The Effects of Mathematical Literacy on Standardized Tests

by

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ABSTRACT

The purpose of this study is to examine the algebra-based questions on the 2017, 2018, and 2019 STAAR exams for grades 3rd, 4th, 5th, 6th, 7th, and 8th. The paper focuses on analysis of the various types of representations in question-and-answer type. The representations were found to be graphical, numerical, verbal, and symbolic. Within each algebra-based problem on the STAAR exam, each item was categorized to be a combination of a representation for question and a representation for answer. The linear regression and ANOVA found that students struggled in questions that were both verbally asked and had a verbal answer choice. This led to the conclusion that students need improvement of real-world situations and problem-solving to work their way through application problems. To provide a suggestion to help correct this error and produce a higher percentage in these types of questions, mathematical literacy was suggested as a possible solution.

Keywords: Mathematical literacy, STAAR test, Representation, Teacher training, Algebra based questions

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INTRODUCTION

In the state of Texas students are required to take and pass a standardize math test, the State of Texas Assessment of Academic Readiness (STAAR), to show competency of the grade and advance to the next grade level. Embedded within these math STAAR tests, are core concepts that are foundational to bringing success mathematics. The Texas Education Agency, (TEA, 2021), provides a list of general and grade specific concepts that are assessed in each test. Based on data from the outcome of past STAAR tests for grades 3rd through 8th, there is a need for investigation in what is being tested and a breakdown of the representations in the question and answer in order to see if these factors are potentially affecting academic achievement. Along with this, research has shown that standardized tests are taking away from students being able to problem solve and think critically in addition to teachers placing too much importance in students passing a test and not enough on students learning the content. Bhattacharyya et al. (2013) agree that standardized test scores create an instructional focus on memorization, neglecting critical thinking skills, and being able to problem solve, a vital component in being prepared for mathematics outside the classroom. One downside of standardized testing is that it has been proven that many teachers “teach to the test” resulting in the concentration on only mathematically obvious questions and not so much on mathematical literacy (ML) for interpretation and problem solving.

A focus area that was seen to be problematic to the students getting the question correct was those problems that were asked with a representation heavy in terminology and verbosity. Bhattacharyya et al. (2013) believed that a large factor that needed to be addressed and researched was student's preparedness in ML. This paper analyzes what ML is and how it effects the outcome of students test scores. Along with this it is considered that if more focus on ML is made, then students could potentially perform better.

Purpose and Research Question

This research enquiry seeks to determine if students are missing questions on the STAAR exam due to being underprepared in problems that focus on the capability to answer questions that have a strong area of ML needed. The purpose of this paper is to analyze the 2017, 2018, and 2019 STAAR math exams for grades 3rd through 8th, and see if the amount, rigor and performance of the question is correlated to students' being unsuccessful in all representations of algebra-based questions. Another benefit in this research is to bring awareness to the positive effects ML could have, leading to an increase in the overall scores. This study draws on previous work by Dr. Shirley M. Matteson of Texas Tech University. Matteson (2006) previously analyzed the 2003 and 2004 Texas Assessment of Knowledge and Skills (TAKS) test to see if the representation of answer and question had any effect on the rate at which it was answered correctly. The research from 2006 was outdated and needed to be reanalyzed to get modern data and compare it to the past findings. This will help to determine if there is a difference in the TAKS and STAAR exam along with revealing if there is change in students' performance on certain representations.

LITERATURE REVIEW

Suggestions on Implementation of Mathematical Literacy

Firdaus et al. (2017) provided a definition and purpose to ML and suggest two methods in which students can be introduced to the concept. The authors started by explaining in detail why ML is an important and valuable outlook for students. The authors stress the importance of education and how it is intended for students to better themselves and prepare for life after school (Firdaus et al., 2017). Reasoning as to why ML is meant to generate students who can utilize life mathematical skills is also emphasized. Problems that are non-routine, involve higher order thinking skills, use two or more formulas, need interpretation to solve and entail creativity and justification are examples of problems that require ML (Firdaus et al., 2017). Once the foundation of ML was given, the way it could be taught was introduced. One of the instruction methods suggested by these authors was problem-based learning. Problem-based learning, PBL, was defined as, "learning that utilizes problems, questions, or puzzle as a trigger for students learning process" (Firdaus et al., 2017, p. 214). Explanation on how this style of instruction helps build the ability to connect real life situations and improve students' mathematical skills was stated. The second style mentioned was direct instruction (DI). Having the educator explain the concept and then asking the students to show what they learned with guidance is how direct instruction was defined (Firdaus et al., 2017).

In their study Firdaus et al. (2017) how the teachers for the study taught as well as how they must measure students. The method for the study was a quasi-experimental in connection to how the research was conducted in hopes to gain new knowledge of the topic by having changing conditions and comparing them (Firdaus et al., 2017). The study consisted of all fifth-grade students, county, and city, in primary school of Bandung. They style of research instrument used was a test sheet for evaluating the students ML in geometry (Firdaus et al., 2017). The studies goal was to determine if PBL or DI was a better choice in teaching ML. ANOVA results found that PBL was the better option. "Those students who received the PBL model significantly obtain an average increase in literacy mathematical greater than those students who received DI models in primary schools" (Firdaus et al., 2017, p. 215). This study adds value to the importance of ML, how it can be defined and provides methods in which instructors could use to have students build on ML.

Importance of Mathematical Literacy

Another article by Salsabila et al. (2019) explained the importance of ML for the students. ML was defined as, "an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical procedures, facts and tools to describe, explain and predict phenomena" (Salsabila et al., 2019, p. 1). The following definition along with more description throughout the article on how ML assists students to make connections to the real world concur with the previous literature. An additional piece of information the authors provided is how intense analysis of the ML in students' needs to be explored so that the way the students thinking can be seen and how their metacognition plays a vital role in developing ML (Salsabila et al., 2019). Salsabila et al. (2019) revealed that when students can identify any misunderstanding, they had within a problem leading to a mistake in solving, they are able to build on the skill itself and correct it. This is important to recognize because, “Students’ mistakes in solving problems can be a hint to find out how far they acknowledge the mathematical literacy. Students’ mistake can also be useful to find out the students’ way of thinking about concepts which they had learned (Salsabila et al., 2019, p. 2).

The goal of Salsabila et al. (2019) was to evaluate each students ML in geometry based on student’s metacognition. The results of this research convey a connection to ML and metacognition.

Setiani et al. (2018) investigated the Program for the International Student Assessment, (PISA), scores for Indonesian students. “PISA measures 15-year-olds’ ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges” (OCED, 2021, What is PISA?). Based on the findings it was concluded that Model Eliciting Activities, MEA, should be applied in the classroom in hopes of students being better prepared for real life problems presented in the MEA exercises (Setiani el al., 2018). The authors used MEA in the research that aimed to “(1) identify learning quality applying MEAs using MT (metaphorical thinking) approach toward mathematical literacy ability, (2) analyze mathematical literacy ability of Junior High School students in MEAs learning using MT approach covering students with high, medium and low level of self-efficiency” (Setiani el al., 2018, p. 2).

Conducted a mixed methods approach that was parallel with a qualitative model, where the qualitative side was the main approach for the study. The experiment was done in SMP Negeri 3 Semarang Indonesia in 2015-2016 on VIII grade students with experimental and controlled groups. Within the analysis it was found that MEAs help students become more ML and help with conceptual understanding. This research adds value to the current study as it helps give suggestions to what can be done to help strengthen ML skills in students at all levels.

With ML as an established construct, educational stakeholders are starting to come to the realization that being competent in ML is a skill that needs to be required. Authors Rizki and Prianta (2018) provided reasoning as to why ML should be in demand and mandatory for students to become skillful in.

> the modern society in this century does not only require content knowledge, but also requires skills including critical thinking, problem solving, creativity, innovation, communication, collaboration, flexibility, adaptability, initiative, self-diversion, social, cross culture, productivity and accountability, leadership and responsibility, and information literacy. Mathematical literacy is one of the components needed to construct 21st century skills (Rizki & Prianta 2018, p. 1).

The reasoning behind Rizki and Prianta's (2018) research was to present the abilities a student must have to show ML skills, be able to think and reason mathematically, be able to communicate mathematically, model problems, represent within problems and solve the problems using tools or technology (Rizki & Prianta, 2018). In their review of literature, Rizki and Prianta (2018) spoke about all the parts it takes to fluently make up a skillful ML student, this is very valuable to my research as it will help set a pathway for teachers to follow. The conclusion of this study found that ML is indeed a valuable portion of life skills one needs to become successful due to it build strong senses of problem solving and critical thinking (Rizki & Prianta, 2018).

Teacher preparedness in Mathematical Literacy

Webb et al. (2015) questioned how higher education institutions can help produce quality teacher guidance for ML to serve students, focusing specifically on students of South Africa (Webb et al., 2015). Introducing ML within this article, the authors argue that a reason behind the need for ML is that it produces learners who will become citizens that can navigate and function in a world full of economics and everyday calculations (Webb et al., 2015).

This study relates how the teachers understanding and perception of a course is how the students will be able to view the class mentally and emotionally throughout their time learning. “Teachers’ agendas are driven by their conceptions of the purpose of ML, and it is these conceptions that will ultimately affect the extent to which the curriculum will succeed” (Webb et al., 2015, p. 2). The authors explain that teachers need to be fluent in the content and understand the knowledge that needs to be gained from the course. The authors break ML into two aspects of content knowledge: first, basic skills topics and second, application topics (Webb et al., 2015). The importance of teachers being able to correct prior misunderstandings and allow them time to get a good understanding of the topic will be crucial to the success of the course. Another noteworthy element educators for ML must possess is that they are able to help students verbally contextualize problems and apply them to mathematical operations (Webb et al., 2015). Along with the two prior suggestions teachers must provide, another is that the teachers need to be able to create activities and tasks that are relatable to ML in real world situations.

The benefit of Webb et al. (2015) research for the study conducted in this paper is to provide suggestions on professional development courses that need to be offered to provide adequate training for teachers of ML. Based on the demands this course offers above, the authors suggest that teachers need reflections of students work and reflection in observation of the process in teaching the course. “Professional development programs need to provide opportunities for teachers to engage in critical reflection about the ML they teach, about its purpose, how they teach it, and why they teach it in the way they do (Webb et al., 2015, p. 5). This ending message provides a powerful statement in the importance of the future implications of ML.

The research by Machaba and Du Plooy (2019) viewed ML and mathematics in an analytic and subjective perspective from the teachers and student’s viewpoint. One of the first issues the authors mentions is the assumptions that those who teach mathematics can also teach ML without any additional training or knowledge of the course, this leads to educators making the two subjects identical with no differentiation in the course (Machaba & Du Plooy, 2019). This precedes to the main argument and purpose of the article, “we argue that M (mathematics) and ML are dialectically linked, and viewing these seemingly contradictory mathematically pathways from multiple perspectives suggests that we are, in fact, completely reconcilable” (Machaba & Du Plooy, 2019, p.365). When comparing mathematics and ML, the authors state that ML is intended to influence learners to problem solve, reason, interpret and view life in a mathematical lens while mathematics should be viewed in a more contextual lens so that the main point of the problem is to understand the mathematical side and not the side that is appliable to life (Machaba & Du Plooy, 2019).

Machaba and Du Plooy (2019) conducted their research based on a document study, literature review and semi-structured interviews used to collect qualitative data for an exploratory case study. The sample of people that were used for the investigation were two classes of about 30 in the 10^{th} grade, these two classes were taught by the same teacher and one class was mathematics based and the other ML based. During the interview process ten random students were selected from each class to be interviewed and collect personal information on the designated subject. During the interviews it was found those students who were in the mathematics class felt their class was the ‘straightforward’ problems that required little to no reading (Machaba & Du Plooy, 2019). In comparison, ML learners felt that in their class they solve problems due to finding the known variable and seeking the element in which it represents. (Machaba & Du Plooy, 2019). Valuable information from the learners and teachers, found that most preferred to only study mathematics and did not like having to apply everyday knowledge into the problems. From the study it was found that ML is a necessary course for career readiness and everyday life. The authors propose that this course should be required into course of study and taken to help build critical skills for life (Machaba & Du Plooy, 2019). This article supports the idea that ML is beneficial to the students and that teachers need to help create a course that students feel is an asset to them.

Colwell and Enderson (2016) examined pre-service teachers view of ML and the changes it brings to the education system. The authors began by stating that the integration process of adding literacy to all content areas in the secondary setting has been a focus and abstained from the educator’s position (Colwell & Enderson, 2016). As the demand for placing literacy in mathematics rises, the obtainability for more research in this area does too, however research is lacking in the aspect of how to prepare teachers. The authors aimed to provide more research in this area. “Noting the importance of teacher perspectives and perceptions in the successful implementation of literacy in content areas” (Colwell & Enderson, 2016, p.64).

Colwell and Enderson (2016) provided information on how pre-service teachers understood ML and if the systematic changes in mathematical education created an adaptable incorporation of ML into the mathematics classroom. The foundation of the research was the perspective of disciplinary literacy in mathematics. Colwell and Enderson (2016) conducted as a qualitative case study researching two questions: How do pre-service teachers view ML? What are the factors from their education program persuaded this viewpoint? The sample used for the study was seven students from the secondary mathematics education program from the mid-Atlantic region who agreed to do the study. The study gathered perceptions of ML from the pre-services teachers as well as collected data on what influenced these feelings towards it. From the research questions, themes were developed such as “(a) the importance of communication, application, and vocabulary; (b) bridges and disconnects between CAL and mathematical literacy; and (c) barriers to teaching mathematics using a disciplinary approach” (Colwell & Enderson, 2016, pp. 68-69).

Along with being able to understand what ML from a teacher’s point of view and provide the appropriate material to build students ML skills, there must also be support from the teacher to the student. Hermawan et al. (2019) conducted in a math class at SMPN 3 Jember of 35 students, a facility that had been teaching general literacy but not particularly ML. A learning activity was performed by the students to present their ML abilities, this consisting of three problems that were scored on a scale of 1 to 4, 4 being the best. Once the problems were scored a qualitative method was used to present the students work (Hermawan el al., 2018). With the 35 students that participated, they were divided randomly into groups of five and each group solved all three problems together. While students worked through the problems, they were observed to see which of them used ML skills and if it affected the way they solved the problem and reached an answer. In the study it was found that those students that were able to use ML skills had a higher and easier chance to get to a solution, this was based on the fact they were able to reason and work through problems (Hermawan el al., 2018). This offers value to the current study as it shows that when students can apply ML skills, they have a better chance of reaching a correct answer.

Parallel Research

Matteson (2006) performed research that correlates with the current study being conducted. The author analyzed the TAKS exam, the previous name for the test comparable to what is now known as the STAAR exam for Texas's standardized testing. Within Matteson's (2006) study she presented the statement molded from the National Council of Mathematics website that,

> One problematic issue of mathematics education is that students must read and comprehend a variety of mathematical representation- critical elements which support students' mathematical understanding, aid the students in communicating mathematical knowledge, create connections among mathematical concepts, and can be used in applying mathematical concepts in the real world (Matteson, 2006, p.207).

The author used this examination of the 2003 and 2004 TAKS test for grades 3rd through 8th looking specifically at the question and the answer representations for the algebra-based problems (Matteson, 2006). Data was collected from the TEA website using an item analysis report, the TAKS answer key, a summary report for test performance for all students who took the TAKS test in the years 2003 and 2004, and then lastly copies of the 12 tests used to collect questions and data from (Matteson, 2006). Questions and answer representations were coded as verbal, numerical, graphical, symbolic, or dual representation which implied that more than one representation was used. Matteson found that grades 3rd through 5th had more dual representations than the higher-grade levels, leading to help in students transition to more abstract representations in the future years to come (Matteson, 2006). The author also found that throughout all grade levels verbal representations was deeply used along with graphical representation Matteson (2006) expressed that she felt there should have been a wider range of representation used on the TAKS test considering representation played a valuable role in teachers identifying students understanding (Matteson, 2006). The author also added that teachers are significant in students experiencing a plethora of representation, are key to students building ML skills, and they should place more attention in students developing important real-life math skills instead of having high TAKS scores (Matteson, 2006).

Matteson's (2006) research is vital to the current study. Previously answered questions focusing on algebra-based representation were focused on analyzing for the TAKS test, this idea is now being revisited to modernize the data for the STAAR test. The data found from her 2006 study can be used to compare to results obtained from the 2021 study done throughout this research. This will help to evaluate if time has created change and placed more representation and improvement of ML in modern times.

Algebra Based Question Representations

In addition to what ML is and how to provide opportunities for students to obtain these skills, this study also aims to bring attention in the impact of different types of representations in algebra questions regarding to students' correct response. Andra et al. (2012) used observation of eye movement while students were reading algebra questions with different representation to see if there was different eye movement in reading questions asked with graphs versus those with formulas. The purpose of the study was to verify if different types of mathematical representation have varying effects on the students in addition to if cognitive processes are important regarding visual experiences from the learners' view (Andra el al., 2012).

Andra et al. (2012) conducted an exploratory study with 43 stimuli consisting of 15 formula to plain text questions, 12 graph to plain text questions, and 16 text to formula questions. A total of 46 students from a Swedish University participated, they had various backgrounds such as never studying math to studying one year of math. By the end of the study it was found that, based on eye-tracking, there is a noticeable difference in the way the student views formula and graph representations. The authors found that formulas tend to be more difficult and lead to the lowest correct answers, graphs seemed to be easier for students to answer. This study supports the idea that representation matters for a students' outcome in getting an algebra question correct.

Ross and Wilson (2012) bring additional support to the idea of representations contributions to standardized exam achievements. Along with a focus on the representations in their study, Ross and Wilson (2012) also concentrated on teaching methods and student engagement. Two research questions were proposed for the study:

“1. To what extend do representations, constructivist teaching approaches, and student engagement predict middle school students’ procedural knowledge and conceptual understanding of algebra 2. To what extend are procedural knowledge and conceptual understanding correlated among students” (Ross & Wilson, 2012, p. 117).

For this study, a sample of 16 lessons were reviewed from a seventh and eighth grade teacher along with those student enrolled in the course from a rural Texas area. Students were required to take a pretest and posttest from the National Science Foundation-IEA-ETS Research Institute- funded project. The purpose of the pretest was to bring awareness to the level at which the students were able to use procedural knowledge and conceptual understanding with questions that focused on variable change (Ross & Wilson, 2012). Video recording of the teacher’s lessons were used to determine pedagogical tools and strategies. To analyze procedural knowledge and conceptual understanding, nine predictor variables were used and determined with a structural equation modeling system. Ross and Wilson (2012) found that representations, constructivist approaches and student engagement are important predictors for identifying procedural and conceptual understanding. Results from this study convey that students can remain engaged and learn when teachers focus on constructive strategies and enactive representations (Ross & Wilson, 2012).

Based on the review of literature, it was found that ML is an important skill for students to have as it is foundational to them becoming successful in life past school. However, ML should be a subject that teachers have the chance to be trained in so that they have the tools to adequately educate students on what ML is and provide them with the skill set to use it in problems solving. Teachers have much pressure from tested subjects. There is a possibility that this could help reduce that if they felt students had all essential tools to be set up for success on the test. The review of literature also gave support to the variations of algebraic representations having effects to student outcomes on tests. With this fact, and the idea of how students preparedness in ML positively affect their ability to answer an array of algebraic representations, there is now support in the awareness of teaching students ML in order to produce a higher pass rate for all areas of algebraic representation.

Conceptual Framework

The conceptual framework for this study is the importance of students building ML and if having strong ML is essential in getting questions correct on the STAAR exam. ML is defined as "the ability of a person (in this case students) to formulate, implement, and interpret mathematics in various contexts, including the ability to perform reasoning mathematically and using the concepts, procedures, and facts to describe, explain, or predict phenomena/events" (Firdaus et al., 2017, p. 214). In 2006 ML was first introduced in South Africa as a separate path that was corresponding to a mathematics course. In the first years of its development many used this class as a course for 'stupid learners of math' and had educators who were not prepared to teach such a program, thus the lesson was not reaching its full potential or significance (Machaba & Du Plooy, 2019). However, in recent times, and with the demand to shape students into problem solvers and thinkers, the demand to have students showcase a knowledge of ML is high in the United States (Oxford Learning, 2010).

Research has found that students who can use, apply, and correctly work through ML questions are better prepared for life after school. Machaba and Du Plooy (2019) explained that students who are ML learners can leave school and start life prepared and exposed to an array of adult and career life situations in mathematical circumstances. Due to this demand and need for students to become more mathematically literate, it only makes sense for more of these types of questions to be asked and expected to be understood on the STAAR exams. The focus for this study was analyzing the algebra-based questions on the STAAR exam and to determine how students performed on these specific types of questions. The attention on algebra-based questions is influenced by the correlation to algebra's impact on a student's mathematically academic career, including those in elementary up to post-secondary schooling. In a response to this recent change, many teachers are not preparing students to accurately think algebraically in a ML manner, leading to this set of questions missed more often (Oxford Learning, 2010). In taking studies explaining the importance of ML and applying them to the data concluded from this study, there can be implementation from both investigations and possible conclusion emphasizing the need to teach ML to increase achievement on the STAAR test.

In conducting this study and building the conceptual framework on improving STAAR test scores for all grade levels by ensuring that students are confident in ML and the process of ML, articles were needed for analysis. In developing validation for this topic, a foundation of ML must be laid and how ML can assist building skills in the classroom. Researching the topic included gathering different opinions on ML and the importance it has in the future of students. Multiple definitions for ML will be gathered to compare and establish if there is a continuous and sound definition. Another important component researched extended to how, and if, teachers needed training in how to instruct using ML in their classroom. A literature review is an important aspect of the study as it gives reasoning on why ML is an important area that needs to be shown to students and why they would benefit in becoming fluent in it. Research supports the idea of training teachers so that they can accurately introduce ML to the students and how the stress of the standardized test can lead teachers to neglect the concept of ML in general. The literature is not only used to support the study but also offer other possibilities to consider when searching for answers of this topic.

METHODOLOGY

This study used an exploratory sequential mixed methods approach. This was the design of choice because it allowed the research to have both qualitative and quantitative components. Reasoning for use of a sequential design, as opposed to concurrent, was that the qualitative data had been collected, interpreted, and needed exploring through analysis using a quantitative method. The research was done in two phases. Phase one was the qualitative study conducted by Dr. Shirley Matteson and Dr. Audrey Meador. Following the completion of the qualitative study, analysis of the data was completed using a quantitative study. In completion of both phases, that data was combined to interpret the findings for the design.

Qualitative Analysis

The qualitative side of the research was conducted first by Dr. Shirley M. Matteson of Texas Tech University and Dr. Audrey Meador of West Texas A&M University. Matteson and Meador (2020) collected the data from 2017, 2018 and 2019 released STAAR exams from the TEA website for grades 3rd, 4th, 5th, 6th, 7^{th,} and 8th. Once the tests were collected, Matteson and Meador, (2020) proceeded to analyze the questions that were only algebra based TEKS, collecting a total of 216 questions to examine. Following the organization of the questions, Matteson and Meador (2020) then analyzed each problem to categorize the question and answers into different representations. Each question and answer were characterized into four representative groups. The groups were categorized as verbal, graphical, symbolic, and numerical. The findings can be seen in Table 1.

Table 1

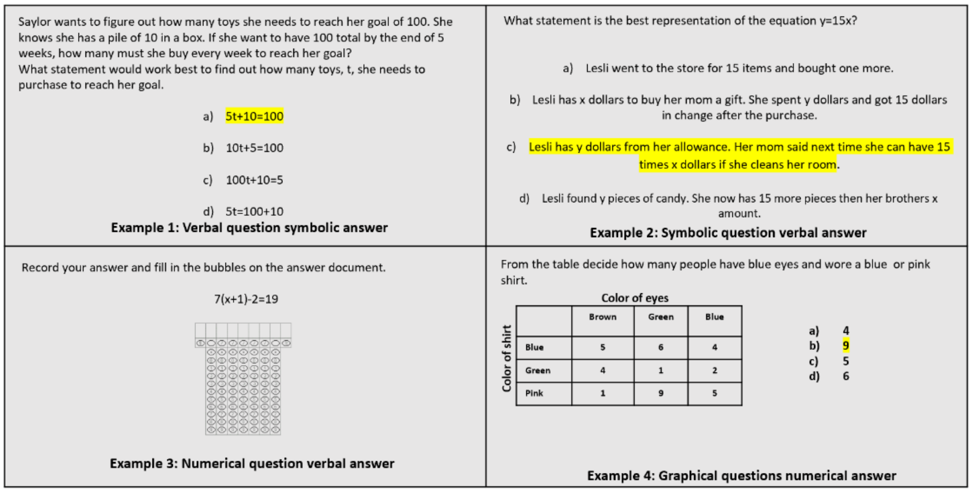
Categories of Representations

Code	**Question Representation**	**Code**	**Answer Representation**	**Total with this combination**
1	Verbal	1	Verbal	10
1	Verbal	2	Graphical	26
1	Verbal	3	Symbolic	28
1	Verbal	4	Numerical	87
2	Graphical	1	Verbal	13
2	Graphical	2	Graphical	2
2	Graphical	3	Symbolic	24
2	Graphical	4	Numerical	22
3	Symbolic	1	Verbal	14
3	Symbolic	2	Graphical	11
3	Symbolic	3	Symbolic	5
3	Symbolic	4	Numerical	14
4	Numerical	1	Verbal	1
4	Numerical	2	Graphical	1
4	Numerical	3	Symbolic	0
4	Numerical	4	Numerical	3
			TOTAL	261

A question was defined as verbal if the problem required students to understand written language, described in any way, critically think through a question, or interpret what was being asked. Graphical questions meant that students had a visual model to use such as a chart, vertical or horizontal, or coordinate graph. Numerical questions had the use of real numbers such as decimals and fractions or numerical lists. The last representation, symbolic, entailed that formulas, equations, expressions, and variables were used within the problem. Figure 1 provides an example of each question type.

Figure 1

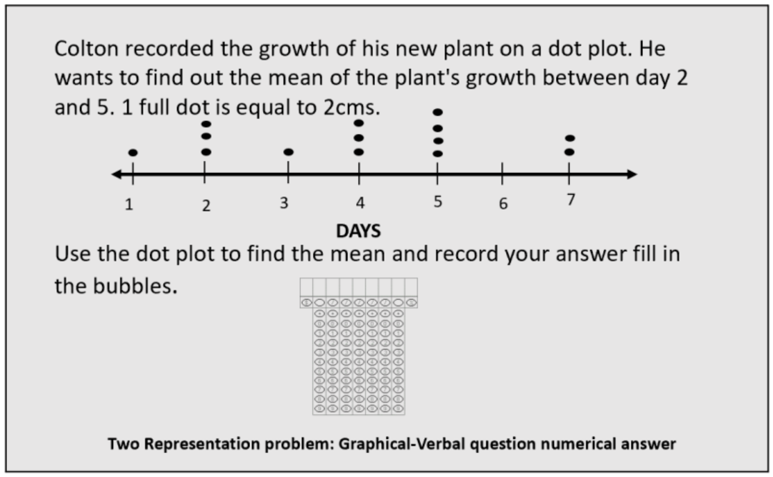
Example of Question Types



Within these classifications, a combination of the representative categories could be considered for the question and answer choice. It also needs to be stated that both the questions and the answer types could have one or more different representations, an example of this is that a question could have been marked verbal-symbolic and an answer numerical-graphical. The question was decided to have one major representation which it was coded as under questions, however with it having a sub-representation it was marked as 2 in the question representation coding. An example of problem with this type of representation can be seen in Figure 2. In this example this would have been coded as a 1 for verbal in question type but also a 2 in question representation because it also had a graphical representation.

Figure 2

Example of More Than One Representation Question



Along with analyzing the questions and answers into different representations, questions were separated by TEKS assessed and were then labeled as readiness or supporting. An example of how the questions differ can be seen in Figure 3.

Figure 3

Readiness versus Supporting TEKS

Readiness	Supporting
These are standards that focus on content that is pertaining to the current grade level.	Introduced to students but not made to be fully developed.
They are also used to help prepare students for the future years.	Will be used as a readiness standard in upcoming years.
Help students build on deeper understanding of a topic.	Only briefly taught, no deep understanding is developed yet.

From here each question was reviewed to state the percentage of students that correctly answered the question.

Quantitative Analysis

Matteson and Meador (2020) qualitative findings were used to conduct the quantitative analysis. In doing this, the goal was to assess if there was a relation to the different combinations of question-and-answer type and if they had any effect on the pass rate per algebra-based problem asked to the students. This also corresponded to the exploratory sequential mixed methods design where qualitative data was first collected and analyzed to inform the quantitative collection and analysis.

Variables

The response variable used in this experiment design was the percentage found from the students STAAR test score. Along with this there were seven independent categorical variables used. In addition to representation of question and answer being used as variables in this study, it was also considered if the year the test was given, grade it was asked, number of representations within the question or answer (one or two), and whether the question was labeled as a supporting or readiness could also influence the selection of the correct response. Following this, each variable was coded to run the collected data using STATA. Grade was coded with 3^{rd}=1, 4^{th}=2, 5^{th}=3, 6^{th}=4, 7^{th}=5 and 8^{th}=6. Year was coded as 2017=1, 2018=2 and 2019=3. The category of TEK was readiness-1 and supporting=2. Question and answer were its own variable, but both were coded with the same system such as verbal=1, graphical=2, symbolic=3 and numerical=4. The last variables were question representation and answer representation, this indicated how many representations were used within each problem on the STAAR. The coding was the same system for each variable such as, only one type of representation-1, or more than one type of representation-2. All variables and the coding method can be seen in Table 2.

Table 2 *Coding for Variables*

Independent Categorical Variables	
Variable	**Code**
Years	2017-1
	2018-2
	2019-3
Grades	3^{rd}- 1
	4^{th}- 2
	5^{th}- 3
	6^{th}- 4
	7^{th}- 5
	8^{th}- 6
Category	Readiness- 1
	Supporting- 2
Questions	Verbal- 1
	Graphical- 2
	Symbolic- 3
	Numerical- 4
Questions Representation	1 representation- 1
	More than 1 representation- 2
Answer	Verbal- 1
	Graphical- 2
	Symbolic- 3
	Numerical- 4
Answer Representation	1 representation- 1
	More than 1 representation- 2

Statistical Tests

A regression test and an ANOVA test were ran using the coded variables with a significance level, α, of .05%. The test used the hypothesis such that, if the p-value was greater than or equal to α then it was not significant to the study. This implied that the variable had no effect on the outcome of the problem. If the p-value was less than α then it was significant to the outcome. In working with such a large set of data, a regression test was selected starting with all variables as a single set. Following this analysis, variables determined non-significant were eliminated. Criteria for elimination of variables was done in order of furthest from .05, until one taken away caused a dramatic change in the regression test, being that the difference in coefficients were 30% or more. Two-way interactions were then added to determine which were significant to this study. Interactions greater than two variables were not ran since consideration of more than two variables has no true significance to a study. Once the variables were found that had significance to the regression test, an ANOVA was performed to support the findings.

RESULTS

Results obtained from the ANOVA test were concluded to be that the only single variables that were significant to the study were grade, question, question representation and answer. Out of those four, grade was the only one truly significant (implying that it had a significance level less than α). However, given that there were interactions that were significant, the single variables used within the interaction was also needed to run an accurate test. It was found that the interaction of grade and question representation along with the question-and-answer interaction were significant to the analysis of the study. Adjusted R-squared was 22%, but with such a large set of categorical data, this was expected. The ANOVA results are available in Table 3.

Table 3

ANOVA Test

Number of Observations	*261*	*Adjusted R-Squared*	*0.2215*	*Root MSE*	*12.8857*
Source	***Partial SS***	***Degrees of Freedom***	***Mean Squared***	***F-value***	***Prob>F***
Model	*16,433.56*	*25*	*657.34*	*3.96*	*0.00*
Grade	*7,289.24*	*5*	*1,457.85*	*8.78*	*0.00*
Question	*645.47*	*3*	*215.16*	*1.30*	*0.28*
Question Representation	*12.36*	*1*	*12.36*	*0.07*	*0.79*
Answer	*381.48*	*3*	*127.16*	*0.77*	*0.51*
Grade-Question Representation	*2,179.41*	*5*	*435.88*	*2.63*	*0.02*
Question-Answer	*3,053.20*	*8*	*381.65*	*2.30*	*0.02*
Residual	*39,019.89*	*235*	*166.04*		
Total	*55,453.48*	*260*	*213.28*		

To give support to these results found in the ANOVA test, the residual of the data was found so that a normal residual plot, residual versus fitted values, and residual versus significant single variables could be ran. As for the residual versus the fitted values, it is apparent that the data is random and scattered evenly providing support that the data set is in fact an independent set. Figure 4 show cases the normal residual plot and the residual versus fitted values, the line for the normal plot is tight to the linear line, having tails right on the ends.

Figure 4

Normal Residual Plot and Residual versus Fitted Values

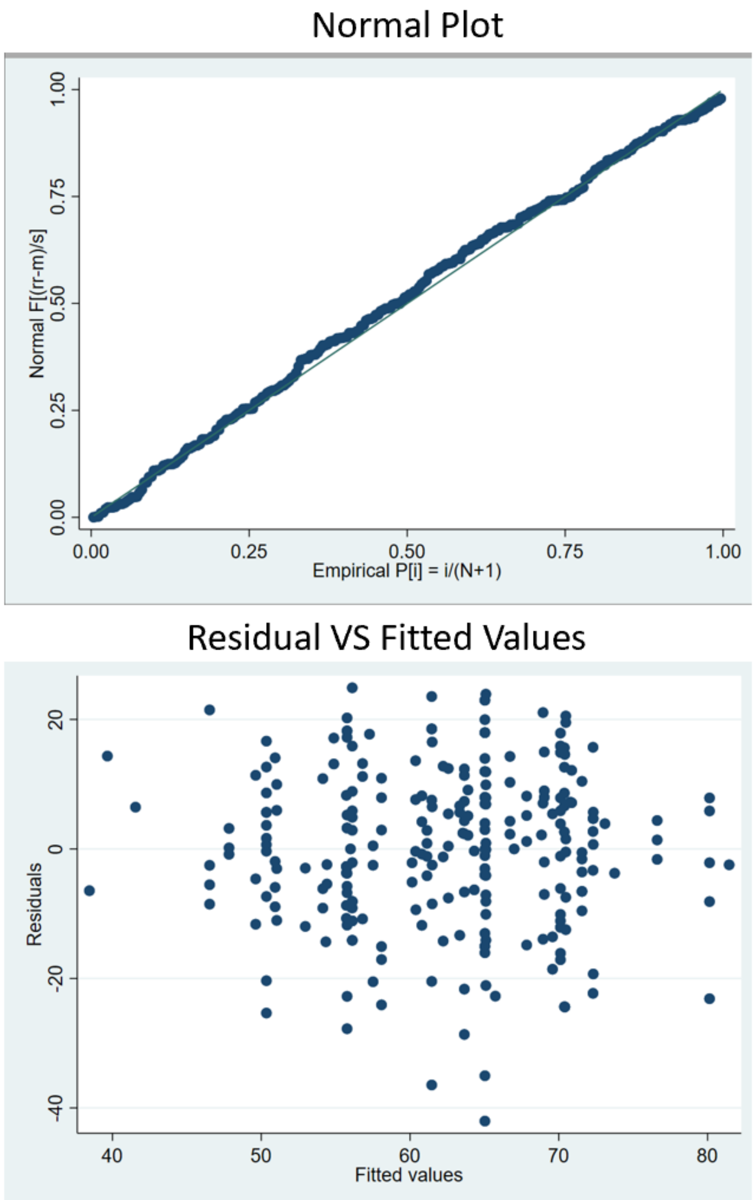
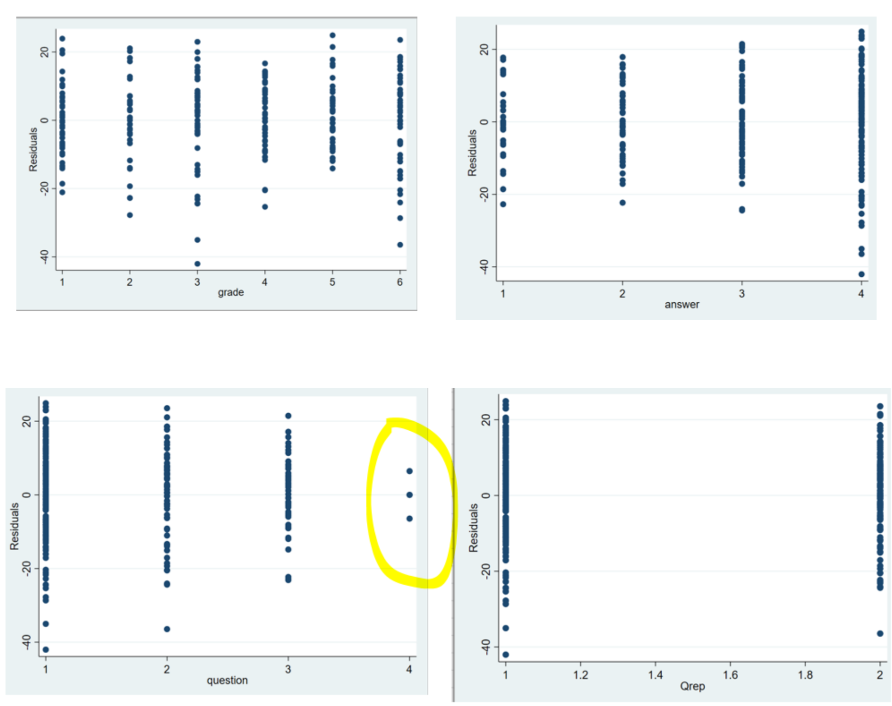


Figure 5 provides the residual versus each single variable that was used in the ANOVA test.

Figure 5

Residual versus Single Variables



All graphs had issues of spread amongst each piece in the variable except grade, which was the only true significant single variable in the study. In addition to using the residual numbers, margin plots where ran with single variables and interactions. Single variable margin plots were used to show the variation and difference amongst the means.

The interaction of grade and question representation bring awareness to sixth grade, in either question representation, having a low mean of pass rate per question. Third grade has the highest mean for both representation. Fifth grade, with more than one representation used has highest mean overall. When looking at the interaction of the question and answer, the highest mean is when a graphical question is asked with a graphical answer. Alternatively, the lowest mean is when a verbal question is asked with a verbal answer choice. Following this, the next lowest combination is when a numerical question is asked with a numerical answer, more than likely a bubble in answer. Overall, the question choice with highest means are graphical questions. In looking at the margin plot with answer versus question the same results were obtained maintaining that graphical answer choices have the highest mean. Both layers of the output of margin plots was used to help verify that this margin plot was in fact useful and thus enforcing that the best results are graphical questions with graphical answers.

The last assistance to support the data that was used was a pos-hoc Tukey test. The Tukey test was used in each single variable that was used in the ANOVA. The results from each test agree with the findings from the ANOVA test on this data set. The main test that gave support to the ANOVA table was the Tukey multiple comparison statistical test was conducted on the significant interactions and agreed with the results, this can be seen in Table 7.

Table 7

Tukey's Test for Interaction

Interaction of Grade-Question Representation	***Mean***	***Unadjusted Group***
1-1	*68.08*	*DEF*
1-2	*66.08*	*CDEF*
2-1	*57.71*	*ABC*
2-2	*71.00*	*EF*
3-1	*65.52*	*DE*
3-2	*74.4*	*F*
4-1	*52.57*	*A*
4-2	*55.14*	*AB*
5-1	*58.17*	*ABC*
5-2	*52.32*	*A*
6-1	*68.07*	*DEF*
6-2	*61.10*	*BCD*

Interaction of Question-Answer	*Mean*	*Unadjusted Group*
1-1	*47.00*	*ABC*
1-2	*67.50*	*D*
1-3	*64.43*	*CD*
1-4	*59.86*	*BC*
2-1	*66.61*	*CD*
2-2	*72.50*	*BCD*
2-3	*61.65*	*BCD*
2-4	*64.00*	*CD*
3-1	*53.58*	*AB*
3-2	*66.90*	*CD*
3-3	*47.86*	*A*
3-4	*69.41*	*D*
4-1	*56.00*	*ABCD*
4-2	*67.00*	*ABCD*
4-3	*N/A*	*N/A*
4-4	*40.00*	*A*

Within the multiple comparison test the means are easily produced which allow the results to speak for themselves. Each interaction is compared in all possible outcomes. The mean of the outcome is given so that it can be determined where the major areas of concern are. Another positive result of this test is it provides unadjusted groups that give support to the significance amongst each level. For example, looking at the grade-question representation, it is noted that in the 3^{rd} grade the amount of representation shares the same letters, DEF and CDEF. This provided support to the means being close and it not having much significance in this grade level. Whereas in observing 4^{th} grade, the letters for one representation are ABC and more than one representation is EF. This allows the data to have a conclusion that in this grade level the number of representation in the question have a major impact on the outcome of the pass rate for a problem. Based on these results it can be supported that in grades 4^{th}, 5^{th}, $6^{th,}$ and 8^{th}, the number of representations within a question have great significance in the outcome. Similar ideas can be taking from the interaction of question-answer. In verbal question and verbal answer this is significance to the study along with symbolic question symbolic answer. A final note that can be taking from this test is that numerical representation in both question-and-answer choice is lacking and is unable to provide accurate information in this areas due to being underrepresented.

DISCUSSION

The data gathered and analyzed, along with the review of literature, support the idea of students needing to become improved in ML so that they are set to be successful in all areas of representation in algebra-based questioning. Students performed highly in graphical question and answer problems validating that the issue does not lie in the visual aspect of understanding. Results indicated that students could look at figures and analyze what is asked. The main issue found in interpretation of the data was that students are not performing well on questions that are verbally asked and require a verbal answer choice. Questions asked verbally require students to not only understand how to compute the mathematical side of the questions but also interpret what is being asked to reach the level of computation for the question. Verbally asked questions compel the students to make connections to real life situations that involve mathematical problem-solving skills,

> These real-world applications show students not only why they'll need the concepts being taught in math class, but also how to solve the real-world problems they encounter using math they already know. Connecting the dots between math class and everyday life is what will reinforce concepts outside of the classroom. Eventually, these basic math concepts will become second nature (Thinkster Math, 2018).

If students had a stronger understanding of, and more practice with, ML skills then verbally asked questions could potentially have a higher percentage of pass rate. Webb et al. provide suggestions on ways students can reach these goals are by accessing, using, interpreting and critically assessing numerical information used in real-life context.

Relation to Mathematical Literacy

Ways to incorporate ML skills into an classrooms would involve that teachers are exposed to what ML is, how it works and what it would require to teach it in a manner that students would be successful in learning and retaining it. School districts should provide professional development, on campus training, and mentorships so that a set of teachers are created who are capable in adequately teaching ML skills to their students. Having educators who can effectively transmit ML to students would present two possibilities. One option ML could be presented is throughout the current classroom. Teachers could find ways to bring it into the curriculum they already teach and find ways to make students use the skills in problems already within the curriculum.

Another avenue for incorporation of ML would be the addition of a new course that focuses only on ML. This course could focus on establishing ML to students, allow for practice of questions that use ML, and instruction using teaching strategies that encourage work with these problems. Creating a course for ML content was suggested within the literature. However, this may be difficult to do in many schools and other settings. Having students who focus only on building ML skills would be ideal. If not possible, at least incorporating it into the classroom would still bring much benefit to students. The earlier the students can be introduced to ML the better the skills would become over time. Firdaus et al. (2017) support the belief that students need to develop ML skills as young as primary school. Based on the results of this study, it is suggested that having a class that is focused on ML could be beneficial in the elementary grades before testing is started. This material could then be combined into a traditional math classroom until the completion of secondary schooling.

Suggestions for Further Study

If a ML course was developed, further research could compare students who take a ML course, or have it incorporated in their math class, to those who did not have any teaching to ML. This research would help analyze if students are able to enhance the outcome of verbal questions and problem-solve through mathematical word inquiries. ML could also be incorporated into the post-secondary curriculum. This area could also provide another avenue for research to determine if students who had become fluent in ML performed better during an undergraduate program of study. The outcome from bringing ML to the American education program could possibly result in higher standardized test scores for questions that utilize algebraic representations. Having students that can answer various types of representations produces individuals who can work through an array of real-life situations and contribute effectively to society and the future of the world.

CONCLUSION

Studying the STAAR test data from 2017, 2018 and 2019 in grades 3rd through 8th presented the concern that students are not prepared to perform well with various representations used in algebra questions. This research found that students do not have high achievement in questions that are verbally asked or answer choices that are verbally based. The research suggests that a possible solution to the issue is for students to be introduced to ML and become fluent in its mathematical language. Research findings suggest students be provided the opportunity to develop ML in the elementary grades, then slowly have ML incorporated into mathematics curriculum throughout. In turn, there is hope that the student's overall math skills would potentially increase. Studies, such as this project, support the idea of the benefits of ML to a student's success in all levels of math. Implications from this study to also extend the idea that teachers be adequately prepared to teach ML to students as a stand-alone course or through the current mathematics curriculum.

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