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Mathematics Vocabulary Knowledge of Eighth-Grade Students

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Mathematics Vocabulary Knowledge of Eighth-Grade Students

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Dedication

For my family, Halil Unal, Emine Unal, Busra Unal, Hafize Unal, and my sponsors, Dr. Mustafa Ulusoy, Lutfiye Tutuncu, Aylin Ozer, Bulent Ozer, Nergiz Dagoglu, Cemal Karabel, who supported me during my master's education and made tremendous contributions to my academic career.

Abstract

Mathematics Vocabulary Knowledge of Eighth-Grade Students

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The purpose of this study was to develop a mathematics vocabulary measure for eighth-grade students and to determine the relationships among general vocabulary knowledge, mathematics vocabulary knowledge, and mathematics computation. Students (n=34) took three tests in the following order: (1) mathematics vocabulary, (2) WRAT Computation, and (3) GMRT Vocabulary. Mathematics vocabulary results revealed that the mathematics vocabulary test was highly reliable. Based on students' scores in all tests, the correlation between mathematics vocabulary knowledge and general vocabulary knowledge as well as the relationship between mathematics vocabulary and mathematics computation were strong. However, there was no significant association between mathematics computation and general vocabulary knowledge. Mathematics vocabulary knowledge was a mediator between the two.

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CHAPTER 1: INTRODUCTION

Vocabulary Knowledge and Mathematics

As an important aspect of language skills, general vocabulary knowledge plays a vital role in mathematics development (Purpura, Hume, Sims, & Lonigan, 2011) because students use vocabulary as a medium to understand content and to communicate about mathematics topics (Nagy, & Townsend, 2012; Zhang, Hu, Ren, & Fan, 2017). Research has shown that general vocabulary knowledge predicts success in various mathematics areas including numeration and word problem-solving skills (Gray, & Reeve, 2016; Harvey, & Miller, 2017; Singer, Strasser, & Cuadro, 2018).

In addition to general vocabulary knowledge, students need to acquire appropriate academic vocabulary (Nagy, & Townsend, 2012; Schleppegrell, 2001), including specialized technical vocabularies, words pertaining to a particular area, which comprise morphologically complex terms related to the particular content areas as well as subject-related uses of common words and phrases (Nagy, & Townsend, 2012; Snow, & Uccelli, 2009). Therefore, acquiring the language of a new subject is a part of developing competence in that content area (Schleppegrell, 2007). In mathematics, specifically, students need to know the meanings of such words as "some" and "many" and phrases like "twice as much" and "during peak hours" (Schleppegrell, 2007), which Thompson and Rubenstein (2000) referred to as *mathematics vocabulary*.

There has been increasing research interest in mathematics vocabulary and mathematics competency. For instance, Powell and Nelson (2017) showed that first graders' mathematics fluency, as a predictor of their mathematics competency (Mabbott & Bisanz, 2008), had a strong positive correlation with their mathematics vocabulary. Similarly, Powell, Driver, Roberts, and Fall (2017) determined that third- and fifth-grade students' mathematics vocabulary knowledge was positively associated with their computational skills. Also, Peng and Lin (2019) showed that Chinese fourth graders' measurement and geometry vocabularies contributed to their word-problem-solving performance. But while previous research indicates that mathematics vocabulary has a positive impact on mathematics achievement in early grades, there is no research, to my knowledge, showing similar findings for later grades after elementary school.

Furthermore, how general vocabulary knowledge is associated with the relationship between mathematics vocabulary knowledge and mathematics achievement in later grades needs to be investigated. Researchers have addressed this association in early grades. For example, elementary students' general vocabulary has been found to be significantly correlated with their mathematics vocabulary knowledge (Forsyth, & Powell, 2017; Powell, & Nelson, 2017). Likewise, Toll and Van Luit (2014) found that kindergarteners' mathematics language as measured by items including quantity and spatial words was a mediator between their general language skills, as measured by their receptive vocabulary knowledge, and their mathematics skills. However, conducting a study is necessary to determine whether or not the relationship is similar in later grades.

Previous mathematics vocabulary measures

Purpura and Logan (2015) developed a 16-item mathematics vocabulary test for kindergarteners and included terms related to early numeracy, such as "*under*" and "*more*". They asked the questions orally using pictures and reported internal consistency as .85. To assess first graders' mathematics vocabulary knowledge, Powell and Nelson (2017) composed a 64-item test comprising mathematics vocabulary from four domains, namely operations and algebraic thinking (e.g., *equal*); number and operations in base 10 (e.g., *tens*); geometry (e.g., *circle*); and measurement and data (e.g., *hours*). The researchers found strong reliability ($\alpha = .85$) in the measure and a wide variety of students' responses.

For later elementary grades, Forsyth and Powell (2017) generated a mathematics vocabulary measure for English-speaking fifth grade students, and Peng and Lin (2019) designed one for Chinese-speaking fourth graders. For the former measure, the authors included 129 items coming from kindergarten through sixth-grade items in the following domains: whole numbers, fractions, measurement, and geometry. They used various response types such as writing definitions and matching to a word bank, and they stated Cronbach's α was .96. For the latter measure, Peng and Lin (2019) included 93 mathematics vocabulary items from grades 3, 4, and 5 in the areas of measurement, geometry, and numerical operations. Students responded to both multiple choice and oral questions. The authors reported Cronbach's alpha for measurement vocabulary, geometry vocabulary, and numerical operation vocabulary as 0.63, 0.80, and 0.70, respectively.

At the middle school level, Hughes, Powell, and Lee (2018) prepared a 57-item middle school mathematics vocabulary measure combining sixth, seventh, and eighth-grade vocabularies. There were two types of questions; (1) finding the definition among four choices for a given mathematics term, and (2) choosing the term among four options for a given definition. Cronbach's alpha was .912. While this test was for all late middle scholars, the measure proposed for the present study specifically targets eighth-grade students. After validation of the test, results will be used to determine performance differences in mathematics vocabulary by different categories and to look at correlations among mathematics computation skills, mathematics vocabulary and general vocabulary as well as to find out whether mathematics vocabulary is a mediator between general vocabulary and mathematics computation, and to examine the extent to which mathematics vocabulary knowledge and general vocabulary knowledge were related to each other at this grade level.

Purpose and Research Questions

The purpose of this study was to (1) develop an eighth-grade mathematics vocabulary test and find out students' performance in the test, (2) determine the correlations among mathematics vocabulary, general vocabulary measure, and (3) find out whether mathematics vocabulary is a mediator between general vocabulary and mathematics computation. My research questions were as follows:

1. What is the reliability of the eighth-grade mathematics vocabulary measure?

2. With which category of mathematics vocabulary do eighth-grade students have the most difficulty in understanding?

3. What are the correlations among eighth-grade students' general vocabulary knowledge, their computation skills, and mathematics vocabulary knowledge? How do the correlations differ across different mathematics categories?

4. To what extent, does mathematics vocabulary knowledge mediate the relationship between general vocabulary knowledge and mathematics computation as a proxy for mathematics achievement?

CHAPTER 2: METHOD

Participants

Participants were 34 eighth graders (18 female and 16 male) at a private school in Texas. Mean age was 14.21. The student population was 76.6 % Caucasian, 17.6 % Asian American, 2.9 % African American, and 2.9 % Hispanic (see Table 1). Students' native language was English, and none had disabilities. Their reading and mathematics performances were at or above grade level according to the school teachers' report. None of the participants was eligible for free-reduced lunch. The majority had

parents with college degrees.

Table 1. Demographics and Descriptive Data (*N = 34*)

Variable	*n*	*(%)*
Gender		
Female	18	53.9
Male	16	46.1
Race		
African American	1	2.9
Asian American	6	17.6
Hispanic	1	2.9
White	26	76.6

Materials

General Vocabulary

I measured students' general vocabulary knowledge with the vocabulary subtest of the Gates-MacGinitie Reading Tests, Level 7-9 (GMRT; MacGinitie, MacGinitie, Maria, & Dreyer, 2000). This measure was appropriate for this study because my purpose was to determine students' general vocabulary knowledge. The vocabulary test consisted of 45 items to be completed within 20 min. Each item featured an underlined vocabulary item for which students choose the closest synonym among four options. Each correct answer yielded one point for a maximum of 45 points. Within the sample, Cronbach's alpha was .88.

Mathematics Computation

I assessed students' computation skills with the Math Computation subtest of the Wide Range Achievement Test-4 (WRAT; Wilkinson & Robertson, 2006) because computation competency predicts students' mathematics achievement (e.g., Jordan, Kaplan, & Hanich, 2002; Mabbott, & Bisanz, 2008). The test included 40 computation questions and arranged in order of progressive difficulty to be completed within 20 minutes. The total number of students' correct answers was their score on the test. Within the current sample, Cronbach's alpha was .81.

Mathematics Vocabulary

I developed the mathematics vocabulary measure based on the National Center of Teaching Mathematics (NCTM) and the Texas Essential Knowledge and Skills (TEKS) mathematics standards. First, I identified 81 mathematics terms most frequently used by both NCTM and TEKS. Next, I determined the most frequently repeated 135 vocabularies in the Partnership for Assessment for College and Careers (PARCC) and the State of Texas Assessment of Academic Readiness (STAAR) exams. I selected 47 mathematics vocabulary items which were included in both the mathematics standards and the standardized exams. I eliminated those introduced before sixth grade, which left 36 items for the final measure. Grounded on TEKS and NCTM standards, I grouped these items into four mathematical categories, including (1) number and operation, comprising terms related to students numeric knowledge (e.g., irrational number and radical expressions); (2) algebra, containing terms related to expression, equation, and functions (e.g., linear equations with two variables); (3) geometry, comprising terms pertaining to transformation and similarity (e.g., rotation and similar figures); and (4) data and measurement, containing terms related to data interpretation (e.g., the best fitting line and scatter plots) . After selecting and categorizing mathematics terms, I consulted the glossary section of the McDougal Littell Pre-Algebra book to determine the definitions of the terms (Larson, Boswell, Kanold, & Stiff, 2005).

The test included three types of multiple-choice questions: (1) choosing the term that best fits a given definition best, (2) selecting a definition that best fits a given mathematics term best, and (3) choosing an option that best fills in a blank in a given statement. After reading directions, students answered questions on the 36-item mathematics vocabulary test for 20 min. For the current sample, Cronbach's alpha was .84.

Procedure

I had experience in standardized test administration procedure, so I collected the data. All tests were the whole-class test, and there was an instruction period before each test. I administered the tests in two consecutive days in the following order: (1) mathematics vocabulary, (2) WRAT Computation, and (3) GMRT Vocabulary. Students complete the tests within a total of 60 minutes. The score for each test was the total of correct answers. Inter-scorer reliability of the measures was 99.6 percent for GMRT Vocabulary, 99.2 percent for WRAT Math Computation, and 99.5 percent for Mathematics Vocabulary.

CHAPTER 3: RESULTS

Student scores on mathematics vocabulary test ranged from 14 to 34 (maximum score 36) and with an average score of 24.97 (*SD* = 5.78). To address the first research question, I calculated Cronbach's alpha using SPSS for the reliability of the mathematics vocabulary, which yielded .84 for the 36 items, indicating high reliability. I further checked whether the deletion of any item made a significant difference, defined as a .02 increase (Powell & Nelson, 2017), in the value of Cronbach's alpha. No item removals changed the alpha significantly, so I retained all items in the test.

Next, I calculated the accuracy percentages of the mathematics vocabulary in each category to determine the extent to which the eighth-grade had difficulty with comprehension. The accuracy percentages were 73%, 75%, 76%, and 62 % in the number and operation, algebra, geometry, and data and measurement categories respectively see Table 2 for category means, standard deviations, and accuracy percentages). Additionally, I examined the average accuracy per item to find the most difficult items. More than 85% of the students correctly identified the meanings of *scientific notation, function, variable, rise, run,* and *reflection*. In contrast, almost half of the students could not identify the meanings of *irrational numbers, base, linear equation with two variables, constant terms, terms of expression, slope,* and *rotational symmetry*.

Table 2. Number of items by Category

Categorical Vocabulary (total possible)	*M*	*(SD)*	*Accuracy*
Number and Operation (8)	5.82	1.80	73%
Algebra (13)	8.68	2.23	75%
Geometry (11)	8.38	2.39	76%
Data and Measurement (4)	2.44	0.79	62%

I also examined the correlations between the mathematics vocabulary test and GMRT vocabulary test results and between the mathematics vocabulary test and the WRAT computation test results. Both correlations were positive and significant, .462 and .454 respectively (see Table 3 for means, standard deviations, and correlations among the variables). Then, by calculating coefficients of determination (R^2) for each measure, I determined that WRAT math computation scores explained 20.6% variance in mathematics vocabulary scores and the GMRT vocabulary scores accounted for 21.3% of the variance in mathematics vocabulary scores. Next, I performed multiple regression analysis (see Table 4), and when I entered GMRT vocabulary and WRAT computation scores as predictors, the model was significant, $F(1,32) = 8.742$, $p < .001$. General vocabulary combined with mathematics computation scores explained 36.1 percent of the variance in mathematics vocabulary. Mathematics computation was a significant positive predictor of mathematics vocabulary scores after general vocabulary was controlled, (B =.564, β = .389, $t(34) = 2.674$, $p < .05$). Every increase of one point on the WRAT corresponded to an approximately 0.56-point increase in the students' mathematics vocabulary scores.

Table 3. Means, Standard Deviations, and Correlations *(N=34)*

	Raw Score		Correlations	
Variables	*M*	*SD*	WRAT_C	GMRT_V
WRAT_C	35.06	3.99	1	
GMRT_V	37.62	6.07	.164	1
Mathematics Vocabulary	24.97	5.78	.454**	.462**

Note. GMRT_V = Vocabulary subtest of Gates MacGinite Reading Test; WRAT_C = Calculation subtest of Wide Range Achievement-4. ** *P* < 0.01.

General vocabulary was also a significant positive predictor of mathematics-vocabulary scores after mathematics computation was controlled (B = .379, β = .398, $t(34) = 2.734$, $p < .05$). Every increase of one point on the GMRT corresponded to an approximately .38 points increase in the students' mathematics vocabulary scores.

Table 4. Summary of Regression Analyses

Predictor	*B*	*SE B*	*ß*	*t*	*p*	R^2	ΔR^2
Model 1:							
GMRT Vocabulary	0.440	0.149	0.462	2.944	.006	0.213	
Model 2:							
GMRT Vocabulary	0.379	0.139	0.398	2.734		0.361	0.148
WRAT Computation	0.564	0.211	0.389	2.674			

Note. GMRT-V = Vocabulary subtest of Gates MacGinite Reading Test; WRAT-C = Calculation subtest of Wide Range Achievement-4.

The relationship between general vocabulary knowledge and mathematics computation (as a proxy for mathematics achievement) was mediated by mathematics vocabulary knowledge. The standardized regression coefficient between general vocabulary knowledge and mathematics vocabulary knowledge was statistically significant, as was the standardized regression coefficient between mathematics vocabulary knowledge and mathematics computation. The standardized indirect effect was (.44). (.33) = .15. I used bootstrapping procedures to test the significance of this indirect effect and computed unstandardized indirect effects for each of the 34 bootstrapped samples. I calculated the 95% confidence interval by finding the indirect effects at the 2.5^{th} and 97.5^{th} percentiles. The bootstrapped unstandardized indirect effect was .15, and the 95% confidence interval varied between .010 and .39. Therefore, the indirect effect was statistically significant.

CHAPTER 4: DISCUSSION

The primary purposes of this study were (1) to determine the reliability of mathematics vocabulary test; (2) to determine the category of mathematics vocabulary with which students struggled most; (3) to determine the associations among general vocabulary knowledge, mathematics vocabulary knowledge, and mathematics computation; and (4) to determine the extent to which mathematics vocabulary knowledge mediates the relationship between general vocabulary and mathematics computation as a proxy for mathematics achievement.

My first research question concerned the reliability of the mathematics vocabulary measure used in this study. Because there was no pre-existing standardized eighth-grade mathematics vocabulary test available, as a first step, I developed a mathematics vocabulary measure, which I found to be highly reliable.

My second research question concerned the mathematics vocabulary category with which the students had the most difficulty. The result showed that the accuracy of data and measurement vocabulary was the lowest. Describing statistical methods to analyze data is possibly quite compelling for eighth-grade students, so they might have difficulty to understand related mathematics vocabulary. For further analysis, I performed an item by item examination to identify the most challenging vocabulary items. Interestingly, although the accuracy of algebraic vocabularies was quite high, there were certain terms such as *linear equation* in *two variables* that most of the students missed, suggesting variation in the difficulty of algebraic terms for eighth-grade students. Additional research is necessary to identify this variability in the Algebra category.

Next, I addressed my third question by determining the correlations among general vocabulary knowledge, mathematics vocabulary knowledge, and mathematics computation performance. Previous research with kindergarteners and with first, fourth, and fifth graders demonstrated significant positive correlations among these three variables (Forsyth, & Powell, 2017; Peng, & Lin, 2019; Powell, & Nelson, 2017; Purpura, & Logan, 2015). Therefore, I expected the relationships would remain strong for eighth graders as well, and the results were partially in line with this expectation. On the one hand, there was a significant positive correlation between mathematics vocabulary knowledge and mathematics computation as well as between mathematics vocabulary and general vocabulary knowledge. These findings suggest that general vocabulary knowledge might help students learn and that students may rely on general vocabulary for mathematics vocabulary (Zhang et al., 2017), and students can use mathematics vocabulary as a mean to make sense of mathematical concepts (Nagy, & Townsend, 2012). On the other hand, contrary to my assumption, there was no significant association between mathematics computation and general vocabulary knowledge. (Zhang et al., 2017), and students can use mathematics vocabulary as a mean to make sense of mathematical concepts (Nagy, & Townsend, 2012). On the other hand, contrary to my assumption, there was no significant association between mathematics computation and general vocabulary knowledge. A possible interpretation of this low correlation might be that academic language may become more crucial while the importance of general vocabulary knowledge decreases over time in later grades. However, additional longitudinal research is needed to determine how the impacts of general vocabulary knowledge on mathematics change over time.

For further analysis, I categorized mathematics vocabulary based on NCTM and TEKS standards including number and operation, algebra, geometry, and data and measurement to determine whether correlations among mathematics vocabulary, general vocabulary and computation varied across different mathematics categories. Although there were significant positive associations between general vocabulary and mathematics vocabulary knowledge in each area, the correlation was the strongest for number and operation-related vocabularies. This finding indicates that the relationship between language and numeracy skills demonstrated in the early years of schooling (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Harvey, &Miller, 2017; Passolunghi, Lanfranchi, Altoè, & Sollazzo, 2015; Sowinski, Skwarchuk, Kamawar, & Bizans, 2015) might continue in later years. Students who perform highly on number and operation vocabulary portions of the test might have a better understanding of number-related terms through their semantic language skills. For instance, knowing the lexical meaning of rational numbers may have helped students find the meaning of irrational number on the vocabulary test. Concerning the relationship between mathematics vocabulary knowledge and computation skills, all vocabulary categories except data and measurement vocabulary exhibited a significant correlation. Strikingly, the link between geometry vocabulary and computation skills was the strongest among all vocabulary categories. Even the association between computation skills and number and operation vocabulary was not as high. This finding supports the earlier research showing that low achieving geometry learners have difficulties in computation and that arithmetic problem-solving skills are distinguishing factors in geometry success (Bizzaro, Giofre, Girelli, & Cornoldi, 2018). Future research should focus on the mechanisms of geometry learning to examine why such a relationship was found in this study.

My fourth research question addressed whether mathematics vocabulary knowledge can be a mediator between general vocabulary knowledge and computation skills. Although there was no direct relationship between general vocabulary and computation, mathematics vocabulary had a strong relationship with both. Therefore, I hypothesized that mathematics vocabulary could be a mediator between general vocabulary and computation. The results confirmed this hypothesis, indicating that general language skills play an indirect role in mathematics development through mathematics language. The function of mathematics language as a mediator demonstrated in mathematics studies of early grades (Purpura, & Logan, 2015; Toll, &Van Luit, 2014) continues in later grades. We might explain these findings through the multi-semiotic structure of mathematics which includes linguistic, visual and symbolic components (O'Halloran, 2000).

According to this model, students need to understand not only numerals and symbols but also words and vocabulary related to mathematics (Adams, 2003). It is possible that students use their general language skills to understand the meanings of mathematics terms, with which they make sense of mathematical concepts and, think about and communicate disciplinary content (Nagy, & Townsend, 2012). Future research is needed to examine the effects of mathematics vocabulary knowledge on students' understanding of different mathematics concepts in the eighth-grade curriculum.

CHAPTER 5: LIMITATIONS

This research has some limitations. First, I collected data from only one private school with a small number of students. Participating students had middle-to-upper income families and received extra support from both their parents and schools. Educational advantages related to the students' social-economic status might help them grow more in comparison to low-income students, which in turn might have affected their levels of performance in comparison with those of low-income students, thus limiting the generalizability or transferability of the findings to other populations. Future research is necessary to explore whether the findings are similar for students with different socio-economic backgrounds.

Also, the mathematics vocabulary test that I composed for this study was not normed for a larger population, so further research is necessary for the test to be validated with larger groups. Additionally, I focused only on mathematics computation skills while looking at the role of mathematics vocabulary in mathematics achievement. However, the association between mathematics vocabulary and other mathematics topics such as word problem solving, and geometry can be different. The function of mathematics vocabulary in various mathematics areas remains unanswered. Therefore, future research using measures for different mathematics contents is warranted.

CHAPTER 6: IMPLICATIONS

The present study has significant implications that may help educators better understand why learning mathematics is quite challenging for some students. The finding that mathematics vocabulary knowledge, as a part of academic language, was significantly correlated with both general vocabulary knowledge and mathematics computation suggests that mastery of terminology can be an essential component of mathematics achievement (Thompson, & Rubenstein, 2000). This suggestion in line with Forsyth and Powell's (2017) study showing that students who had both reading and mathematics difficulties performed significantly lower than typically achieving students on a mathematics vocabulary measure. It is likely that students experience word and text level difficulties because of the density of academic language (Prediger, Erath, & Opitz, 2019). For instance, school texts have substantial lexical and grammatical features, as well as shortened and nominalized expressions (Schleppegrell, 2001). To understand text content, students need to have both mathematics vocabulary knowledge and strong mathematics content background. In light of the current findings and previous research, it is likely that mathematics vocabulary instruction is beneficial for students who have difficulty in understanding mathematics contents.

Appendix: Mathematics Vocabulary Terms

Question ID	Terms	Answer Choice
1	Irrational numbers	Term
2	Real numbers	Term
3	Base	Term
4	Perfect square	Definition
5	Exponent	Term
6	Radical expression	Definition
7	Scientific notation	Term
8	Square root	Term
9	Linear equation with two variables	Term
10	Slope intercept form	Term
11	Function	Term
12	Coefficient	Term
13	Constant terms	Definition
14	Like terms	Definition
15	Variable	Term
16	Terms of expression	Definition
17	Numerical expressions	Definition
18	Variable expression	Term
19	Rise	Definition
20	Run	Definition
21	Slope	Definition
22	Center of dilation	Term
23	Center of rotation	Definition
24	Dilation	Term
25	Reflection	Definition
26	Translation	Term
27	Rotation	Term

Question ID	Terms	Answer Choice
28	Rotational symmetry	Term
29	Transformation	Definition
30	Corresponding angles	Definition
31	Corresponding parts	Term
32	Similar figures	Term
33	Trend line	Definition
34	Best fitting line	Term
35	Ordered pairs	Term
36	Scatter plot	Term

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