DESIGNING AN ONLINE VIDEO-BASED ENVIRONMENT FOR PROMOTING MATHEMATICAL ARGUMENTATION

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During the past two years, the COVID-19 pandemic has forced teachers to shift their instruction online, further exacerbating the challenges for teachers in orchestrating rich mathematics discussions. To tackle this issue, this study explored an approach that integrates online video-sharing culture (e.g., YouTube) into mathematical practices. Specifically, I designed an environment to engage children in creating and sharing mathematics how-to videos online for subsequent peer discussions. Guided by design research principles, I recruited four upper elementary children in the United States. The analysis of this qualitative study showed that the environment created offered unique opportunities for the children to communicate their ideas in a multimodal way and engage in mathematical argumentation. The findings provide insights into how an online environment can be designed to reshape children's argumentative discourse.

Keywords: Design Experiment; Instructional Activities and Practices; Online and Distance Education; Reasoning and Proof

Mathematical argumentation, a type of discourse that involves communication of mathematical ideas with reasoning, is central to the development of mathematical knowledge (Conner et al, 2014). This discourse fosters greater conceptual understanding (Wood et al., 2006) and advances academic achievement (Chapin et al., 2009; Kazemi & Stipek, 2001). Although benefits of mathematical argumentation are evident, enacting such practices in classrooms challenges many teachers (Conner et al., 2014). This problem has been exacerbated during the past two years. The COVID-19 pandemic forced in-person classes to be conducted remotely, while most teachers have little experience or support with how to engage children in mathematics discussions online. Indeed, the literature on mathematical argumentation in fully online contexts is relatively scarce as compared to that of in-person contexts. By designing a video-based online learning environment, this study addresses the necessity to investigate ways to engage learners in mathematical argumentation.

Video technologies have been used for mathematical teaching and learning in various ways, such as anchored instruction (Cognition and Technology Group at Vanderbilt, 1992) and flipped instruction (De Araujo et al., 2017). However, little is known about how videos produced by learners themselves can be leveraged for promoting mathematical argumentation. Indeed, research that explores the use of video production as a means for mathematics learning is just emerging. In a recent study that investigated how middle school students collaboratively produced mathematics tutorial videos, Oechsler and Borba (2020) found that this activity changed the classroom dynamic and engaged students in communicating mathematical ideas with multiple modes (e.g., language, gesture, image, and music). They argued that video production is a new way of expressing mathematics and its multimodal affordance prompts students to reorganize their thinking. Their findings suggest video production has the potential to foster children's mathematics discourse. It is therefore reasonable to further investigate ways to design an environment involving video production activities for promoting mathematical argumentation.

This study explored an approach that integrates children's online video-sharing culture (e.g., YouTube and TikTok) into a problem-based learning model. Specifically, this approach uses a process during which children solve math problems, create online videos to explain their strategies, and then discuss strategies after watching peers' videos. I hypothesize that when learners use templates from online video platforms to communicate their mathematical ideas, they likely attend to the validity of mathematical statements and thus engage in mathematical argumentation. The proposed approach allows an investigation into the development of an online video-based learning ecology and children's mathematics discourse. The guiding research questions are: (a) *How can an online video-based environment be designed to promote mathematical argumentation?* (b) *In what ways do children participate in mathematical argumentation in the designed environment?*

Theoretical Framework

This study is framed by the emergent perspective (Cobb & Yackel, 1996) and humans-with-media perspective (Borba & Villarreal, 2005). The emergent perspective is a version of social constructivism that attempts to explore the complementary area between sociocultural and constructivist constructs. The premise of this perspective is that learning is a constructive process that emerges when learners participate in and contribute to socially organized activities (Cobb & Yackel, 1996). According to Cobb (2007), the emergent perspective agrees with the constructivist view of learning as an adaptive process; however, it is informed by a distributed cognition view of learning as a social activity supported by cultural tools and thus expands the meaning of a learning activity. Cobb et al. (2001) argued that the tools and symbols used in the contexts are not additions to but constituent parts of learners' activity. Therefore, this view connects with the notion of semiotic mediation in the sociocultural theories, and learner's engagement in mathematics activities entails reasoning with tools and symbols (Cobb, 2007).

The idea of reasoning with tools and symbols in the emergent perspective aligns with the premise of humans-with-media perspective (Borba & Villarreal, 2005). That is, collective efforts of human (e.g., students, teachers) actors and non-human actors (e.g., computers, mobile phones) contribute to the reorganization and production of human knowledge. In this perspective, human and media technologies influence and shape each other through interaction, negotiation, and reflection. As claimed by Borba and Villarreal (2005), discourse supported by digital media is qualitatively different from oral or written language, primarily because it involves a combination of visual and audio information, such as images and music. It is therefore reasonable to assume this type of discourse can shape human thinking in a distinct way.

In this study, participants' discourse and learning are mediated by online videos they themselves created. When producing a video, a participant coordinates their verbal explanations and visual representations in a coherent way. This requires them to externalize and reorganize their mathematical ideas. When viewing a video, a participant attempts to make sense of a mathematical strategy through the verbal explanations and visual representations in the video. These online interactions are therefore multimodal through technologies, which distinguishes it from typical classroom interaction. I posit that, with an appropriate design of activities, video-based discourse has the potential to drive learners to attend to the validity of mathematical statements, leading them to productive mathematical argumentation.

To develop a video-based environment for promoting mathematical argumentation, it is important to understand how learners engage in communicating their mathematical thinking with technologies. Since this process involves collective efforts of the designer, participants, and technologies, taking the emergent and humans-with-media perspectives together enables me to conceptualize discourse and learning that occur during human-media interaction.

Methodology

In this qualitative study, I aimed to develop an environment and learning theories for video-based mathematical argumentation in an online environment. I adopted principles of design research (Cobb et al., 2003) because using video production as a means for learning mathematics has not been an established practice in typical classrooms (Oechsler & Borba, 2020). Therefore, these principles make this study interventionalist and characterized by an iterative cycle of design, enactment, analysis, and refinement. In addition, I drew on the conjecture mapping technique (Sandoval, 2014) for conceptualizing and carrying out my design. Figure 1 shows a conjecture map I have developed at the current stage of the research design process. My design conjecture is that if learners participate in the discursive practices guided by an online video-based activity structure, then the mediating processes will emerge. My theoretical conjecture is that if these mediating processes take place, they will bring about the desired learning outcomes- that is, constructing viable arguments and reorganizing mathematical ideas. The proposed activity structure will be introduced in the next section.

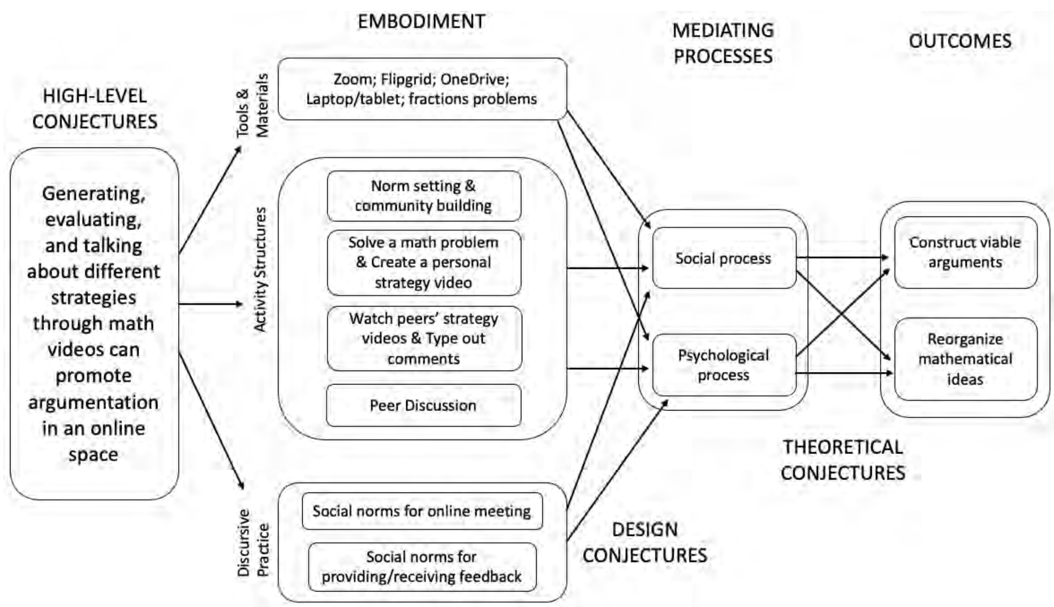


Figure 1. Conjecture map for conceptualizing this design study.

VBAS Environment

Currently, I have developed a four-phase video-based activity structure (VBAS) that aims to promote mathematical argumentation for small groups in an online space. This VBAS environment involves participants using three online technological tools: Zoom, OneDrive, and Flipgrid. Particularly, Flipgrid is a video platform that allows users to produce personal videos and disseminate them in a designated virtual community for viewing. Supported by these technologies, learners participate in a sequence of four activities: (a) setting up norms and building community, (b) independently solving a math problem and creating a strategy video, (c) watching strategy videos and taking notes, (d) discussing the strategies with a partner. Following this design, I worked with a pair of participants at a time. Since I situated my design in a problem-based model, each cycle of research sessions started with a problem-solving task. The mathematics problems employed in this study were about fraction comparisons. An example is shown in Figure 2.

> Imagine that you were invited to a home party. You saw the same pies being served at three tables of your friends: one table serves two pies with two people, another table serves three pies with three people, and the third table serves five pies with six people. Friends at each of the tables call out to you to pull up a chair and share the pies. You are to join one of the tables. Is there any helpful way that you can use math to help with your decision-making?

Figure 2. Fraction comparison problem used during a design cycle.

Rationale of the Designed Environment

The proposed environment features video production activities. When children produce a mathematics video, they realize that their explanations need to make sense to themselves first so that the viewers can understand. Such a self-explanation process can help individuals modify their existing knowledge with new information and promote their problem-solving skills (Chi et al., 1994). This may also help the children see themselves as capable mathematical thinkers.

Participants & Settings

This study is part of a larger project examining children's video-based mathematics discourse in an online environment. I recruited two fifth graders and two sixth graders in the United States, who were female Asian Americans. The participants were grouped into pairs since peer discourse is the focus of this study. During each research session, I met with one pair remotely via Zoom as they used their own computers or tablets at home. Each pair participated in a series of 60–90-minute sessions. In addition, I conducted semi-structured interviews with each participant after they completed the research sessions.

Data Collection & Data Analysis

Data collected for this study came from multiple sources: (a) video recordings of each Zoom session, (b) online math videos created by participants, (c) feedback on videos typed by participants, and (d) the researcher's memo.

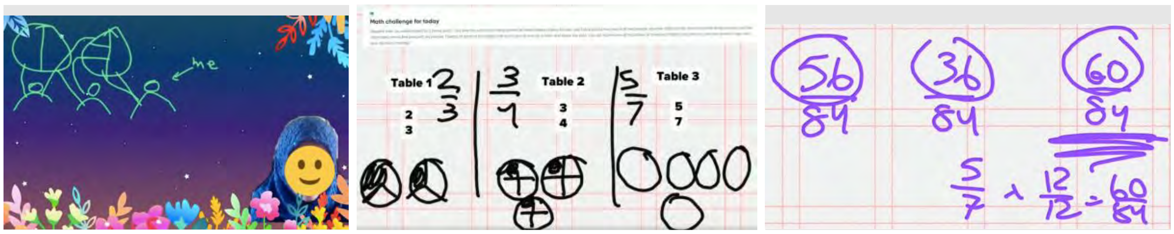
To analyze the data, I adopted the constant comparison method (Corbin & Strauss, 2014), which enables me to identify themes of significant phenomena. My analysis involved examining mathematics videos created by the participants and video recordings of research sessions to highlight and transcribe episodes in which participants generated mathematical arguments.

Results

Here I present some findings from a research cycle of VBAS that employed the problem introduced in Figure 2 and involved a pair of sixth graders, named Alissa and Nancy. Prior to this cycle, the pair had participated in two cycles of research sessions. The analysis here focuses on how the children engaged in three VBAS activities: (a) problem solving and strategy video production, (b) video viewing & commenting, and (c) peer discussion.

Problem Solving & Strategy Video Production Activity

This activity asks participants to independently solve a math problem and create a short video, less than two minutes, in which they explain their strategies. The goal is to activate their existing math knowledge and construct viable argument. As shown in Figure 3, Nancy and Alissa used different strategies in solving the problem that involves comparing fraction magnitudes. Nancy only considered the situation in the first table of the problem. She first cut each whole into halves, creating four halves. Then she distributed each half to each person. Next, she cut the remaining half into three smaller parts and shared them with three people. In contrast, Alissa considered all the situations. On the first and second table, she divided each whole into equal parts based on the number of sharers, and then each person would take one part from each whole. However, she stopped using this strategy for the third table. She probably noticed the drawing would not help her compare the magnitudes, so she switched to a more formal strategy- that is, first finding a common denominator for the three fractions, next converting all fractions to share the common denominator, and finally comparing the numerators.



(a) Nancy's work. (b) Alissa's work-part 1. (c) Alissa's work-part 2.

Figure 3. Screenshots of two participants' strategy videos.

In addition, Nancy and Alissa used different features afforded by Flipgrid to represent their video contents. Nancy's video was stylish as she put herself in the corner with a flowery frame and a starry night scene as background. In contrast, Alissa's video is more simplistic, focusing on the mathematical representations. Moreover, the pair used different background music.

Video Viewing & Commenting Activity

The third activity asks participants to individually watch each other's video twice and jot down their thoughts in a table with three sentence starters on OneDrive. The goal is to prompt a participant to examine their partner's strategy video carefully or even critically. Figure 4 displayed Nancy's contributions.

In the "I notice…" row, Nancy expressed her observation of the difference between Alissa's strategy and hers, claiming Alissa's strategy was complicated and her speech pace was fast in the video. In addition to the comments on the strategy video, Nancy stated that she understood Alissa had limited time to explain such a complicated method.

In the "I wonder…" row, Nancy expressed her inquiry about why Alissa kept using this strategy. This inquiry probably comes from the fact that Alissa had used this strategy during the previous two research cycles.

In the "I would suggest…" row, Nancy suggested Alissa try a different strategy that would make sense to lower graders. The reason why Nancy offered this suggestion is worth further investigation.

I notice…	that she is using factions in the more complicated way, and she is going fast (I understand this though, she had limited time)
I wonder…	why she always uses fractions with inequivalent denominators then changes them to common denominator fractions
I would suggest	to try a different technique, like, using a less complicated way for maybe 5th or 4th graders?

Figure 4. Screenshot of Nancy' comments.

Peer Discussion Activity

During this activity, participants' notes are screenshared, and they are encouraged to talk about their comments with their partner and respond to each other. The goal is to see if the pair would engage in mathematical argumentation. Presented below is an episode in which Nancy first talked about her comments. Note that Alissa did not show her face during this interaction.

Nancy: you always use like fractions like that, you find fractions with unequivalent denominators, and you find them equivalent denominators. How do you always… how do you always find a way to do that?

Alissa: The reason I think is because like, it's easier to compare that way and how I like, what I do to find the multiples that sometimes I'll like, multiply the number by like the other number to get multiple. Or like, I try to find, like, more like the least common multiple and I...

Nancy: How do you find a number… How do you find a number to multiply with?

Alissa: For example, like, if I try to find the common multiple of three and seven, what I would do is, I like, I do three times seven. So I would find 21.

In the above vignette, Nancy first described what she noticed about Alissa's consistent use of an algorithm that converted fractions with unlike denominators into fractions with the same denominators. She asked Alissa how she could always identify a number (i.e., common multiple) that she could convert different denominators to. Alissa first responded with a general rule, but it seemingly did not fully convince Nancy. Therefore, Nancy rephrased her question in a more specific way, and then Alissa described the rule by using an example. Their conversations continued as follows.

Nancy: But do you always like a certain technique or something? Like, try to find something they'll have in common or something?

Alissa: Oh, yeah. So like, sometimes, like, what I'll do is that I'll also try to find if I think that maybe like a number is like, maybe like there's a smaller number than that. What I tried to do with that, uhh…I'll..umm

This vignette demonstrated that Nancy went back to her original inquiry about Alissa' consistent use of such method. Alissa probably did not think about the question before because her response revealed some level of hesitance. Speculating that writing down her thoughts might help process her thinking, I thus intervened and asked if she would like to share her screen and use the Zoom whiteboard. Alissa seemed to agree, so she shared her screen immediately. She then began writing down mathematical symbols on the whiteboard while explaining a different method (see Figure 6).

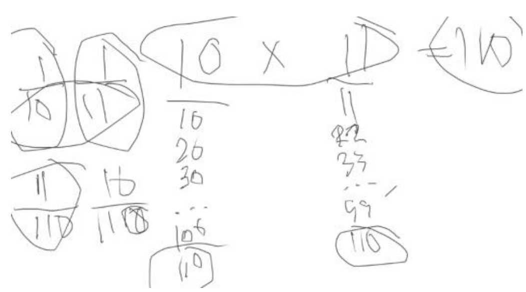


Figure 5. Alissa's writing on the whiteboard.

Alissa: [shares her screen immediately] So like, let's say I have like the numbers 10 and maybe 11. So what I would do is I would list maybe the multiples until, or what I would do is [talking while writing on the board] I would go like that and then 110, or what I would do is that I'll go 100. And like I will go umm so times one it's 10, times two, times three, and then so on and then 100 and then 110. And then I would go to 11. And then I would go like times one, times two, times three and then I don't know, then like 99, and then I get…

Nancy: 110. One thing that both have in common, okay.

Alissa: Yeah, something like that.

Nancy: So go multiply them until you find a way to find the number, okay.

Alissa: Yeah, like, so I don't usually do that. I just usually will be…uh… I'll like multiply these numbers together to get this number [circling numbers on the board].

The above vignette showed that writing might help Alissa externalize her thinking. She proposed another example and explained another way to find a common multiple for two different numbers. This method made sense to Nancy as she replied with an answer to Alissa's example and replied with her interpretations. After talking about the rule, Nancy inquired about Alissa's decision of using the rule.

Nancy: Um, okay. But why do you always use this one way?

Alissa: Because like, let's say I want to compare like 1/10 and 1/11. So they're not equal [circling 10 and 11]. I wouldn't be able to properly compare them. And like just looking at them and then like maybe deciding, I think 1/11 is bigger, really? Or 1/10 is bigger, then so it's better to go like 11 over 110, and then 10 [writes 10/110]. This one is bigger [circling 11/110].

In this vignette, Nancy 's question had potential to shift their discussion from procedure-focused to concept-focused. However, Alissa did not articulate the underlying concepts. As demonstrated in her response and Figure xx, she applied her previous example to a fraction case and showed how the algorithm worked. Nancy seemed to accept Alissa's response and proposed her suggestions as follows.

Nancy: Ok. So, umm…So if you had to explain this problem to maybe a fourth grader, how, would you use a different technique or use the same technique? with more explanation?

Alissa: I would use the same technique with more explanation. So that they would understand better because …yup!

The above episode indicates that Nancy and Alissa engaged in asking questions and justifying their ideas with limited intervention from the facilitator. Particularly, Nancy's questioning showed that she attended to Alissa's responses, and her questions prompted Alissa to develop a more comprehensive account for finding a common multiple for denominators when comparing fraction magnitudes. However, their discussions were focused on procedures. This finding is evident in a few other episodes when participants talked about their strategies toward other fraction comparison problems.

Discussion

This study investigated how an online video-based environment can be designed to support mathematical argumentation and the way children engage in mathematical argumentation in such an environment. The results indicate that the proposed environment created unique opportunities for the participants to communicate their mathematical thinking in multiple modes and engage in mathematical argumentation. The video production activity involves a multimodal process of constructing viable mathematical arguments as the children individually coordinated their verbal explanations and relevant visual representations. Moreover, the video viewing and commenting activity encouraged the children to carefully examine their partner's arguments. Since the children were asked to type comments based on their observation, they would re-watch the part they did not understand and reorganize their thinking. This process is also multimodal as the children attended to the mathematical ideas that were verbally and visually transmitted. Furthermore, the peer discussion activity allowed the children to talk about their ideas to each other in real time. Because the previous two activities have engaged participants in thinking through their arguments and their partners' arguments, they may come to this activity with inquiries or revised ideas. Therefore, a productive mathematical argumentation like the one presented in the results section could likely happen, and in humans-with-media terms (Borba & Villarreal, 2005), the videos play an acting role as important as human participants during this discourse.

The video production activity that involves participants designing math videos based on their own strategies is featured in this study. This process involves a great deal of autonomous problem-solving and decision making since participants need to figure out affordances of the video platform, activate their existing mathematics knowledge, and arrange presentation contents in a way that makes sense to themselves and their peers. In addition, the participants often added pleasant backdrops and cheerful music to their videos, which makes them appealing to the viewers. In this sense, the math videos are not merely pertaining to mathematics, but also communication and personal identity.

Much of existing literature on mathematical argumentation focuses on teacher's moves, such as questioning (e.g., Conner et al., 2014). In contrast, this study attempted to lessen the need for the facilitator to directly guide children's discourse by proposing a sequence of learner-centered activities. The VBAS design offers scaffolds to prepare children to lead their discourse by themselves. This way of positioning children as capable agents is different from that of using adult-created videos for flipped classrooms or using ready-made dialogic videos for vicarious learning, which usually involve obedience-oriented ways of problem-solving strategies and explanations. Indeed, the proposed design encourages children to not only engage in video-based discourse but also come to take ownership of their mathematical learning.

While the findings seem promising, there are limitations to this study. For instance, the participants of this study were upper elementary children who knew each other, had some experiences with video production, and felt comfortable sharing their mathematical ideas online. It is unknown how learners with different backgrounds engage in the proposed environment. Additionally, this study has not analyzed how the children's knowledge on fraction comparison developed over time throughout the sessions. These are important areas that need further research in order to understand how to better support children's mathematical argumentation in an online space.

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