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"MAGIC MATH MINUTE" VIDEOS TO FOSTER UNDERSTANDING OF EARLY MATHEMATICS LEARNING

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Technological advances afford teacher educators, designers, and researchers the opportunity to use videos as an instructional tool to help parents, caregivers, teachers, and other adults support young children's mathematical development. We created five Magic Math Minute videos to highlight examples of young children's mathematical thinking and to show how adults can engage children in mathematics conversations. We intended for these videos to inform adults about the ways children explore mathematics and to foster productive adult-child interactions around mathematics. This article documents how we designed five distinct but related formats of a Magic Math Minute video. It describes the video content, design constraints, three online studies evaluating the videos, and how the results of these studies informed revisions to our design.

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FOSTERING EARLY MATH LEARNING

Young children can benefit from joint engagement in math activities with parents (Gojak, 2013; Starkey et al., 2004) and teachers (Clements et al., 2004; Fuson et al., 2015; Klibanoff et al., 2006; NCTM, 2010) as they facilitate children's understanding of foundational math concepts. Children's participation in math-related activities, whether formal math learning, like engaging in counting or writing numbers, or informal activities with quantitative components, like cooking or playing board games, can promote math learning (Lefevre et al., 2002; Lefevre et al., 2009). Fostering math learning is important because children who enter school with a basic understanding of numbers (e.g., comparisons, cardinality, and ordinality) are better equipped to learn arithmetic skills than children with low numeracy skills (Ginsburg et al., 2008; Griffin & Case, 1996). Children with lower math skills will likely face difficulties in later school years because early math skills are predictive of later mathematics achievement (Duncan et al., 2007; Jordan et al., 2006; Lee & Burkam, 2002).

Videos can enhance learning (Schmid et al., 2014), serve as an effective educational tool (Hsin and Cigas, 2013; Kay, 2012; Lloyd & Robertson, 2012; Moore & Smith, 2012; Rackaway, 2012), and promote critical thinking (Ginsburg, 2016; Ginsburg et al., 2010). To bolster parents' and caregivers' understanding of early math development and support prospective and practicing teachers' training in early mathematics, we created five Magic Math Minute videos of individual children engaging in a mathematical task with an adult.

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MAGIC MATH MINUTE VIDEO CONCEPT AND CREATION

Beginning with Piaget (Piaget, 1967; Wadsworth, 1971), psychologists showed how children's thinking is different from the ways adults think. Because of this contrast, it is important to understand children's thinking to support their learning as they develop. As educators and researchers, we had the idea of developing short videos that would present children's thinking in an exciting and engaging way. The work of Piaget and others provided the theoretical basis for the design of the videos.

Informal conversations with parents and caregivers revealed their interest in videos designed to demonstrate how young learners think about math. When we informally discussed the concept of the videos with educators (pre-service or in-service teachers), they offered suggestions on ways to feature a math video clip with an accompanying narrative.

We also weighed design decisions, selected, and edited content based on the expertise of Dr. Herbert P. Ginsburg. Together, with our combined professional experience in math education and our conversations with caregivers and educators, we justified the time and effort needed to create Magic Math Minute videos.

The brief three-minute videos we designed to show how children talk about math, express their curiosity, enthusiasm, and misconceptions when problem-solving, and highlight the "*magic*" behind their mathematical thinking. A narrator describes specific events in each video to highlight pivotal learning moments, encourages adults to observe and interpret children's mathematical understanding, and offers suggestions on how to foster future conversations or activities with young learners (Ginsburg, 1997).

We wanted each video to be concise, useful, engaging, and generalizable to the ways a child thinks about math. We chose to cover diverse mathematical domains for young children, such as counting, operations, patterns, geometry, and spatial relations, based on the National Council of Teachers of Mathematics (2000b) standards. The videos also adhere to Common Core standards and existing early childhood standards (Head Start and National Association for the Education of Young Children). Each Magic Math Minute showed excerpted video clips of a child engaging in a mathematical task, an adult reading a picture book, or an adult conducting an informal "clinical interview" with the child.

Clinical interviews are effective in assessing children's mathematical thinking (Ginsburg, 1997; Ginsburg, & Opper, 1969; Piaget, 1967). With clinical interviews, adults do not just learn whether children can solve a problem or answer a question, but how they arrived at their answers (Ginsburg, 2009; Ginsburg, 1997). Adults can think of clinical interviews as engaging a child in math thinking conversations built through a relationship of mutual trust and respect with the child (Ginsburg, 2017).

The video clip excerpts used in the Magic Math Minute compilations came from a digital archive spanning over a decade and were recorded for education or research purposes with parent permission and the child's verbal assent. Parents also signed video release forms. The excerpts featured children between the ages of three and five years old. We wanted the videos to tell a story about a selected math topic (e.g., spatial relations or patterns) and how a child interacted with the topic. Members of the research and design team culled through the video clip archive and selected clips to feature in the video series because they included: (1) a young child who explored math while using a physical object or engaged in a mathematical task or topic, (2) a memorable moment when the child's mathematical thinking was prominent, (3) a child's epiphany, surprise, or an exciting math explanation, and (4) reasonably clear audio and video quality.

The video clips were recorded using portable cameras set on a tripod either in school classrooms, libraries, or in family homes. Some of the video clips selected from the digital archive were not recorded using high definition cameras but were included in our designs if they met the selection criteria. One primary editor within our group created, processed, and refined the preliminary Magic Math Minute video compilations. These compilations were then reviewed and edited as a group. We selected a video clip from the digital archive that best fit the math topic, drafted a rough outline, assembled images, and wrote annotations.

Our initial challenge began with reviewing video clips collected over decades and how to best curate them for our purpose. We needed to establish a systematic way to review each chosen video clip and determine if it was best to feature in the Magic Math Minute video. One team member reviewed the vast archive and recorded metadata (e.g., date recorded, video length, etc.) in a spreadsheet for the video clips and renamed the files for ease-of-access.

After cataloging the archive, the team previewed videos and voted to determine which clips to use in the Magic Math Minute video design.

As part of the workflow, the primary editor drafted a script, tailored it to match the video clip, and sent the text copy to the team for feedback. Using feedback from the design team, the primary editor trimmed and streamlined the script. The script incorporated deliberate pauses, where we inserted questions into the video compilation to encourage adults to engage in reflection before and after the child's math encounter. We intended for the script to guide adults to observe how children make connections and build their math understanding (Ginsburg et al., 1998). We ended some of our

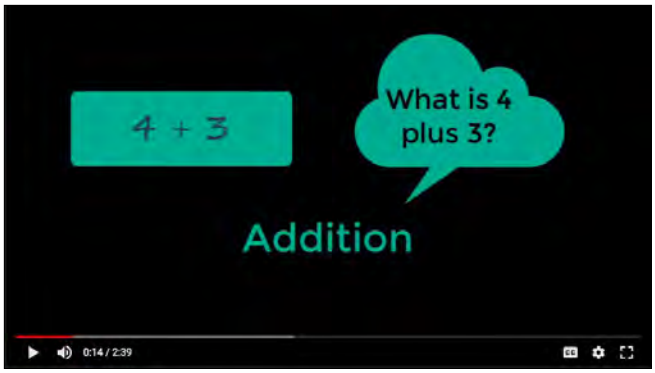

FIGURE 1. A screen capture example prompt at the end of the video for viewers to try a new activity.

videos with a prompt for the viewer (e.g., "Here's something you can try..." or "Here's an idea…") (see Figure 1).

After curating a final set of video clips, we evaluated different video editing software to design our Magic Math Minute videos and purposely avoided complex software installations.

We first used iMovie to design the videos. While iMovie is often used as a video-editing program to polish video clips, embed audio, and add special effects, it is limited in that it does not capture screenshots. We then tried using QuickTime. This is a Mac-only software and not available for Windows 10. For compatibility reasons, we decided not to use QuickTime.

We decided to use Camtasia Studio for the video creation and SnagIt for the art creation and placement in the video. Camtasia Studio software allowed us to upload the selected media (video clips and image files), add screen captures, and edit them together to create the transitions. The software is user-friendly, offers online tutorials, and allowed the primary editor to freely annotate the video, embed animations, and add transitions.

After the team finalized the script to match the selected video clip, the primary editor recorded the narration using a Universal Serial Bus (USB) microphone and layered it with the video clips, images, annotations, and animations using Camtasia Studio (see Figure 2 for the Camtasia Studio design view). We then reviewed the compiled Magic Math Minute video as a team.

During the review process, we looked for ways to streamline the script to better match the video clip—including rejecting concepts that stalled the flow of the video. We avoided wordy descriptions with educational jargon. We wanted viewers to observe the child engage with the math task and pay attention to key moments related to the video topic. We tailored our design to spark an adult's interest and keep them engaged for the duration of the video. We asked viewers to notice the child (e.g., "What did you see the child do?"), explore their own math knowledge ("What do you think

FIGURE 2. Camtasia Studio design view in preview mode.

of when you think about…?"), consider the child's math knowledge (e.g., "What do young children know about…?"), ask questions about the child's behavior (e.g., "What happens when the adult focuses on the child's thinking, not mistake?") or make predictions ("What do you think a child can learn from reading this story?").

After the revision process, we re-recorded the final script and inserted the final video clips and images. We designed the videos for release on video sharing platforms such as Vimeo.

MAGIC MATH MINUTE VIDEO CONTENT

The Magic Math Minute videos aimed to promote careful observation and analysis of children's thinking and learning. Our videos emphasized an approachable method to show adult-child interactions that caregivers and teachers could use as models for engaging young children (Ginsburg et al., 1998). The video topics included: (1) operations (i.e., addition); (2) spatial relations, (3) shapes, (4) pattern picture books, and (5) math concepts in a fairy tale storybook (see Appendix A through E for Magic Math Minute video screen captures).

The topic selection for the videos was largely exploratory. We weighed several factors, including which math topic to feature in the video and how to portray instances when children expressed a mathematical misconception or epiphany. The videos showed how children interpreted, handled, and responded to a math problem and their mathematical thinking. We framed the videos to focus on specific math topics and weaved early math learning concepts like how to guide a child or how to identify a child's understanding.

Operations Magic Math Minute Video

A child may conceptualize addition as the joining of two or more groups together. The *Operations* video focuses on a simple addition problem. The video highlights an adult's response when a child makes a math mistake. For example, a child may fail to correctly solve a math problem on the first try and may need to think about the problem repeatedly before grasping the concept. If the adult quickly interjects to

correct the child, the adult may never know what the child understood about the task, only learning that the child did not immediately find the correct sum on the first try.

The *Operations* Magic Math Minute video began with the title "Young Children's Addition." The narrator asked, "What do young children know about operations like addition?" Two images appeared on the screen showing 4 + 3, and a thought bubble as the narrator stated, "[Children] may not understand written problems like this (4 + 3) or abstract verbal statements like, 'What is 4 plus 3?'" The video transitioned to a clip where an adult told the child a story problem about toy animals. The adult began the story with a rabbit and a squirrel. "The rabbit has three carrots," the adult stated, "And the squirrel has four carrots." The adult asked the child to confirm the number of carrots for the rabbit and squirrel in the story. The child accurately repeated the numbers and confirmed her understanding. Then, the adult asked the child, "How many carrots do they have altogether?" On the first try, the child added the numbers incorrectly, by stating, "six," as the sum of 4 and 3. Instead of correcting the child, the adult asked, "How did you figure that out?" The child explained her thought process and said, "I, like, had in my mind a four and a three." An animation of carrots accompanied the child's words to demonstrate the child's thought process while adding. The child asserted that she visualized the carrots in her mind and stated she moved one carrot over to the four to make five, and she moved the other carrot over to make six. She explained how she was counting one item, then the other, as she mentally moved one carrot over to the other group. At this point, the child realized her calculation error and paused. The adult then asked, "Is there anything left?" And the child replied, "Yes, seven," to complete the total addition of 4 plus 3. The adult in the video clip affirmed that the child calculated the total sum accurately. The narrator concluded the video by stating that adults can "Make up your own addition stories and incorporate them into imaginative play."

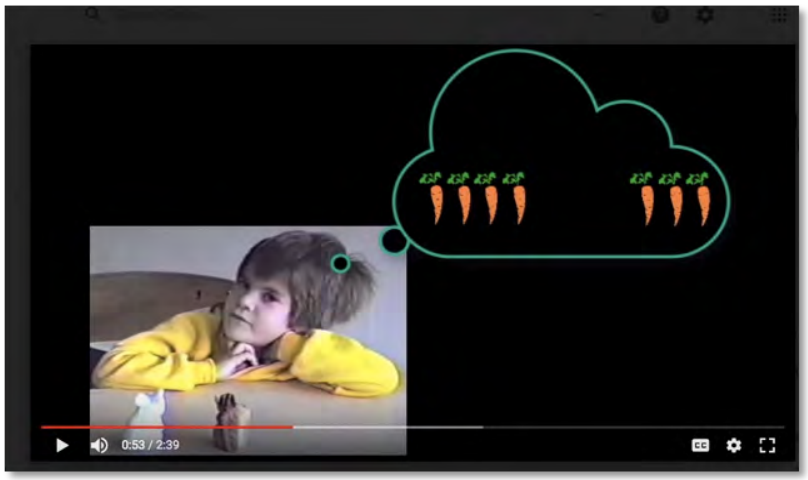

FIGURE 3. Operations Magic Math Minute Video: This video showed a child counting the total carrots. The child in the video made an addition error. https://media.dlib.indiana.edu/media_objects/nc581507

This video showed the importance of encouraging children to think through and verbalize a math problem to reach a final solution. Even when a child inaccurately adds small numbers, an adult does not need to immediately provide a correction. Prompts and questions offer engaging ways for adults to invest in the child's thinking and gradually guide the child towards the correct answer (see Figure 3 and Appendix A).

Spatial Relations Magic Math Minute Video

Spatial relations refer to the relationship among objects in a space. When children describe locations of objects as "in front of," "on top of," and "under" they are using spatial relations. Spatial awareness enables children to locate objects in a space. Spatial reasoning allows children to navigate the location of an object in relation to themselves and others. With spatial language, children can express their needs, describe the world around them, and organize things in their world.

The video highlights a child's frustration when attempting a new or challenging spatial task. When adults verbally and nonverbally encourage a child to reflect on a failed attempt and try again, they are confronting the child's frustration and giving them a way to work through it. In these contexts, adults can provide different examples, model a strategy that may lead to the correct answer, or offer incremental explanations. Confronting negative beliefs about math (i.e., "I can't do this"), even at a young age, can motivate the child to persist and complete the task. Adults can also present complex tasks gradually and observe how the child responds.

The *Spatial Relations* Magic Math Minute video began with the title "Geometry" and focused on a child's understanding of spatial relations. The narrator asked the viewer, "What do you think of when you think about geometry? You probably think about shape." The narrator continued, "But do you also think about space?" The narrator then explained spatial relations or knowing where one object is in relation to another, as an important part of geometric knowledge. The narrator stated, "One way to find out about what children know about space is to use grids," and transitioned to the video clip of an adult placing four red chips one-at-a-time in a horizontal line across a paper grid placemat while a child observed. The adult in the video clip asked the child, "Can you make yours the same as mine?" The child replicated the horizontal line task with ease using her own grid and exclaimed, "Ta-da!" The adult then asked the child to copy the placement of chips in a more complex relationship—laying

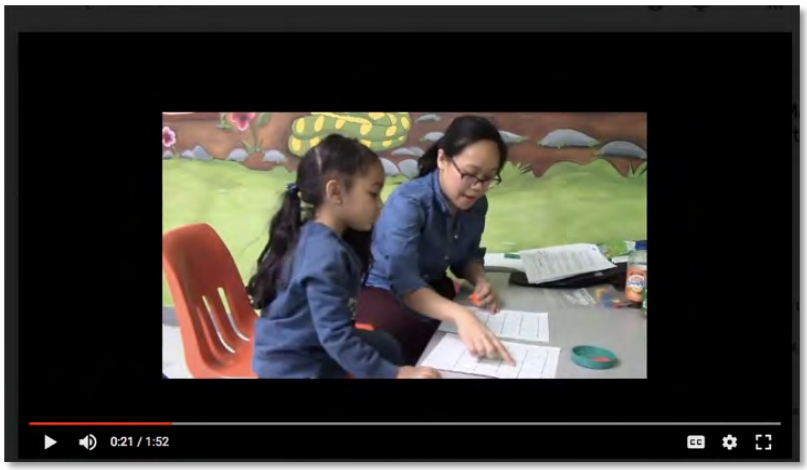

FIGURE 4. Spatial Relations Magic Math Minute Video: The child had difficulty implementing a diagonal line on a grid. https://media.dlib.indiana.edu/media_objects/41688131h

FIGURE 5. Shape Magic Math Minute Video: The adult rotated the right triangle 180 degrees as the child observed. https://media.dlib.indiana.edu/media_objects/2227n596h

chips diagonally on the grid placemat. The adult asked, "Can you make yours the same as mine?" The child placed the first red chip accurately, but by the second chip, the child shifted placement from a diagonal line to a vertical line. The child placed the third and fourth chips inaccurately and was visibly upset. In frustration, the child pushed the chips away from the grid and said, "Oh, I don't know!" The video clip paused, and the narrator explained that the diagonal line placement requires more complex spatial awareness than the straight line and is a challenging concept for a young learner to implement. A video animation shows how a diagonal line is a complex spatial relation for young learners because it is positioned up and then across on a grid instead of a horizontal or vertical line positioned across or down on a grid.

Initially, the child in the video clip seemed unmotivated to repeat the challenging task. Although not depicted in the video, the adult stated, "That's okay. You can make your best guess," to encourage the child to reattempt the task. For the sake of time, we showed the nonverbal responses of the child reattempting the task and not the verbal exchange between the adult and child.

The video clip resumed showing the child's excitement at successfully recreating the diagonal task after taking the time to think it through. An adult can encourage a child to reattempt a task both verbally (e.g., "You can do it!") or nonverbally (e.g., head nod) (see Figure 4 and Appendix B).

Shape Magic Math Minute Video

Children learn to identify and name circles, triangles, squares, rectangles, and ovals at a young age. When children identify a shape like a triangle, they often rely on a mental image and not on counting the number of sides of the shape. For a triangle, that mental prototype is usually an equilateral triangle or a right triangle. A child may not identify an obtuse triangle as a triangle because it is different from the image of a triangle in the child's mind. To counteract this tendency, adults can expose children to different kinds of triangles, such as isosceles and scalene triangles and their properties (e.g., three sides and three corners). Adults may also expose children to triangles rotated or oriented in different ways.

The *Shape* Magic Math Minute video began with the title, "Geometry," and featured the orientation of a shape. The narrator asked, "What do young children need to know about geometry? Many parents and teachers would say young children need to know the basic shapes—like triangles." The narrator then introduced a video clip where an adult showed a young child a shape and asked, "What shape is this?" The child accurately responded by saying, "triangle." The adult then rotated the right triangle 180 degrees and asked, "Is it still a triangle?" When the child said, "No" and shook his head, the adult pointed to the rotated triangle and asked, "What [shape] is it now?" The child remained silent. The adult asked, "Do you think this is a circle?" or "Do you think this is a square?" The child responded, "No" to both questions. The adult repeated the first question, "Do you think this is a triangle?" The child again said, "No." Then, the adult asked, "Do you think it's a rectangle?" The child responded, "No." The video clip paused, and the narrator explained that the child might be confused because the rotated right triangle no longer matches the image of what a triangle looks like in the child's mind. The narrator explained that for adults to

understand what a child really thinks about a triangle they would have to ask specific questions about the shape.

The *Shape* video demonstrated how a child might have difficulty naming a shape when it does not match the prototypical image of that shape the child has visualized. Parents, caregivers, and teachers who are aware of children's misconceptions can engage in preventative measures by exploring non-prototypical shapes in picture books and toys or by focusing on shape properties and not just shape names. Adults can focus children's attention on the properties of any shape, not just its name or how it looks. Children can practice drawing shapes and explore what happens when these shapes are rotated in different ways (see Figure 5 and Appendix C).

Patterns Magic Math Minute Video

Patterns are arrangements of objects, numbers, or text that repeat in a systematic and logical way. Recognizing repeating patterns enables children to make predictions based on observations. Understanding patterns can prepare children for learning complex number concepts and mathematical operations like addition, subtraction, multiplication, division, and grouping.

However, during interactions, a child may misinterpret an adult's question about the repeating pattern. The video clip shows an adult reading a pattern picture book with a young English language learner. This video shows the importance of exploring the differences between the ways an adult poses a question and how a child might interpret or respond to that question, especially if the child is learning a new language. The video also shows how children may express their understanding about what comes next within a sequence, or make logical connections based on words and images. Making predictions helps children refine their reasoning as they start to understand mathematical relationships and identify patterns. To understand what a child knows about math, adults may need to repeat the same question or vary the phrasing of the question until the child understands.

The *Patterns* Magic Math Minute video began with the title, "Patterns in Picture Books," and focused on how a four-year-old English language learner responded to patterns in a picture book. The narrator stated, "Children love to read picture books with parents and teachers. Many picture books tell stories, but some picture books are about different topics like math." The narrator introduced *I See Patterns* by Linda Benton (1998) as a picture book about math. The viewer is then shown a video clip where an adult read to a child while pointing to the picture book. The adult instructed the child to describe the pattern in the book. From right-to-left, the child pointed to different colored blocks and accurately named the color pattern of "blue, green, red, blue, green, red, blue." As the child identified the colors, a spotlight in the video simultaneously highlighted the colors on the book's two-page spread.

The narrator asked the viewer, "What did you see the child do?" and explained, "The child described the pattern. He read the colors of the six blocks shown on the page from right-to-left, but then he said 'blue' for the seventh block even though only part of the seventh block was shown [on the page]. Did he say that because he saw part of the blue block? Or does he know how to continue the pattern?" The narrator returned to the adult reader in the video clip, urging the viewer to continue watching to find out what happened next.

The adult reader recited the pattern again from right-to-left, "blue, green, red, blue, green, red" and asked the child to predict what color should appear after the last red block. The child predicted, "blue," which is the next color in the sequence. The adult asked what block should come after that blue block, and the child repeated, "blue." The video clip paused, and the narrator offered two possible reasons for the child's response—the child did not understand how to continue the pattern, or the child did not understand the adult's question. The video explored these two possibilities by showing what happened when the adult covered a different pattern in the picture book. The adult recited the pattern, "gold, brown, gold, brown, gold, brown," and with her hand, she covered the last two objects in the pattern and asked the child to predict the next two colors. The child accurately predicted the colors in the pattern and said, "gold and brown." The adult uncovered the colors to show the child's predictions were accurate. The adult asked the child,

FIGURE 6. Patterns Magic Math Minute Video: On the left, the adult showed the child the patterns in the book. The child was asked questions about patterns. https://media.dlib.indiana.edu/media_objects/vq2805272

"Is that a pattern?" and the child nodded in agreement (see Figure 6 and Appendix D). Although not depicted in this adult-child interaction, the adult could have checked the child's understanding by asking, "How did you know it was a pattern?" The narrator concluded the video by recommending *Pattern Fish* by Trudy Harris (2000) as another book for adults to read to children.

Goldilocks Magic Math Minute Video

The *Goldilocks* Magic Math Minute video, a dual-language video, began with the title, "Finding the Math in a Picture Book," and focused on how an adult read and described math topics in *Goldilocks and the Three Bears* to a child. Spanish is spoken during the interaction, and English subtitles are provided to translate. The video allowed the viewer to see how a (digital) storybook, not explicitly about math, can be used to explore math concepts about size and quantity. The video also demonstrated the universality of math conversations between a child and an adult in any home language.

FIGURE 7. Goldilocks Magic Math Minute Video: The adult showed a page from the story *Goldilocks* and asked, "Which chair is the smallest?" ("¿Cuál es la silla que está más chiquita?"). https://media.dlib.indiana.edu/media_objects/hq37w616v

In the video, the narrator stated, "Children enjoy reading picture books, and they can learn a lot from them. Let's think about a classic fairytale like *Goldilocks and the Three Bears*." The narrator continued, "What do you think a child can learn from reading this story?" The narrator then described reading and literacy as common concepts to learn from *Goldilocks* in addition to math topics. The viewer is then shown a video clip of an adult reading the *Goldilocks* story to a child. The adult reader in the video clip asked the child, "¿Cuál es la silla que está más chiquita?" (Which chair is the smallest?), then "¿Cuál es la silla que está más grande?" (Which chair is the biggest?), and finally "¿Cuál es la silla que está mediana?" (Which chair is medium-sized?). In all cases, the child accurately identified the smallest, biggest, and medium-sized chair by pointing to the corresponding chair in the book. The adult then asked the child, "¿Cuántas sillas son?" (How many chairs are there?). The child responded, "Tres," (Three) and held up three fingers. The adult acknowledged the child's accuracy both nonverbally (i.e., nodding her head) and verbally by enthusiastically repeating the word "¡Tres!" (Three!).

The narrator stated that there were several math concepts on one page of the *Goldilocks* book and explained two concepts in detail. "First, the child was asked about the sizes of the chairs." The narrator continued, "Next, the child was asked for the number of chairs." The narrator explained that question-answer interactions between the adult and child did not distract from the story. The reader used the questions about size and quantity to further engage the child in the images of the book. The child looked visibly excited as the adult asked these questions and the child quickly identified the accurate response to each question (see Figure 7 and Appendix E).

At the end of the video, the narrator suggested *The Story of the Three Little Pigs* as another popular fairytale story where adults can use math concepts to enhance the reading experience. For example, adults can ask a child to count the three little houses or three little pigs, compare the size differences between the wolf and pigs, or describe the features and shapes used to build the houses.

MAGIC MATH MINUTE VIDEO CONSTRAINTS AND CHALLENGES

We used clips from archived videos and kept the final Magic Math Minute videos to less than three minutes in length. We found that weaving together the featured video clips, annotations, images, and narrations was time-consuming. We also grappled with creating high quality and consistent video format for both the video narration and the selected video archive clip, without losing crucial math content. For example, we wanted the screen format, and color-scheme layout to enhance the viewers' experience and not detract from it. Our design decisions resulted in two primary design constraints and two challenges.

Time Constraints

To avoid competing with the busy schedules of parents, caregivers, and teachers, we decided to keep each video less than three minutes. We had originally discussed creating one-minute Magic Math Minute videos, but rejected that idea since that was too brief. Due to our self-imposed time constraint, we were limited in our ability to delve deeper into mathematical topics, and some of the videos did not

include the child's full response to the math problem. The shortened video clips also meant viewers lost the incremental steps leading the child to the final answer. We grappled with balancing the child's experience with the math and the narrator's explanations. The narrator often had to fill-in-the-gaps for the viewer.

We consulted researchers at DREME (Development and Research in Early Math Education) for insights on whether the videos conveyed important and clear information, despite their brevity. Since its inception in 2014, the DREME Network has sought to improve preschool children's opportunities by advancing early mathematics research and resources. Network members and affiliates conduct research to develop tools designed to address early math topics.

During our design process, we wanted to provide adults with family-friendly resources to inspire their understanding of early math learning. The URL address for the DREME Network website was placed at the end of each Magic Math Minute video: "For more information on children's math, go to: https://dreme.stanford.edu." The DREME website includes resources about early childhood math that align with the main content in our videos. The website also contains related resources such as reading guides for math picture books and support for math teachers. Individuals can view our Magic Math Minute videos on the DREME website.

Video Clip Constraints

The video clips we featured in the Magic Math Minute series were collected from various projects and were part of a digital video archive. We chose to use these archived videos because we had obtained video release forms to use them for research, publication, and educational purposes, they were relevant for our project goals, and they were easily accessible and could be adapted to serve our design purposes (see Figure 8).

The video clips pulled from the digital archives were recorded in school classrooms, libraries, or in family homes where access to professional video production and lighting equipment was typically scarce. For this reason, the video clips featured in the Magic Math Minute series often had an informal, documentary, or *cinema verité* feel to them. We decided that the informality of the video clips made the overall experience of the Magic Math Minute accessible to viewers because the adults and children in the video clips were not paid, actors, or professional models. Instead, they were ordinary people in natural settings learning and engaging in mathematics topics.

FIGURE 8. A screen capture example of a video clip from the archives. This video was originally recorded in 1987.

Audio-Video Quality Challenges

The archived clips included different audio and video quality levels. Viewers could easily detect these audio and video differences because the archived video clips' audio was often less clear than the narrator in the Magic Math Minute video compilation. In fact, in the *Shapes* Magic Math Minute video, the narrator stated, "It was a little hard to hear, but the child said it was a triangle," after the child in the video clip quietly said, "triangle." At times, the video clips featured in the Magic Math Minute compilations contained background noises common in school settings (e.g., students chatting, furniture moving, etc.). These external noises could be distracting especially if viewers expected high-quality video and audio.

Additionally, the adult and child were often recorded from the side, making it difficult for viewers to clearly observe their facial expressions or other nonverbal cues. The children in the videos might even turn their back or shoulder to the camera as they gestured or responded to the adult. For example, in the *Goldilocks* Magic Math Minute, the video clip was recorded in a family home, and the adult angled the electronic book to face the child, not the viewer. For these reasons, the viewer had only a sideways view of the book.

Despite these audio and video challenges, we continued to use the video clips because they were rich with meaningful and insightful adult and child interactions. We made accommodations whenever possible to repeat phrases heard in the clips, or use annotations, subtitles, or images to ease the audio and video challenges. We decided to tailor the script for each individual video clip and guide the viewer through the child's experiences of math knowledge in the most direct and concise way possible, even if that meant we lost some of the incremental steps the child took along the way.

Video Clip, Image, Annotation, and Narration Compilation Challenges

The Magic Math Minute video design was exploratory, which contributed to inconsistencies in our video designs across all five Magic Math Minute videos. For example, the videos all had different color palettes, and the images were not always centered on the screen. We weighed several factors like, "Should we include a thought-bubble here?" or "Should we bold the text there?" or "How do we write a concise and conversational script to transition between math topics?"

These design questions led us to experiment with the layout, rather than create one pattern for all the videos in the Magic Math Minute series.

We later consulted a videographer to develop style guidelines to reinforce consistency that matched the DREME color scheme as we referenced their website at the end of each video. The videographer hosted training sessions with our primary editor on how to best use Camtasia.

We also wanted to engage viewers with the featured video clip, image, annotation, and narration in a logical sequence, all in less than three minutes. This meant that we transitioned between concepts quickly as we experimented with the narration recording and image displays. These transitions and explorations could pose a challenge for viewers unfamiliar with children's early math learning because the information may be too hurried or seem disjointed.

VIDEO EVALUATION AND DESIGN ADJUSTMENTS

We evaluated our Magic Math Minute videos by seeking feedback from early childhood professionals associated with the DREME Network. DREME members, including teachers, scholars, and experts in preschool mathematics education, offered insights into the math terms we used within the Magic Math Minute videos. Their insights resulted in the following video, and design changes, (1) streamlined math descriptions, (2) topic preview, and (3) tailored content with examples.

Asking early childhood education professionals to review math videos introduced changes we had considered but did not know how to best apply. For example, we wanted concise video narration, but not at the risk of causing information gaps. The early childhood professionals suggested we provide viewers with concise descriptions of the concepts we planned to present in each video and offered phrases they perceived would best fit our target population. For example, our definition of spatial relations in our original video was, "Knowing where one object is in relation to another." After feedback from one professional, we defined spatial relations in our revised Magic Math Minute video as, "Knowing where one object is in relation to yourself and in relation to other objects."

DREME members suggested we prepare viewers for the math concepts on the video (e.g., "There are two concepts to consider") or streamline the content to focus on one math concept at a time within each video. Early versions of the narration included the terms "prototypical triangle." Reviewers suggested we avoid educational jargon and simply state, "This shape looks like a triangle," and elaborate on why an equilateral triangle turned in a typical way might look like a triangle to a child and why when rotated might confuse a child.

DREME members suggested we offer adults strategies to try. We added statements like, "Here's something you can try" followed by a math strategy at the end of each video. The targeted feedback we received from DREME members proved essential as we refined the math content in the videos.

After receiving feedback, we identified points where we could improve the video narration. For example, we added verbal pauses, adjusted the script to make it sound conversational in tone, and paced the phrases to avoid sounding rushed.

DREME associates also offered feedback on how to tailor the video content for a general audience and not just math teachers or experts. For example, adults without an early math learning background may find the child's responses in some of the videos bewildering, as they may assume all young children have a similar baseline knowledge of mathematics. In response to the feedback, we decided to prompt adults to assess the children's understanding and specifically highlight instances when the child offered an unexpected response to the math task. With feedback from DREME, and the revised definition of terms, we felt better prepared to inform adult viewers about the math content in each Magic Math Minute video and foreshadow what they might observe from the child featured in the video.

Online Evaluation Studies with Adult Participants

Based on the feedback from DREME professionals, we prepared the videos for three independent online evaluation studies to examine how adults responded to the five Magic Math Minute videos. For these studies, we did not target math educators, but adults who had some familiarity with early childhood learning. While we could not control who clicked on our online study link, our recruitment materials asked for adults familiar with preschool learning or preschool children's storybooks, or adults who had experience interacting with a preschool child. We explained the purpose of the study, as shown in Figure 9. Participants were recruited online from Amazon's Mechanical Turk (Mturk) and received a nominal fee ($0.20) for their participation (for a description of Mechanical Turk participant pools, see Paolacci et al. 2010).

In addition to a video design assessment, the study would help us determine if we should continue to invest expertise, time, resources, and effort in future designs. We wanted to determine if viewers found the videos useful, informative, and interesting, which parts worked well, and which components needed adjustment.

For the first study, we evaluated the *Operations* and *Patterns* videos. Then, we evaluated the *Goldilocks* and *Spatial*

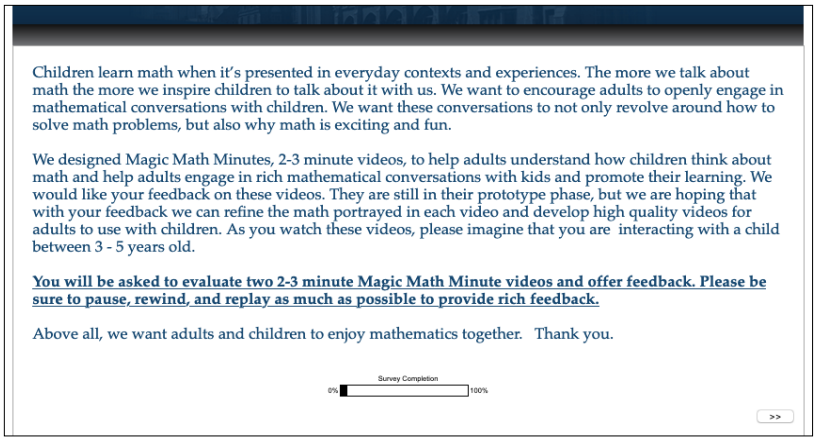

FIGURE 9. A screen capture example of the introduction for the online evaluation study of the Magic Math Minute videos.

Relations videos. Lastly, for the third study, we evaluated the *Shapes* video. We evaluated the videos in this order based on which videos were edited and finalized for further evaluation in an online format.

A total of 140 adults participated in these three online studies and completed our surveys until the end (93 females and 47 males). In the demographic survey, we asked, "Are you a parent, teacher, both a parent and teacher, or neither?" The demographic survey showed there were 60% parents, 2% teachers, and 13% both parents and teachers for study one (n =47); 68% parents for study two (n=47); and 50% parents for study three (n=46). While all participants provided qualitative feedback, seven participants provided brief or vague comments. The remaining 133 participants provided more substantive comments similar to the type of feedback we received when discussing our educational materials with adults in focus groups and interviews.

Participants evaluated each Magic Math Minute video by responding to the following general statements using a 4-point Likert scale (1=strongly agree to 4= strongly disagree). Study participants were asked to gauge if the Magic Math Minute videos were well designed (e.g., "The goal of the video was clear," "The video was easy to understand," "The video was interesting," etc.). Open-ended questions in the survey included, "Did anything about this video surprise you?", "What do you think is the most important or interesting thing you learned from this video?", and "Can you make any suggestions for improving this video?"

We coded the qualitative responses to the survey questions by grouping them into these categories: (1) what aspect of the Magic Math Minute surprised the viewer, (2) what the viewer thought was important, and (3) viewers' suggestions for video improvements. We then looked for emergent and recurring themes from participant responses for each Magic Math Minute study.

Across all three online studies, most participants were satisfied with the Magic Math Minute videos. Specifically, most of the participants agreed that the videos had a clear goal, and the explanation about how children think about mathematics was easy to understand. We will primarily focus on the open-ended qualitative responses from study participants as they provided insights into how viewers responded to the video design. We emphasize responses related to design considerations, questions, or insights.

Online Evaluation Studies: Did Anything Surprise You

We created Magic Math Minute videos of individual children engaged in a mathematical task to bolster adults' understanding of early math development. We intended to show a child's epiphany, surprise, or an exciting math explanation within the video clip. We wanted to gauge if viewers were surprised by any part in the video, what they thought was important, and to better understand their assumptions about young learners. We believed these insights would support our design efforts for future video creation.

Did anything about the videos surprise you

We predicted adults would express surprise about children's problem-solving strategies. For example, in the *Operations* Magic Math Minute video, some adults were surprised at how the young girl solved the problem mentally and how the adult in the video responded to the child's mistake. One study participant stated, "I was surprised that the child was able to mentally visualize the carrots and try to add them that way," and one participant was "…surprised that they didn't just correct the girl, they had her talk out her solution, so she came to the correct solution on her own."

We also predicted adults would express surprise about a child's inability to solve a problem, as adults may find the solution obvious. For example, one participant stated, "I was surprised that the child could not identify that the shape was still a triangle after she turned the shape to a different angle" and "I was surprised that the child's perception of the triangle changed simply [by] turning it upside down."

Some adults were surprised by the videos in ways we did not predict. For example, one participant responded with surprise to a teaching technique in the *Patterns* video. "How just covering up helped with the pattern. The child didn't really know the pattern at first." The participants' response demonstrates how simple actions (e.g., covering up a part of the page in the book) can support a child's understanding.

Participants expressed surprise that a young child could interact with math concepts in complex ways. For example, in the *Patterns* video one participant stated, "I thought the kid might be a little young for patterns." In the *Spatial Relations* video, a participant stated, "I thought of geometry as more math when a child is way older with shapes, not at this age." We were intrigued by these responses as adults may avoid challenging a young learner's math knowledge and choose to limit their exposure to elevated math topics.

Adult participants' expression of surprise offered inspiration for us to further investigate how adults might respond to the videos and what parts of a child's math knowledge is most surprising or interesting to them. This information could guide us in our math topic selection and presentation of future videos.

Online Evaluation Studies: Most Important

When asked, "What do you think is the most important or interesting thing you learned from this video?" study participants shared insights into early math topics and questioned personal presumptions about young learners.

Most important or interesting thing you learned from the videos

"The most interesting thing to learn is that a child can find other ways to solve a problem," stated one participant. Another said, "Kids can reason abstractly; they just need a little help to start making connections on their own." This expression was common throughout all three online studies and shows that some adults view math as an accessible domain for young learners. Adults were also interested in how they can best help children learn mathematics. For example, adults commented on the importance of helping "… the child without correcting the child," and ways to help like, "using a little story influenced how the girl got the answer."

Assumptions about young learners

The videos also challenged adults' presumptions of early math learning. For example, one adult stated, "I should not presume to know what a child will find interesting, based on my own frustration with the subject area." In response to the *Patterns* video one person found the child's behavior interesting and stated, "How quickly he picked up on the patterns without being led." For the *Spatial Relations* Magic Math Minute video, one participant stated, "… I was surprised to learn that spatial relations could be found and used as examples in simple things."

Another common theme from the evaluation studies focused on mistake-recovery and self-discovery. Some adults expressed newfound awareness of the value of mistake making and incremental learning. For example, one participant stated, "Let kids make mistakes; then have them explain their reasoning. They might find their own mistakes that way." Other adults reinforced the importance of a child's individual math discovery, "I liked how the adult asked the child what she was thinking about before she gave her answer." One adult stated, "Complex thinking isn't developed instantly, but should be learned over time." Another adult described adult-child interaction this way, "The child [in the video] reminds me of my 5-year-old. I will have to encourage them not to give up."

Participants' comments conveyed the importance of challenging adult's presumptions about early math learning. If adults dislike a math domain or believe a child cannot learn a challenging math concept, they may avoid the topic altogether. This avoidance may delay children's mathematical understanding and impact their long-term learning. These comments also offered insights into the importance of showing adults how children persist past mistakes towards the final answer.

Online Evaluation Studies: Suggestions for Improving the Videos

Participants were asked, "Can you make any suggestions for improving this video?" Their responses repeated the need for improved video and audio quality, including volume, narrative pacing, image formatting, and design layout. For example, one participant stated, "I think a higher quality video would enhance the learning experience for the viewer." Another participant stated, "Better microphones/some noise-canceling for clearer/better sounding audio" would improve their experience with the video. Participants also suggested we increase the video length and offer more examples for the viewer, "…you can make it a little longer and also let the child interact more with the story." Based on the comments from adults, we plan to further improve the video and audio quality and reconsider the video length.

Another common suggestion for improving the videos was to emphasize the importance of math concepts a young learner needed to know. For example, one respondent commented, "Children need to know why the shape is a triangle so that they can tell it is still a triangle when it is upside down or sideways." Instead of asking children to simply identify shapes, this comment to the *Shapes* Magic Math Minute video suggests that viewers considered ways to challenge children to think about the characteristics that define these shapes. One adult stated, "Kids can reason abstractly; they just need a little help to start making connections on their own," and another stated, "…you have to keep asking questions to get answers to those questions about how [the] child thinks." Participants also commented on the need to understand why engaging in math activities is beneficial for young children. For example, one participant said, "I didn't really understand WHY it's important to engage in this type of exercise. What skill is actually developed?" Adults expressed

interest in understanding how a child learned math and ways to challenge a young learner's thinking. Based on these responses, we realized we needed to make explicit links to show why a child should learn a specific math skill and how that knowledge would apply to the child's future learning and development.

Exposing adults to the way children think about mathematics can inspire them to reflect upon their own adult-child interactions as they facilitate children's understanding of foundational math concepts. We will consider explicit ways to show why early math learning skills are important for children and suggest activities, like storytelling, to support math skill development.

Overall, participants' feedback highlights the potential of our videos to encourage adults to engage in meaningful interactions with their children or students. For example, one adult stated, "I learned that I need to be asking more mathematically engaging questions instead of just judging literacy while reading to my Kindergartener." These evaluation study findings suggest that adults thought about the importance of asking a variety of questions to assess children's math knowledge after watching the Magic Math Minute videos. However, they may need further clarification on why early math learning is important.

Video Design Adjustments

We plan to make four primary design adjustments to our future Magic Math Minute videos: (1) improved video and audio quality, (2) video length, (3) design consistency, and (4) engaging adults and children in math conversations.

Video and audio quality

The clip archives we accessed to create the Magic Math Minute videos spanned decades. The visual and audio quality of these videos showed their age. However, their uniqueness and educational value warrants their use in future Magic Math Minute video compilations. We aim to compensate for any technological variations in the video clips by reinforcing a clear and consistent narration.

While we cannot re-create the exact moments from the archived video clips, we do plan to record new adult and child interactions using similar math topics and approaches. We plan to record the new videos using higher-quality audio and video cameras and setting up external bidirectional microphones to more fully capture the communication exchanged between the adult and child. We still plan to use natural settings and non-actors for our video clips because the interactions are spontaneous and authentic.

Video length

We plan to make one short and one long version of some videos to show different math skill levels or different ways to approach the same math topic. The short videos will maintain the Magic Math Minute design parameters and remain under three minutes in length. We plan to design a second, longer video version (up to 10 minutes), named Magic Math Story, to include deeper descriptions about children's math portrayed in the video. These longer videos may include more than one child or clips of the same child at different ages. By varying the video length, we can show how children develop math skills through a range of easy and difficult to solve math problems and elaborate on the reasons why it is important for adults to engage children in early math learning. We believe the shorter video version provides a concise and informative view of how children think and discuss math. The longer videos can offer adults further insights and detailed information.

Design consistency

In future iterations, we plan to streamline our design and create a design template with similar font types and sizes, a consistent color scheme, and format. Because of our ongoing professional relationship with the DREME network, we plan to match our Magic Math Minute videos with the color palettes, fonts, and designs specified in their video style guidelines. We are currently revising the Magic Math Minute videos for the DREME website. We hope the consistent design templates and pre-selected color palettes will make the videos more alike and easier to follow. The templates will also help decrease the time we spend on the design format and allow us to focus on the design quality and video compilation.

Engaging adults and children in math conversations

Adults may need guidance in inspiring children to explore mathematics in everyday interactions. The Magic Math Minute videos are designed to promote adult-child interactions and to show how preschool children are capable of insightful mathematical thinking. Future videos will further demonstrate ways to make mathematical conversations simple. For example, an adult can discuss basic addition problems with a child using prompts such as, "I wonder how you know this is a triangle…" or "What do you think will happen if…" or "Can you guess what will happen next?"

As with most conversations, there is a turn-taking process, not a rapid-fire question and answer succession. For young learners, conversations may take a slower pace as they work out an answer to a problem on their own. Future videos will focus on ways adults can encourage the child to think about problems and work out an answer independently.

While participants in our evaluation studies did not express difficultly understanding what was happening in the video, it may be helpful to explain how and why it is important to develop children's pattern detection and the diverse approaches children might take to solving a math problem. Children

may grasp (and enjoy) certain math concepts more easily than others. We want to convey to adults the variation of children's math abilities and skills. We want the next phase of videos to further demonstrate how young learners adapt to challenging math tasks and engage in diverse math domains. Future Magic Math Minute videos will include ways for adults to engage in math conversations using new topics like measurement, size, and weight.

Revised Magic Math Minute Video: After Expert Feedback and the Evaluation Studies

To address feedback from design evaluations and add new ideas generated by our own experiences with the videos, we recently redesigned the *Goldilocks* Magic Math Minute video (see Figure 10) in three ways: (1) standardized design guide, (2) consistent style, and (3) replaced or revised content.

FIGURE 10. Redesigned Math Concepts in the Goldilocks Magic Math Minute Video after expert feedback and the evaluation studies. https://media.dlib.indiana.edu/media_objects/bv73cg99n

Originally, we used Camtasia's default setting (e.g., Montserrat font and black background) for our videos. We later created a standardized style guide for the layout, images, and video clips. In our guide, we used Arial font, a DREME color palette, and a blue background for all videos.

We improved the style and consistency of our videos and avoided sudden or undefined transitions for the animations. For example, instead of a thought cloud suddenly appearing on the screen, we now fade it into view at a slower and smoother pace.

We replaced the book cover image with a cartoon image of *Goldilocks and the Three Bears*. We made this decision because the book cover on display was different from the book cover the adult read to the child. We replaced this narration, "There were *a lot* of math concepts just on that one page" with, "The reader pointed out *two* math concepts just on that one page" to quantify the actions in the video.

We revised the translations in the *Goldilocks* video. Originally, we included English translations of some Spanish words or phrases. Now, the video includes full sentence English translations.

We intend to test the use of Magic Math Minute videos in parent or caregiver workshops and teacher preparation programs. We will also analyze the effectiveness of delivering digital content on various platforms (e.g., social media or mobile-based applications) and study whether the inclusion of short, informational videos is sufficient to produce intervention effects on the ways adults interact with children.

In future evaluation studies (online and in-person), we will limit our participant recruitment to parents, caregivers, and teachers of preschool children.

CONCLUSION

Design guided by evidence-based research and pilot-testing is critical in creating the optimal user experience. We applied the information we gained from researching our design into actionable improvements to it. We believe there is always something new to learn about how individuals engage with our materials, what problems they face, and how we can best support them through the designs we create.

The Magic Math Minutes video design can foster adults' knowledge of early learning and justifies further research in the use of videos in early intervention or family and teacher learning programs.

Magic Math Minute videos feature adults and children engaging in math topics. They could be used to support parents', caregivers', and teachers' understanding of early math learning. We traced our design creation process, the video content we created, and discussed constraints, challenges, and implementation experiences that shaped the design adjustments. We discussed how we based these revisions on expert feedback and responses from participants in three evaluation studies. We plan to further investigate how videos impact adult and child interactions, enhancing the opportunities to promote early mathematical development in the classroom and at home.

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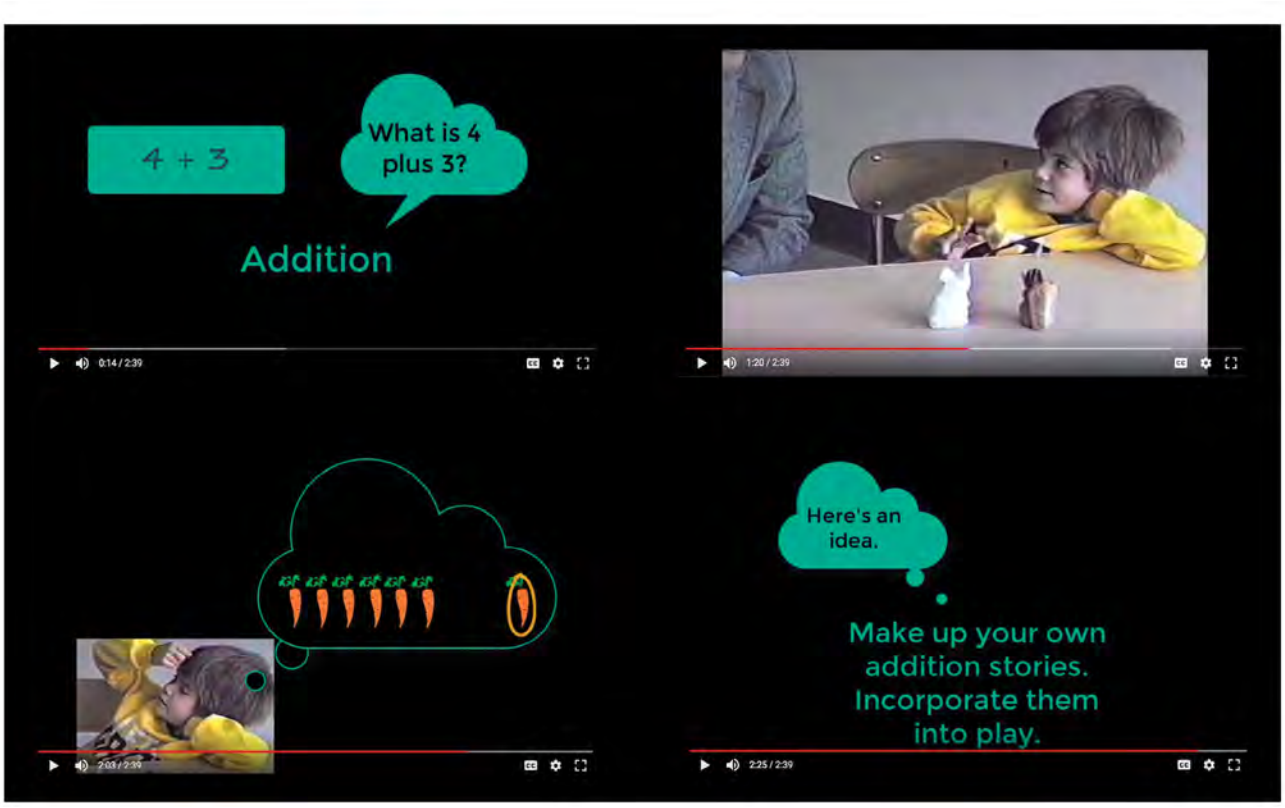
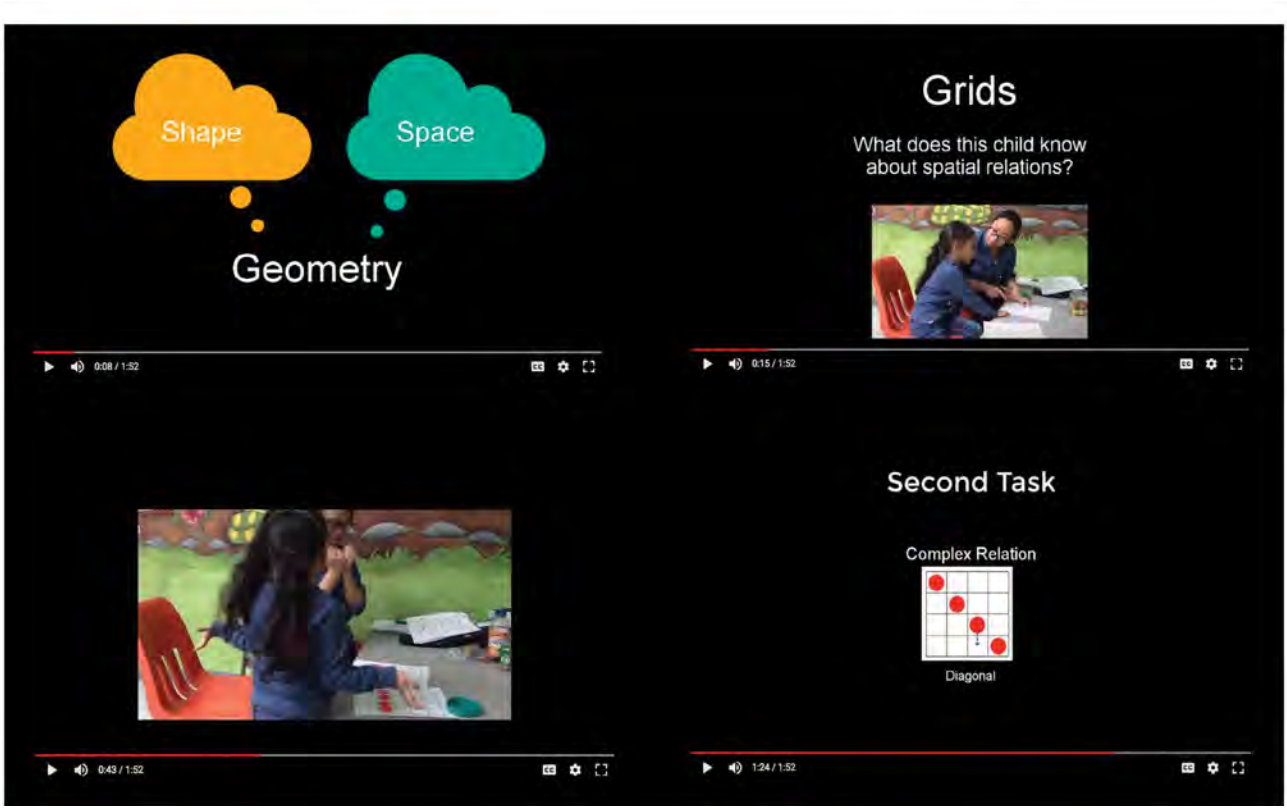
APPENDIX A

Screen Capture Images from the *Operations* Magic Math Minute Video



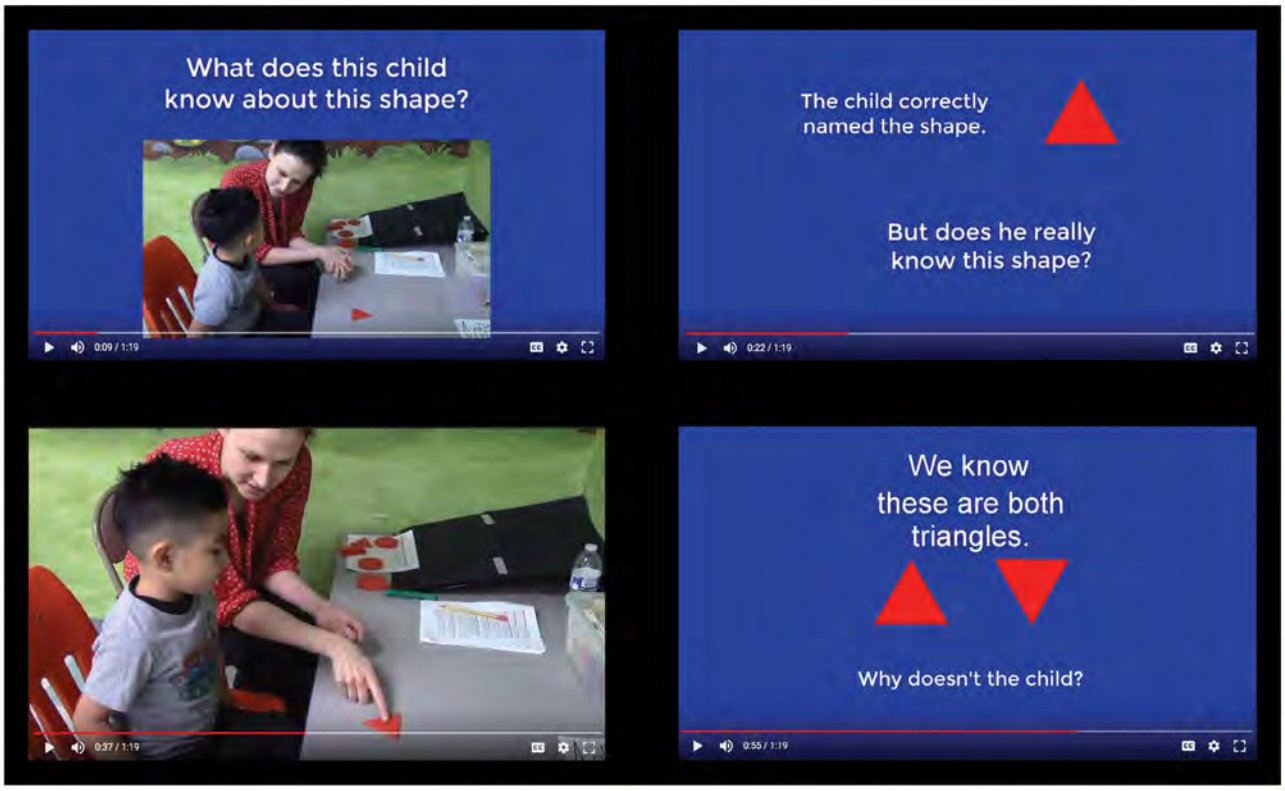
APPENDIX B

Screen Capture Images from the *Spatial Relations* Magic Math Minute Video



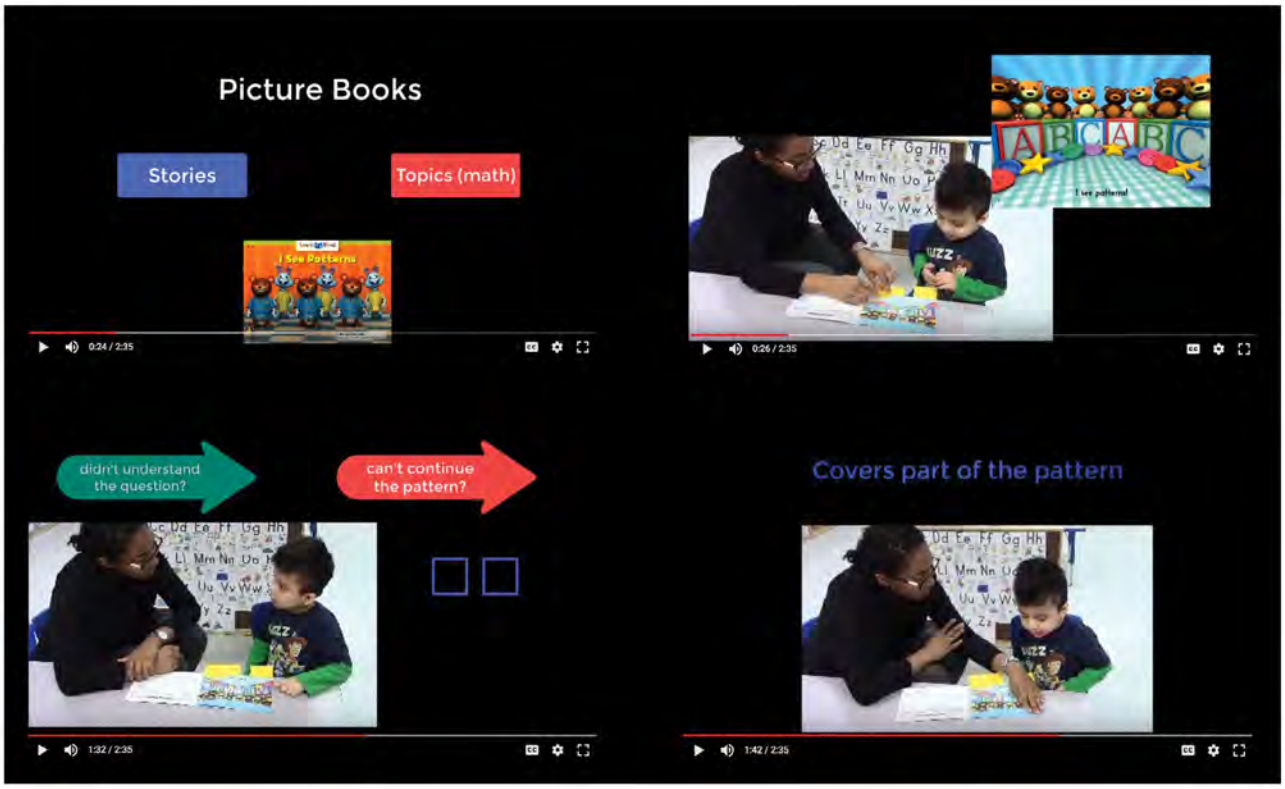
APPENDIX C

Screen Capture Images from the *Shapes* Magic Math Minute Video



APPENDIX D

Screen Capture Images from the *Patterns* Magic Math Minute Video



APPENDIX E

Screen Capture Images from the Storybook *Goldilocks* Magic Math Minute Video