the semester, when asked to reflect on her feelings toward math apps, Sarah felt that math apps were "not that much fun." Sarah no longer experienced a high level of enjoyment when engaging with math apps and preferred regular math over math app math.

Explaining the Math App Motivation Mechanism

While I have used the narrative of Sarah to tell a story about motivation and math apps, and changes to motivation over a semester of regular math app use, I want to further unpack the specific features of math apps that relate to Sarah's motivation (see Figure 4). For Sarah, the multiplayer option on math apps, like Boddle and Prodigy, had a clear relationship to the connection she experienced, or more accurately, a lack of connection, with her peers. Sarah was firm that "we interact a lot more in group work than math apps." For Sarah, the chaotic environment of math app time was jarring, and the "yelling" of peers who "get really mad when they get beaten in a battle" also contributed to a lack of math app enjoyment (Interest).

Math apps often use an internal problem sequence that dictates which problems a student receives and when they are given them, taking away a student's choice of which problems to solve. Sarah described this fixed problem pathway when she said, "The computer's just programmed to do a certain thing. It won't really let you change the problem or do anything." No matter how she felt about the problem given to her by a math app, "you have to solve it whether you like that or not." However, Sarah did not mind this decreased autonomy and acknowledged she might actually choose the easier problems if given the choice. She said, "I don't mind if I have the choice or not. I like hard math problems." Sarah also described a different autonomy with the delivery of math problems on math apps as opposed to paper. She said, "On paper, you can draw out problems there, and you can ask for help," while math apps did not allow Sarah the same autonomy to freely use writing to think through a problem.

The gamified elements and rewards on math apps brought Sarah enjoyment that was in conflict with her view of math. Describing the app Boddle, she said, "That's really fun. It has all sorts of games, and you can design your avatar ... you have a little house." In one session on the app Frax, I witnessed Sarah spend the majority of her math app time customizing her avatar and adding furniture to her avatar's space-themed home. While the gamified elements of math apps were an enjoyable and, at times, motivating factor, Sarah was cognizant that math apps often had "a lot more games than math." And as such, the screen-time saturation led Sarah to state, "It's really fun, but sometimes it's just too much screen time."

Figure 4

The Relationship Between Math App Features and Sarah's Motivation

Components of motivation	Features of math apps				
	Multiplayer	Problem Delivery & Choice	Gamification & Rewards	Feedback & Progress Tracking	Timer
Autonomy		X			
Relatedness	X				
Competence				X	X
Interest	X		X	X	X

Several math apps, like Prodigy and Reflex, had various forms of feedback and visuals that allowed Sarah to track her competence. For instance, Reflex had a Fact Family Pyramid that showed students which fact families they were fluent in. Sarah described this feature of Reflex, saying, "It ... shows you the triangle ... and it shows you if you lose facts." This was a motivator for Sarah as it "tells you how good you are." However, this also detracted from enjoyment when Sarah got problems wrong. She said, "... if you get it wrong, you'll lose a fact." This led her to "... get grumpy when I lose fluency."

Related to the feedback and progress tracking was the timing feature on math apps. At first, the timing feature on Reflex made Sarah "more motivated because I know I have to answer this question right now." The urgency was motivating, and answering problems quickly led to Sarah feeling competent. After several months of this feature, Sarah said, "It's timed, and Gnome will get sad if you don't do it super quick..." She felt a lack of enjoyment and expressed feeling "stressed and frustrated" by the pressurized timer on Reflex. Once she got to Frax, the lack of a timer was a relief that brought enjoyment back. Sarah said, "On Frax, you have time to just stare at the problem for as long as you want to understand it." This feature was a driver for the enjoyment (or lack thereof) Sarah experienced on math apps.

Implications

The findings in this research study offer several implications for math app use in elementary schools. First, we see that Sarah's experience with math apps was not completely positive or negative, and these experiences changed over time. Over the course of four months, Sarah had gone from viewing Reflex's timing feature as making her "more motivated because I know I have to answer this question right now" to feeling "stressed and frustrated" by the timer. Moreover, Sarah felt that math apps reinforced her feelings of competence and success while leaving her with a lack of connectedness that she valued. Unlike previous research, which has shown that math apps significantly improve the motivation and attitudes of elementary students (Chang et al., 2016), Sarah's case yields mixed findings. At times, Sarah was motivated by math apps; at other times, her motivation was undermined. Whether the motivation Sarah experienced was good or bad is up for debate, but what was observed was that the features that traditionally motivate students, like timing mechanisms and multiplayer modes, did not motivate Sarah after a semester of math app use. Instead, they elicited negative emotions, emotions that hinder the development of a positive disposition toward math. Given that a student's disposition of math not only impacts their achievement (Barroso et al., 2021) but also shapes their relationship with math (John et al., 2020), what dispositions of math was Sarah forming through the stress and frustration of being rushed to answer questions quickly? And how might these dispositions be leading her toward future experiences with math?

Second, Sarah's math app experience appeared to coincide with a shift from more self-determined to more controlled engagement, suggesting that some math app implementations may risk undermining intrinsic motivation for some students—like Sarah—under certain conditions. One observation related to Sarah's enjoyment of math apps was that she enjoyed them more than regular math in January, while stating that math apps were less fun than regular math in May. In positing why Sarah experienced a decrease in the enjoyment of math app math, the overjustification effect (Deci, 1971; Lepper et al., 1973) may offer an explanation. The overjustification effect is when a person's intrinsic (internal) motivation decreases after they are given a reward for doing something they enjoyed doing before they were given the reward. In January, much of Sarah's enjoyment of math came from an instinctual place. In several instances of the interview, when asked to describe how she felt about math, Sarah would say, "I like math. It's fun!" or "It's just fun!" In these moments, when probed about her enjoyment, Sarah had trouble articulating exactly why math was fun, but she felt and knew from an inherent (or intrinsic) place that math was fun.

In understanding why Sarah no longer enjoyed math app math in May, it may have been that math apps, which offered incentives by way of game time, digital currency/coins, and other prizes, rewarded Sarah for doing math, something she already enjoyed. The "overjustification" of rewarding Sarah (math on math apps) for doing something she already enjoyed (regular math) may have caused her intrinsic motivation related to math app math to decrease. This may help explain why Sarah experienced declining enjoyment of math apps throughout the semester.

Finally, based on the finding that Sarah had a mixed motivational experience with math apps, I recommend that math app designers include additional or customizable features in their learning programs to minimize the drawbacks and damaging views of math students may glean from being on math apps. For example, Sarah was a student who felt "stressed" and "frustrated" by the timing mechanism on Reflex, which made students solve math facts within a short, fixed amount of time. If teachers had the option to toggle the turning mechanism on or off for individual students, the stress, frustration, and anxiety associated with a timer could be avoided for students who feel negatively about such features. Moreover, students with learning disabilities or students in need of additional time to solve math facts (regardless of emotions toward the timing feature) could be given more time to solve problems. Another example of a feature that would benefit from teacher control is the ratio of non-educational gameplay to math problem-solving. This would allow teachers to control how much game time and educational learning time students have on math apps. At the end of the day or during the time designated as a reward, students could be given a higher ratio of games to math problem-solving, while usual math app time could consist of a higher ratio of math problem-solving. I observed some students who spent forty minutes on a math app buying items for their game character to wear, decorating their game character's room, and wandering around the virtual game world, without having solved a single math problem. This teacher-controlled function would prompt students to solve math problems after a set amount of non-educational app time. These are just a few examples of meaningful features that math app designers should consider integrating into current and future educational technology. In summary, the following points are key implications from this study:

- Math apps relate to students' motivation, and this relationship can change over time—for better or worse.
- Math apps may undermine students with intrinsic motivation for math.
- Allowing teachers to toggle math app features could minimize the negative effects of math app use on motivation.

Limitations and Directions of Future Research

This research study is not without its limitations and constraints. First, although case studies can provide insight into the complexity and nuance between a phenomenon and context (i.e., Sarah's math app use and her motivation), as Eisenhardt (1989) points out, single cases have limitations in generalizability and include information-processing biases such as external validity and observer bias. However, this article did not seek to produce a generalizable case; rather, it sought to illustrate a revelatory and instrumental case that provides a heightened understanding of the relationship between a student's motivation and math app use. Czocher and Melhuish (2024) explain that the point of a research study that utilizes a process lens, like this study, is "not to generalize numerical relationships about variation across categories nor to estimate the likelihood of category occurrence from sample to population" (p. 153). This study sought to provide detailed insights into the connection between a student's motivation and the use of math apps. Given the relationship identified between the phenomenon (motivation) and the context (use of math apps) in this case study, future research should examine this relationship across a larger, more diverse sample of students using quantitative and qualitative methods.

Building on this study, researchers should continue to investigate the use of math apps in K-12 classrooms and their effects on learning and student affect. Achievement and learning gains should continue to be researched, as educational technology developers' internal research findings may be biased or misleading (Kim et al., 2021; Mathewson & Butrymowicz, 2020).

Additionally, there is a need to look at math apps' influence beyond achievement and learning. While learning is a crucial outcome of math app use, students around the world are experiencing a crisis of identity and increasingly negative dispositions toward math (von Davier et al., 2024). Recent TIMSS data show that between one fourth and one third of U.S. students were categorized as "Do not like learning mathematics" and "Not confident in mathematics" (von Davier et al., 2024). In this new age of learning, researchers must continue to understand the holistic impact these apps have on students, including dispositions toward math like enjoyment, anxiety, views related to ability, and other important factors that have been linked to learning (National Research Council, 2001; Schukajlow et al., 2023).

Conclusion

It may be an understatement to say K-12 is experiencing an unprecedented digital age of learning. Given this new age of learning, I believe it is imperative that the larger educational community, which includes researchers, college faculty, district administrators, and leaders, provides appropriate support to help teachers navigate these changes in education. Most current practicing teachers (Taie & Goldring, 2020) did not grow up in an educational system that regularly used today's education technology, had a one-to-one ratio of personal learning devices to students, or implemented math apps. As such, it may be unrealistic to assume that current K-12 teachers will independently become experts in math apps and know the nuances of their use. Parents must also understand that administrators may pressure or mandate the use of learning apps licensed by the school district. However strongly parents may feel about their children spending time on learning apps, the old adage "don't kill the messenger" may ring true in many cases of math app implementation, where teachers face increasing pressure to use district-licensed learning technology, which may have been purchased in conflict with teachers' personal views and feelings toward math learning apps.

The case of Sarah illuminates the relationship between motivation and math app use. Moreover, Sarah serves as a cautionary reminder that introducing new technology may have unintended detrimental consequences; as such, new educational technology should be introduced with healthy skepticism, operating under the assumption that it does not support the learning of all students until demonstrated otherwise. For technology that does support learning, educators and researchers may question whether additional screen time is what children need. Given that the average 8–12-year-old in the U.S. spends 5.6 hours of entertainment screen time each day (Rideout et al., 2022), should precious school time be spent on screens?

Though time has passed since Sarah first told me, "Sometimes it's just too much screen time," I cannot help but wonder whether we are entering a digital age of learning where screen time is no longer a tool for learning—it has become the norm. Perhaps, Sarah is a Cassandra[2] , speaking truth to all who will listen. The question remains: will we heed Sarah's cry?

[2] Greek mythological figure.

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Conflicts of Interest

The author declares no conflicts of interest.

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