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Mathematical Mindset?

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Submitted on May 10, 2017 in fulfillment of final requirements for the MAED degree

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St. Paul, Minnesota

Advisor ________________________________                       Date _________________
Abstract

The purpose of this study was to determine the impact of the YouCubed math program on upper elementary Montessori students’ mathematical mindset and accurate recall of fact families. Students watched YouCubed videos about recent neuroscience research on the positive effects of attitude, challenges, mistakes and visualizing math. Following the video, students summarized what they learned then worked on number sense activities recommended by the program. Throughout the week, students practiced fact families using Standard Celeration Charts to graph results of one minute timings. An attitudinal scale was administered to examine the program's potential effect on students’ mathematical mindset. This research found students had a growth mathematical mindset before the intervention with some improvement and recall of fact families was not greatly impacted by the YouCubed program. Students’ confidence in their math skills increased to take on challenges.

*Keywords*: mathematical mindset, math facts, YouCubed math program
How many times do people say, “I am no good at math”? People who think this way have a fixed mathematical mindset. Everyone has perceptions about their ability to learn math. Recent research identified two different mindsets children could have regarding their math abilities. Students with a growth mindset believed they could work to improve their performance. However, students with a fixed mindset believed math ability was inherent and achievement out of their control. This belief placed students with a fixed mindset at a disadvantage (Boaler, 2016d; Dweck, 2008; Langford, 2016). Fixed mindsets emerged when students were intimidated by tasks or scored poorly on math tests. Faced with setbacks, many students believed they did not have the ability to overcome these challenges; these students believed effort only benefited those with an innate ability. Challenges and mistakes overwhelmed and threatened children who had a fixed mindset (Dweck, 2008; Langford, 2016). Teachers and parents who offered praise for intellect rather than effort made children reluctant to persevere and face their challenges; instead, they chose to give up. Teachers encouraged a growth mindset by helping students realize the power of effort and to see as mistakes opportunities for growth (Boaler, 2016b; Dweck, 2008).

Over the years, I watched elementary students struggle with math. Students became frustrated with the time it took to calculate a given problem or the difficulty they had with processes such as determining Greatest Common Factors, Least Common Multiples, and reducing fractions; all required the accurate recall of math facts. During upper and lower elementary team meetings we discussed our students’ lack of math fact automaticity and higher level mathematical thinking skills. We agreed to use our Math Talk sessions to focus on problem solving skills and learning to communicate
mathematical reasoning. Students would work in small groups on tasks presented by the teachers. The elementary teachers also agreed to make a concerted effort to improve students’ recall of math facts. This action research project is a result of the team’s discussion. I believe the accurate recall of math facts is foundational for mathematical applications and impacts students’ mathematical mindset. I want my students to have a positive relationship with math and see it as both creative and challenging using strategies and patterns to help them with math fact accuracy.

The action research project site is a private school that serves 220 children from birth through fifteen years. It draws families from a variety of socio-economic levels ranging from professional families paying full tuition to those who qualify for full scholarship. My classroom consists of eighteen upper elementary students with eight fourth years, eight fifth years, and two sixth years. I have ten boys and eight girls. Two of my students have Individual Education Plans (IEP), three work with the school’s reading specialist, and three work with the speech therapist. One of the IEP students has anxiety issues and is being assessed for an emotional disability.

I consider important aspects of my action research project to be the insights I gained as a math teacher and my recent paradigm shift in seeing math’s patterns and creativity; this was fostered by activities the YouCubed program suggested. Students watched short YouCubed videos on current brain research hosted by Jo Boaler, a Stanford University mathematics professor and co-creator of the YouCubed math program. After each video, students participated in an activity that challenged them to open their minds to math and showed them that perseverance pays off. With my action research, I was curious to find out if implementing the YouCube math program twice a
week would improve my upper elementary students’ ability to recall math facts and improve their mathematical mindset.

**Review of Literature**

Great mathematicians are people who dedicate themselves to the practice and improvement of their craft (Boaler, 2016b; Dweck, 2008; Langford, 2016); likewise, researchers found students with a growth mindset used reasoning and problem-solving skills to accomplish a task. They had an interest in learning and a belief in the power of effort. These students employed positive strategies to work through challenges (Boaler, 2016b; Dweck, 2008). When praised for their effort and problem-solving skills, students gained confidence in themselves as mathematicians (Boaler, 2016b).

Over the last few decades, parents and educators have tried to build students’ self-esteem through praise. Praise offered for intelligence rather than effort gave children the impression their math ability was fixed. Students were reluctant to challenge themselves and afraid to take risks for fear of failure. In some cases, students had the idea not everyone was mathematically inclined and thought it was okay to give up. Students accustomed to coasting through school with little effort and a lot of praise opted out of situations that made them feel uncomfortable. As teachers and parents know, pushing through difficulty and embracing mistakes are opportunities for growth and should be encouraged (Boaler, 2016b; Dweck, 2008). When students were asked to rate beliefs about their intellectual ability 40% agreed with the fixed mindset, 40% held to the growth mindset, and 20% did not answer consistently enough to measure (Dweck, 2008).

In 2013, a study by Ramirez, Gunderson, Levine, and Beilock explored the relationship between math anxiety and math achievement with 154 first and second-grade
children. They found when under stress the working memory becomes blocked and students were unable to recall math facts. The stress of the timed tests caused approximately one-third of the children to have anxiety (Ramirez, Gunderson, Levine, & Beilock, 2012). This negative impression affected students’ math skills, academic success, and career choices. Teachers and researchers have been aware of math anxiety since the 1950’s and definitions include physical, emotional, and cognitive reactions (Ruff & Boes, 2014). Elementary math curriculums emphasizing memorization and computational skills over the conceptual understanding of math placed students at risk for math anxiety; an alternative would be classrooms that included group work, collaboration and real-life applications (Boaler, 2016b; Ruff & Boes, 2014).

Women and minorities showed tendencies toward a fixed mindset resulting in underachievement in math and science; negative stereotypes contributed to fixed mindsets. The belief that boys do better in math was observed when teachers offered them more strategies for improvement over girls (Ruff & Boes, 2014). Girls had a tendency for deeper understanding through collaboration, hands-on learning, and real-life applications that were typically unavailable in math classes. Assumptions regarding inherent math ability led to girls’ poor achievement (Boaler, 2016b; Dweck 2008). Contrary to this belief, Japanese parents and teachers place emphasis on effort rather than ability; one result credited to this emphasis is that Japan has the highest percentage of female university graduates in mathematics and computer science according to data collected from thirty countries by UNESCO, OECD, and Eurostat in 2004 (Dweck, 2008). Minorities were also influenced by negative stereotypes according to a 2011 study.
by Gillen-O’Neel, Ruble, & Fuligini. Self-doubt caused students to disengage from math; therefore, they suffered low achievement (Gillen-O'Neel, Ruble, & Fuligini, 2011).

Recent brain research supports the importance of mathematical mindset with numerous studies. Mosler’s brain study in 2011 found that challenges and mistakes made brains struggle, causing synapses to spark and the brain to grow. This brain activity was greater in students with a growth mindset because they had a greater awareness for when errors occurred than students with a fixed mindset (Boaler, 2016b; Moser, Schroder, Heeter, Moran, & Yu-Hao, 2011). In 2015, Chen and his team of researchers studied children aged seven to nine for intelligence, numerical problem-solving and math reasoning in word problems, reading ability, working memory, and math anxiety levels. They questioned the students about their competence in math and their feelings toward solving challenging math problems. The survey was done to identify their positive mindset levels in math. Researchers used noninvasive imaging to scan students’ brains and measured blood flow as they focused on a fixed point or checked the accuracy of addition problems. Results showed that the brains of students with a growth mindset worked more efficiently during math exercises than the brains of children with a fixed mindset. Results also showed faster, smoother connections, called upregulation, between the areas of the brain that quickly remember math facts and processes and the area for problem-solving. Students with a growth mindset had higher activation and upregulation resulting in better math performances (Chen, Bae, Battista, Evans, & Menon, 2015; Sparks, 2015).

The brain, analogous to a muscle, was made stronger with repeated exercise. Teachers helped improve mindsets when they informed students about their brains’
plasticity (Boaler, 2016b; Dweck, 2008). Learning environments sensitive to students’ learning styles and promoting the brain’s growth set students up for success. Teachers who presented new skills emphasized perseverance and cultivated new strategies that supported success (Boaler, 2016b; Dweck, 2008). Teachers with a fixed mindset restricted students with their pre-determined perceptions. Their attitudes and preconceived notions about students’ abilities influenced how they communicated to their students. According to Dweck (2008) teacher training programs could solve this dilemma by providing research depicting the brain’s plasticity and its ability to make new neuron connections leading to growth. Curricular material could help guide teachers in lessons with growth mindset as a framework and with suggestions on how to offer feedback.

Jo Boaler, Stanford University’s Professor of Mathematics Education and co-founder of the YouCubed math program, demonstrated the impact classrooms and relational equity had on the math department and students of Riverside High School, a low achieving, urban school. Boaler remarked on the positive change in attitude evident by the rise in seniors’ calculus scores. Boaler attributed this success to seven principles math teachers employed in promoting equity in the classroom. The first four dealt with complex instruction which utilized strategies for group work. This approach included multi-dimensional classrooms, student roles, assigning competence, and student responsibility. The last three were high expectations, effort over ability, and learning practices which contributed to the change in student attitudes toward math (Boaler, 2006).

The classrooms were considered multi-dimensional they were open to student questions, multi-leveled, and provided an environment with materials from across the
Students saw math as broad and interpretive. Students had roles such as facilitator or scribe which contributed to the functioning of their math group. The practice of assigning competence to a student by affirming a relevant and intellectual contribution to the group raised confidence especially when other students built upon the idea. Students were expected to help others with their learning; this was achieved through the assessment process. When a student couldn’t explain the answer to a question, the teacher would expect the group to assist the individual, so when asked later, the student could answer correctly. Students were to ask the right questions and to recognize when their answers were unreasonable. Boaler recognized Railside’s students for their respectful and equitable treatment of others not only in math classes but across classrooms and referred to this as relational equity. The teachers were building successful learning practices in their students. Teachers put into practice high expectations with an emphasis on effort over ability. The improvement and change in the mathematics department’s teaching practice fostered student insights, methods, and perspectives (Boaler, 2006).

In 2012, Boaler worked with the Program for International Student Assessment (PISA). PISA looked at math achievement data from 13 million students worldwide. The United States ranked a disappointing 36th out of 65 Organization for Economic Cooperation and Development (OECD) countries which called to attention to the need for reform in the teaching and learning of mathematics. Boaler’s associate noticed from the data collected that most high achieving math students had a growth mindset and found those with a fixed mindset scored at equivalents of one year and more behind those with a growth mindset. Fixed mindsets were not only observed in students who were low achievers but in some high-performing students as well. These students had high
expectations and were reluctant to risk the possibility of failure so avoided challenging themselves. Boaler was compelled to help students form a new relationship with math (Boaler, 2016b).

Using what she had learned from experience and research, Jo Boaler and her Stanford University team created an online math program called YouCubed at https://www.youcubed.org/ to revolutionize math (Boaler, 2016d). They provided teachers with 21st-century tools designed to engage students and help them reach their math potential. These lessons were based on the latest research in teaching and learning math. The YouCubed program was designed to foster a mathematical growth mindset and rid students of their stifling fear of failure which prohibited action, creativity, and invention. Teachers learned to use students’ conceptual mistakes to discuss their processing errors which helped them to analyze their work. When students realized mistakes were opportunities, they felt liberated (Boaler, 2016a; Boaler, 2016b; Boaler, 2015).

Math achievement should no longer be based on a student’s ability to answer problems quickly (Boaler, 2016a; Boaler, 2016d). The repeated drilling of math facts and overuse of timed tests caused math anxiety in students (Young, Wu, & Menon, 2012). The YouCubed program supported the acquisition of math facts through application instead of memorization (Boaler, 2016a). Students learned facts through number sense, understanding numbers, and seeing the relationship between them. Students had success when they used numbers flexibly meaning they knew what a number consisted of and combined them in different ways to find an answer. Students used strategies such as changing 6+9 to 5+10 to solve problems (Boaler et al., 2015). Using a multidimensional
approach to mathematics, students learned to work and think like mathematicians as they drew diagrams, applied strategies, communicated effectively, and connected ideas. In short, students learned the math needed for life, work, and success (Boaler, 2016a).

YouCubed provided teachers with the methodology, math tasks, videos, and ideas to help students see math as an interesting, open, and creative subject involving deep thinking. Teachers learned to use visuals, manipulatives, and multiple representations of numbers to enhance their students’ understanding of mathematical concepts. They implemented complex instruction to help students work in groups and talk about math to reason through and justify their answers. The tasks provided were accessible to all students and helped them reach high levels of learning (Boaler, 2016a).

YouCubed has met with great success in classrooms across the country. Of the teachers and students surveyed, 98% of the teachers said their students engaged during the lessons, and 96% of the students surveyed said they are not giving up when faced with challenges anymore. YouCubed opened teachers and students to a new way of thinking about math, and that can be world changing (Boaler, 2016a).

Mathematical mindset appealed to me as a topic for my action research because as a student I saw myself as someone who couldn’t do math; I had a fixed mindset. In my high school algebra and geometry classes, I wanted to understand what the formulas meant rather than memorize them. Later during my Montessori training, the math materials helped me to understand concepts and formulas for the first time. I have shared my story with students who struggle and tried to reassure them with, “we can do this together.” Self-reflection on how to teach math and ways to help students think critically continued throughout my action research. I chose Stanford University’s YouCubed math
program for my intervention because its short videos explained to students the recent brain research on growth mindset and provided activities that challenged students to look at math differently and to realize mistakes can be helpful. I felt the inclusion of math facts was important since over the years I had seen students struggle in areas such as fractions, factorization, and operations due to difficulty recalling math facts. As part of my data collection, students timed their recall of math facts in a set of three, one minute timings. Emphasis was on accuracy instead of speed. I realized students’ mindsets were jeopardized when speed placed undue stress on them. I wondered if the YouCubed math program influenced students in trying new strategies for learning math facts and if it influenced their mathematical mindsets.

**Description of Research Process**

The administration of an Attitudinal Scale before the intervention determined a baseline for the upper elementary students’ mathematical mindset (see Appendix A); students also practiced graphing with the Standard Celeration Charts (SCC) (see Appendix B). Students graphed the results of their three, one minute math fact timings on the SCC’s. Guides wanted the SCC’s to motivate students to graph their results; however, the SCC’s narrow lines made recording difficult. Field notes (see Appendix C) taken by the guides recorded students’ responses and anecdotes throughout the intervention.

Throughout the intervention, students practiced fact families with the emphasis on accuracy over speed. The guides wanted fact families to expedite students’ learning by not isolating addition, subtraction, multiplication, and division facts. Students practiced fact families with a partner and flash cards, Montessori memorization games, or with games available on the math shelf. At least once a week, students helped each other with
their three, one minute timings recording the best of the three on their SCC. Most students set a goal of eighteen to twenty correct answers in a minute with adjustments made to fit the needs of individual students. Students decided when to move on to the next set of facts offering students independence from the guide. Students who liked flashcards and the SCC practiced daily; those who didn’t care for math facts stayed away from practice and the CSS’s. Two girls practiced SCC’s about every day with exhilaration.

The one hour, whole group lessons suggested by the YouCubed program did not suit the students. Reflection by the guides led to modification of the lessons. Twice a week, students met in the morning to view Jo Boaler and her young YouCubers present their three to five minute videos on recent neuroscience and mathematical mindset research. Students recorded a brief summary or gist statement in their math journals, guides presented the day’s activity, and then dismissed students to the work cycle. Depending on the activity, students worked in pairs, individually, or in small multi-leveled groups modeling a format used earlier in the year.

The YouCubed program provided activities to facilitate small group meetings, worksheets that helped students see patterns, and teaching aids that demonstrated the flexibility of numbers. The first activity helped students work in groups; students offered ideas for encouraging words and then added discouraging words (see Appendix D). They narrowed the list to seven of each and recorded them in their math notebooks. This list proved very useful as students used the same encouraging words in their small groups. The “Four 4’s” activity (see Appendix E) challenged the students to find every number between 1 and 20 using only 4’s with any combination of operations. After getting off to
a rocky start, the students saw how they could build upon what they had already done. One student said, “After the Four 4’s, I have a better understanding of operations. I used addition, subtraction, multiplication, division, fractions, and square root. In the beginning it was difficult, then after a few it got a lot easier.” Students listed their ideas on the white board as they thought of them. Guides did not point out mistakes; instead, they waited for students to realize the errors and explained why answers were incorrect. The students stepped up to the challenge and wanted to take it home for their parents to try. The next day, two girls reported, “We have been thinking about this and have more equations to add to the list.” This activity got them thinking about the flexibility of numbers.

The next set of videos and activities emphasized the importance of thinking about math visually as well as with numbers and symbols; this utilized different pathways in the brain and was referred to as brain crossing which promoted deeper understanding. Students worked in small groups to make their investigations and shared their ideas on what they saw (see Appendix F). One student noticed, “All the prime numbers go around in a circle because a circle doesn’t have any corners or sides.” Another student noticed all the prime numbers were on a diagonal. Many students continued the work drawing larger numbers.

The next video explained that depth of understanding was more important than speed; this was highlighted by a story of a famous mathematician who was a deep thinker, not a quick thinker. The activity had students folding paper into shapes and then they used their reasoning skills to convince their partner they had indeed folded it into a particular shape and size. The partner acted as a skeptic so the person folding the paper had to justify their solution. Partners switched roles and folded new shapes. Students
knew everything they needed to know to convince the skeptic, they just needed to think hard. One student said, “The skeptic helps you understand a triangle better. It takes confidence to be convincing.” Another activity with the help of a dot card (see Appendix G) demonstrated how people saw math differently. Students briefly saw the card with seven dots on it, and then they drew how they saw the dots arranged on a piece of paper. Students drew how they saw the formations on a white board (see Appendix H). Eighteen students saw seven different patterns.

The students took a mid-intervention attitudinal scale with reminders to be honest since no answer was right or wrong. A review of the SCC’s revealed students’ met their goals but had not moved to the next set of facts. When asked to explain many students reported a reluctance to move ahead independently; they wanted to be told it was all right.

The next set of videos and activities addressed the study of patterns. The video highlighted that math’s patterns and used the Fibonacci sequence as an example. The Fibonacci sequence fascinated some students and they made their own illustrations in their notebooks. When they decided there wasn’t enough room in their notebooks, they moved on to taping graph paper together to make a large diagram. The Pascal’s Triangle activity (see Appendix I) had a mixed response. Students worked in pairs to uncover the many number patterns in Pascal’s Triangle; they needed to know these patterns to fill in open spaces on the worksheet’s triangle. Some students set up road blocks from the start, they quickly said, “I can’t do this” stuck wanting to count and not realizing the relationships of adjacent numbers. When the students stopped looking for only counting sequences, they saw that two consecutive numbers totaled the number below them. Once
they realized this, they completed Pascal’s Triangle and said it was easy. Other students considered the Pascal’s Triangle a puzzle and jumped in with open minds and eager to solve the puzzle. Once they filled in the blanks, they continued by adding additional levels to the triangle.

Students watched a video by Jo Boaler and her YouCubers on the importance of mistakes, challenges, and brain crossing. The accompanying activity, Growing Shapes, (see Appendix J) asked students to describe the gradual growth of a collection of objects. Students worked independently to determine the shapes growth. Once everyone had an idea, students drew their interpretation on the whiteboard. Students saw many solutions to the question. In small groups, they made a table to record the number of squares used in each case and looked for a pattern for growth. Using the table and pattern, students predicted how many squares would be in the next case and higher. As students worked together, they were heard saying, “I see the triangle growing from the top”, “I really want to draw this”, and “I already know that’s not it, look 9 + 1….oh, that is it!”

Fewest Squares, another mathematical investigation, asked students to draw an 11x13 rectangle in their math notebooks and then asked, “What is the fewest number of squares you can draw inside of the rectangle?” Two students working together were heard comparing this work to a Montessori lesson saying, “Remember binomial work or transformation of a square, can that help?” Another team helped a confused member saying, “Try using different sizes of squares,” then “So how many squares do you have, can you make less?” and finally “The trick is to start with a six square then add another square so they equal eleven, plus another square on the other side to equal thirteen.” One student noticed the sides were prime numbers which she thought made it more
challenging. At first, students were hesitant to try this activity, but after a few tries they enjoyed the challenge of finding the lowest number of squares.

The last video of the intervention discussed the power of mistakes, explaining more synapses fired when mistakes were made than when work was correct. The first firing of synapses happened when the mistake was made due to the brain struggling, a second firing occurred when the mistake was realized. Brains, like muscles, grow when challenged. The activity, Emoji Graph (see Appendix K), showed how communicate variability along two dimensions. The graph did not include numbers and required students to think intuitively about what the graph was communicating. Students worked in pairs to make their own graphs. They collaborated to decide what they wanted to illustrate and where to place their items. Some of the graphs made comparisons of candy placing them in quadrants of sour or sweet and hard or soft. Other graphs compared encouraging and discouraging words and whether their use was frequent or infrequent. Students struggled to interpret the emoji graph but later enjoyed making their own graphs and explaining what they represented.

Throughout the intervention students recorded the gist of each video in their math notebooks. With the intervention coming to an end, students wrote a summary of what they had learned from the YouCubed videos. Students also completed the final attitudinal scale for analysis.

**Analysis of Data**

To answer my action research question, “Will Implementing the YouCubed Math Program into Math Talk Sessions Improve Upper Elementary Students’ Math Facts and
Mathematical Mindset?” I collected data from five sources: attitudinal scales, Standard Celeration Charts, field notes, students’ work plans, and students’ reflections.

Before the intervention began, eighteen upper elementary Montessori students completed the attitudinal scale to establish a baseline for their attitudes toward math. At the middle and end of the intervention, students took the attitudinal scale to measure any change in their mathematical mindset. With the intention of the intervention to improve students’ mathematical mindset, this qualitative data tool provided important information. Students chose from six responses ranging; 6 – strongly agree, 5 – agree, 4 – somewhat agree, 3 – somewhat disagree, 2 – disagree, 1 – strongly disagree.

Pretest Attitudinal Scale Class Averages

![Figure 1](image_url)

*Figure 1. Averages for students before YouCubed intervention.*

The first question worded to reflect a growth mindset read, “I am sure I can do math” This identified the students’ overall beliefs in their mathematical ability (see Figure 1). The next five statements required students to further examine their abilities and attitudes; they meant to point out any bias in the first statement’s response and worded to reflect a fixed mathematical mindset. Students had to read carefully and think how to
answer in accordance to their beliefs. Two students with reading disabilities received assistance as needed. Because people often associate math ability with speed rather than deep thinking, students rated whether memorization of math facts and quick answers determined high math achievement. The statement’s average revealed students as undecided whether memorization of math facts and speed indicated math ability. The last two questions pertained to the benefits of math practice and challenges. The students agreed to the importance of challenges, but undecided on the benefits of practice when learning new concepts.

Pre-intervention “I am sure I can do math” Responses

![Pie chart showing attitudes towards math confidence]

Figure 2. Pre-intervention responses to “I am sure I can do math.”

The attitudinal scale indicated students’ confidence in their ability to do math (see Figure 2). Eleven out of eighteen students “strongly agreed” they could do math and five students “agreed” they could do math. Two students marked “somewhat agree” in response to their math confidence, this included a student who has been tested for anxiety issues and works twice a week with a reading specialist. No student felt incapable of doing math.
To simplify responses into a more concise bar graph, I chose to group the responses as “Agree” for values 5/6, “Undecided” for values 3/4, and “Disagree” for values 1/2 (see Figure 3). This simplified legend reflected students’ responses and facilitated the assessment of the data.

**Mathematical Mindset Pretest**

![Figure 3. Mindset statements with changes to legend.](image)

Sixteen of the eighteen students responded with confidence to the first statement, “I am sure I can do math”. Two students’ responses indicated indecision in their math ability. As students responded to specific statements meant to determine bias, their confidence declined. These responses indicated a fixed mindset in the students’ perceptions. Students had concerns in their ability to do advanced math; four responded as incapable of advanced math. Afterward, some students expressed their apprehension to the meaning of “advanced math”.

**Attitudinal Scale Averages for Pre and Post Test Comparisons**
Figure 4. Comparisons of averages for pre and post intervention attitudinal scale responses.

Over the course of the intervention, the students’ perceived abilities, attitudes, and perceptions toward math became slightly more favorable (see Figure 4). In comparing the pretest to the posttest, five students’ perceptions of their math ability improved. One student jumped from “somewhat agree” to “strongly agree.” Another student’s perception dropped from “strongly agree” to “agree.” Students’ belief in their capability of performing advanced math increased after the intervention with nine of the eighteen students answering more favorably. By the end of the intervention, some students had changed their minds thinking it was less likely math would be part of their life’s work. In responding to “math is hard”, there was a shift with five responses indicating it was harder and four responding math wasn’t as hard as originally perceived. Students’ averages made a point 3 shift away from the fixed mindset belief that they had a certain amount of math ability and couldn’t do anything to change it. The largest change was the realization that intelligence does not determine one’s ability. Students’ average responses reflected a point 7 change away from a fixed mindset.
The literature review disclosed that girls were more likely to have a fixed mathematical mindset than boys, resulting in underachievement. These feelings of inadequacy often resulted from the attitudes and assumptions placed on them by parents and teachers; therefore, a comparison needed to be made of the girls’ mathematical mindset to that of the boys’ mindset, and in relationship to the class’ mindset.

Comparison of Students’ Mindset by Gender

![Figure 5. Comparison of Mindset Averages by Class and Gender.](image)

At the onset of the intervention, boys had slightly more confidence in their math ability over the girls (see Figure 5). By the end, no difference existed and both answered confidently in their math capability. Looking further into the students’ beliefs, boys and girls remained very close in their responses; however, both moved toward a fixed mindset by not demonstrating the same confidence as in their replies to the first statement. The biggest divergence in responses was the “math is hard” statement. Girls moved from disagreeing with the statement to somewhat disagreeing, showing they thought it was harder, whereas boys’ responses stayed the same.

This intervention included measuring the accuracy of math facts with the hope that the YouCubed lessons would help students see relationships and patterns in numbers, favorably impacting their recall. Before the intervention, students started
practicing the addition and subtraction of fact families and used the Standard Celeration Charts to graph their results. All students started with sixes with some moving on to sevens by the start of the intervention. Table 1 illustrates when students moved from one fact family to the next. Open spaces indicate there was no change. This data will serve as a baseline for further investigation of students’ accuracy of math facts.

### Progression of Math Fact Results from Weekly Timings

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**Table 1.** Student performance with math facts recorded on Standard Celeration Charts.

The students’ progress in their math fact recall depended upon their practice.

Some students practiced on a regular basis and made steady progress; others rarely practiced and saw little improvement. Students did not have a requirement on how fast or how many facts should be recalled in one minute timings. The focus was on accuracy. Students had the opportunity to move on when they felt they had made progress and felt ready. This decision was made because the Literature Review revealed that math anxiety...
was caused by the stress of timed tests and the expectation for quick recall. The hope was students would not feel the pressure of having to answer quickly but could answer accurately.

Students were not comfortable in moving themselves to the next set of math facts. They waited for permission rather than assessing their own achievement. After a couple of weeks with little recorded progress, guides questioned the students and found out students wanted to wait to move on to a new fact family until instructed by a teacher. This was during the week of January 30th, which explains why so many students moved to the next set of facts at this time. The same apprehension for advancement happened again during the researcher’s prolonged absence in mid to late February. When asked why they didn’t advance on their own, many students voiced reluctance to move ahead without permission.

Students used the Standard Celeration Charts to record the results of their timings. Guides thought students would like to see their results on a graph and watch the slope change; however, the narrow lines made it difficult for students to pinpoint where to marks their scores. Many students dedicated to regular practice had difficulty with the charts and either didn’t record on them at all or marked them incorrectly. The inconsistency in recording results made interpreting the data difficult. A student said, “When you practice facts a bunch you get to know them in a snap, but the graphing is confusing and flash cards are difficult to manage.”

Students use work plans to set goals, plan their day, record work and lessons, and to reflect. Research for the Literature Review revealed the importance of facing challenges and the tenacity to keep trying; therefore, the work plans had Challenges and
Celebrations added to the backside as a student reflection piece (see Appendix L). By mentioning math practice in their goals, challenges, or celebrations, students demonstrated their interest in math, their desire to improve, and the importance of challenging oneself in order to improve; these are traits of a growth mindset.

**Frequency of Celebrations and Challenges from Work Plans**

*Figure 6. Celebrations and challenges listed for curricular areas on students’ work plans.*

The YouCubed intervention placed a great deal of emphasis on math. This was apparent in the amount of math challenges and celebrations recorded on work plans in comparison to the other curricular areas (see Figure 6); math was mentioned over 50% of the time.

**Frequency of Both Celebrations and Challenges in Math**
Students often mentioned YouCubed activities as both challenges and celebrations (see Figure 7). They experienced the exhilaration of working hard and reaching their goal. These are characteristic of students with a growth mathematical mindset. Remarks such as “I can’t do this” decreased and guides observed students persevering through challenging math problems.

Students watched YouCubed videos hosted by Jo Boaler. She explained the recent brain research on mathematical mindset focusing on different topics each time. Students wrote brief statements, gist statements, summarizing what they learned afterwards. After the last YouCubed session, students wrote a summary of what they had learned throughout the intervention. A frequency table with the common words and phrases from the summaries created the graph below (see Figure 8).

Figure 7. Frequency of math challenges becoming a celebration.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>Math Both</td>
<td>25</td>
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<tr>
<td>Math Celebration</td>
<td>40</td>
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<tr>
<td>Math Challenge</td>
<td>39</td>
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<tr>
<td>Total</td>
<td>40</td>
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Frequency of YouCubed Topics Learned
Every student included in their summary that the brain grows. The brain’s plasticity is an important aspect of the YouCubed program and mathematical mindset. Students also recognized the importance of visualizing math. They had opportunities to work on activities demonstrating visual math. Some students found it difficult to see the patterns represented in the activities, but once they opened their minds to new ways of looking at a set of numbers patterns became more visible. Students included many statements that reflected a growth mindset such as, “These are factors that contribute to brain plasticity and a mathematical mindset. Students included statements such as, “Mistakes are helpful for brain growth”, “Your brain grows when it is challenged”, and “Slower is better with math. It means you are thinking deeply.”

**Action Plan**

The literature review and the cycle of reflection, action, and observation characteristic of action research projects improved my teaching practice and therefore
impacted my upper elementary Montessori students’ perceptions of challenges and mistakes. I was happily surprised with the results of the pre-intervention attitudinal scale because it indicated my students believed they were capable of doing math. I had assumed some of them were not confident in their math skills because they did not solve math problems quickly and often relied on their fingers; this was one reason why I choose mathematical mindset as my action research project. Another reason for choosing this intervention was because the YouCubed activities worked on flexible and critical thinking. These skills supported my school’s desire to incorporate more problem-solving into our math curriculum.

Research and the YouCubed videos revealed I had a fixed mathematical mindset. This caused me to reflect on my early math experiences and attitudes, and how they influenced my math lessons. I learned you don’t have to be fast to be good at math and mathematicians are deep thinkers; this initiated a shift in my paradigm. As a result, I have tried to instill the importance of facing challenges and embracing mistakes in my students. During the literature review, I learned about recent neurological studies which demonstrated participants’ brains grew due to additional synapse firings when they were faced with challenges, made mistakes, or saw math in multiple ways. These insights were called to my attention early in the schoolyear, so I couldn’t help but incorporate the message that challenges were opportunities and reason to celebrate into my classroom before the intervention. My co-worker and I added Challenges and Celebrations to the back of our work plans and asked students to list work that fell into these categories. We incorporated these messages regularly into our lessons. I believe this explained the large number of math challenges turning into celebrations on students’ work plans.
In the process of choosing my action research project, I wondered if Montessori math materials supported a growth mindset. Montessori students learn math with materials that move from concrete to abstraction. I already knew Montessori materials provided students with an understanding of numeration, operations, geometry, and pre-algebraic concepts; I was not convinced of its success in developing problem-solving skills. This intervention has shown me Montessori does provide students with the skills and strategies needed for problem-solving. The Montessori materials provided students hands-on representations of mathematical concepts and helped internalize them for recall later. This intervention renewed my belief in Montessori math presentations and equipped me with activities to foster critical and flexible thinking also necessary for problem-solving.

The inclusion of math facts in this intervention brought attention to the importance of regular practice; however, students’ commitment to practice varied. Some students practiced regularly and others avoided practicing as much as possible. Students were also reluctant to move forward on their own which slowed their advancement. The Standard Celeration Charts were more cumbersome than helpful. Many students who practiced regularly and attempted to use the charts had difficulty accurately recording due to the very narrow lines. As I reflect on the inclusion of math fact timings, I believe it worked against an important premise of the YouCubed lessons, that speed is not important. I learned timed tests cause anxiety in some students and can lead to a fixed mindset. In hindsight, the desire for my students to increase their recall of math facts reflected my attitude that one had to be fast to be good at math. In choosing the Standard Celeration Charts, I hoped the pressure for speed would be removed. However, in the
middle of the intervention, I asked myself, “How am I removing the pressure of time, when they are sitting with a timer in their hands?” In the future, I would like to effectively implement the YouCubed lessons on visualizing numbers and recognizing patterns into the curriculum and see how these lessons influence students’ recall of math facts.

I have made use of the helpful suggestions Jo Boaler offered in her YouCubed lesson plans. She suggested not giving a new formula to students but to let them discover it in a task that would eventually lead them to the identification of the formula. This reminded me of how Montessori math materials should be presented and caused me to evaluate my presentation of materials. I thought of lessons such as cubing which revealed the formula in the dissection and labeling of a cube. I have also changed math homework; students now explain a math concept from a recent lesson to their parents who play the critic and challenge their student to defend their explanation. My desire is to encourage students to talk about math and explain their reasoning.

My upper elementary students learned about the benefits of challenges, mistakes, and believing in themselves from the YouCubed videos. At the start of the intervention, students’ responses when faced with unfamiliar or difficult tasks were “this is hard” and “I don’t know how to do this” over the course of the intervention students began to look for strategies to help them accomplish a task. They embraced challenges knowing in the end there would be reason to celebrate. Mistakes became opportunities for growth and the power of believing in themselves was called to their attention. Students had more confidence because they understood math competency was not limited to a few.
Going forward, I will incorporate what I have learned from my action research project into my Math Talk lessons. Students will continue to talk about math using appropriate vocabulary and encouraging words. Lessons will promote reasoning and critical thinking as students solve problems and explain how they achieved a given result. Students will take responsibility for other members in their math group. All members must be able to explain the given concept; if they can’t, then it is the responsibility of the group to help each member reach a better understanding.

My Head of School has been interested in my intervention and saw how it could benefit other teachers. She asked me to continue my work with mathematical mindset and the YouCubed program so I will be taking an online course offered by Stanford University this summer. She wants me to share what I have learned with my colleagues and act as a coach next year. This opens up the possibility to expand my action research by including all the elementary students at my school and seeing if collectively they have a growth mathematical mindset. This research could be further expanded by having traditional students complete the same attitudinal scale. The data from the Montessori students would be compared to traditional students’ data to determine any differences in their mathematical mindsets. I would like to find out if Montessori materials promote a deeper understanding and therefore promote a growth mindset in students. I will continue to assess my students’ acquisition of math facts and use the Celeration Chart’s Table 1 data for a baseline. I am curious to see if some of the strategies for learning patterns suggested by the Youcubed program will help students with the accurate recall of math facts. I look forward to the many opportunities ahead for continued professional development and inquiry into professional practice.
References


Boaler, J. (2016d, January 25). We need to ‘revolutionize’ how we teach math says Stanford's Jo Boaler. (M. Krasny, Interviewer)


For each statement, mark the answer that best describes your feelings. Be honest, there are no right or wrong answers.

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- I am sure I can do math.
- I don't think I could do advanced math.
- Math will not be important to me in my life's work.
- Math is hard for me.
- I have a certain amount of math ability and can't do much to change it.
- How intelligent I am determines how well I can do math.
- How well I memorize facts determines how well I can do math.
- How fast I get a correct answer is a good measure of my math ability.
- Practice exercises are the best way to learn new math.
- Tackling a problem that is not easy to solve is the best way to learn math.
Appendix B

Standard Celeration Chart
Appendix C

Field Notes

Observations and Anecdotes for ___________________________ Date___________

Observations and Anecdotes for ___________________________ Date___________

Observations and Anecdotes for ___________________________ Date___________

Observations and Anecdotes for ___________________________ Date___________
Appendix D

Encouraging and Discouraging Words
Appendix E

Four 4’s Activity

1. \( \frac{4}{4} \times 4 = 4 \)
2. \( (4 + 4) \div 4 = 2 \)
3. \( (4 + 4 + 4) \div 4 = 3 \)
4. \( 4 + \frac{4}{4} = 5 \)
5. \( (4 \times 4) - 4 = 12 \)
6. \( (4 + 4 \div 4) + 4 = 9 \)
7. \( 4 + 4 - 4 \times 4 \)
Appendix F

Number Visuals Activity
Appendix G

Dot Card
Appendix H

Dot Formation Activity
Appendix I

Pascal’s Triangle
Appendix J

Growing Shapes Activity
Appendix K

Emoji Graph
Appendix L

Work Plan with Reflections on Goals, Challenges, and Celebrations

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