Improving Mathematics Vocabulary Learning in the Foundation Phase

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Abstract
Mathematics is more than numbers. Students should be able to understand and use academic vocabulary to think about and discuss mathematical situations. However, vocabulary learning within the mathematical contexts could be very complex and challenging to students, especially for English Learners. The purpose of this study aims to synthesize literature and present a review regarding the vocabulary learning challenges of mathematics in the foundation phase. Peer-reviewed articles (N=42) are gained from Google Scholar via systematically searching key words "mathematics vocabulary" with one or more of the following terms: challenge, difficulty, error, discourse, and analysis. Lee's (2005) study is applied as the theoretical framework. It formulated three main features of vocabulary in the mathematics contexts: same meaning words (same meanings in ordinary English and mathematics, such as discount, and total), math-specific words (technical math words, such as coefficient and linear equation), and multiple- meaning words in ordinary English and mathematics (such as even and function). This study shows a variety of challenges in mathematics vocabulary learning. Also, the study provides suggestions in learning practice and instructional strategies in order to help teachers support students to improve their mathematics vocabulary learning in the foundation phase.

Keywords: mathematics vocabulary, instructional strategies

Introduction

It is common in a mathematics classroom that students do not read the entire problems but just pay attention to numbers when they are solving word problems (Fatmanissa & Kusnandi, 2017). However, mathematics is more than numbers. It lives on its own system that includes symbols, technical language, and concepts. Some words have the same meanings within mathematical contexts as in the daily language. Others are "learned almost entirely at school and are not spoken at home" (Kenney, Hancewicz, Heuer, Metsisto, & Tuttle, 2005, p. 3). Therefore, it is true that developing mathematical vocabulary is like/resembles learning a foreign language (Bicer, Boedeker, Capraro, & Capraro, 2015). When there is a new vocabulary introduced to students, it must be taught and explained clearly. Vocabulary is strongly correlated to reading comprehension, students' comprehension prediction, and content area learning (Espin & Foegen, 1996; Fitzgerald & Graves, 2005; Fisher & Frey, 2008). Only when students understand the new words can they achieve the expectation of "using the language of mathematics to express mathematical ideas precisely" (NCTM, 2000, p. 268).

Developing mathematics language in the classroom is also emphasized by NCTM Process Standards (2010) and the CCSS Mathematical Practice Standards (2010). In NCTM Process Standards, the usage of mathematical vocabulary is the foundation of problem solving, reasoning and proof, and communication. In CCSS Mathematical Practices, students are expected to apply language in the content areas as follows: (a) make sense of problems and persevere in solving them, (b) critique the reasoning of others, and (c) construct viable arguments.

Moreover, researches indicated the indispensable role of vocabulary learning in mathematics. Miller (1993) points out, "without an understanding of the vocabulary that is used routinely in mathematics instruction, textbooks, and word problems, students are handicapped in their efforts to learn mathematics" (p. 312). Smith and Angotti (2012) identify that "words are essential to a conceptual understanding of the lesson" (p. 45). Edgren (2008) pointed out that the obstacle of student low achievement in word problem solving is that students are lack of vocabulary acquisition, clarification of technical words, and class communication on the topic. Moreover, prior literature indicated that vocabulary is a significant predictor of reading comprehension that challenges most students (Blachowicz, Fisher, Ogle, & Watts-Taffe, 2006; Smith & Angotti, 2012). In addition, Schoenberger and Liming (2001) found out that students were weak in their thinking skills because of their use of mathematics vocabulary. If students develop their vocabulary knowledge, they would be easier to "expand their abstract reasoning ability and move beyond operations to problem solving"(Tyminski, 2013, p. 40). Therefore, improving mathematics vocabulary learning needs to be paid attention to.

However, vocabulary learning within the mathematical contexts could be very complex and challenging to students, especially for English Learners and students with diverse educational backgrounds. Teaching vocabulary in the mathematics context, appropriately, is also challenging for teachers. They may feel hard to determine when and how to teach. Bay-Williams & Livers (2009) discussed the dilemma in teaching vocabulary in class. Spending more time in vocabulary previewing means having less time for instruction in class and previewing math

content. Moreover, teachers concern that students may focus on finding out meanings of words instead of achieving the course objectives. In an effort of exploring the difficulties of vocabulary learning in mathematics, the purpose of this study aims to present a review and synthesize literature regarding the vocabulary learning challenges of mathematics in the foundation phase as well as effective strategies during instructions. The research questions are listed as follows:
(1) Why vocabulary learning is challenging for students in mathematics learning?
(2) What efficient instructional strategies could be applied in vocabulary learning within the mathematical contexts in the foundation phase?

Methodology

The study systematically searched peer-reviewed articles (N=42) from Google Scholar via using key words "mathematics vocabulary" with one or more of the following terms: challenge, difficulty, error, discourse, and analysis. However, only 38 of 42 articles could be assessed in the full text. After reading the abstracts and full texts, these research articles were categorized by periods of years (the period of 2011-2019, the period of 2001-2010, and studies before 2001), types of studies (empirical studies, non-empirical studies, and literature review), and content (including vocabulary teaching/learning challenges and strategies, only including vocabulary teaching/learning challenges, and only including vocabulary teaching/learning strategies).

Lee's (2005) study is applied as the theoretical framework, which is specifically applied in categorizing mathematical vocabulary teaching/learning challenges. It formulated four main features of vocabulary in the mathematics contexts: same meaning words (same meanings in ordinary English and mathematics, such as discount, and total), math-specific words (technical math words, such as coefficient and linear equation), multiple- meaning words in ordinary English and mathematics (such as even and function), and multiple-meaning words within mathematics (such as base and square).

Results

This study presented a review and analyzed 38 studies that provided both abstracts and full-texts about improving mathematics vocabulary learning in the foundation phase. See the table 1 below for more details.

Table 1: Description of Collected Peer-reviewed Studies.

Categories	Items	N=38
Periods of years	2011-2019	10
	2001-2010	24
	Before 2001	4
Type of studies	Empirical studies	16
	Non-empirical studies	19
	Literature Review	3
Content	Including challenges and strategies	17
	Only including challenges	21

Same-meaning words. Lee (2005) defined same meaning words as "words that have the same meanings in everyday language as they do in ordinary English – the words that are used to set mathematics in context" (p. 15). Same-meaning words are also known as context-related vocabulary, procedural vocabulary and descriptive vocabulary (Bay-Williams & Livers, 2009; Bowie, 2015; DiGisi & Fleming, 2005). Examples of same meaning words include: theatres, field, compare, grocery stores, wheat, etc. They are widely used in contexts and word problems. However, even though the words that are used in a mathematics classroom are the same as used in everyday situations, some issues existed and were discussed in prior researches. Bay-Williams & Livers (2009) argued that students might be unfamiliar to these vocabularies as related to their cultural relevance and low English proficiency. Students who live in the urban areas and who are English learners may not know or have learned these farming terminologies such as acre, coop, orchard, hay, seeds, etc. Students who have co-existing problems in literacy may find it even more difficult in reading word problems (Nagy, 1988; Schoenberger & Liming, 2001). Besides, Adams (2008) and Borgelt (2008) also concerned that students' low self-esteem and self-confidence in the content area could be a problem in applying and understanding same meaning words.

Math-specific words. Math-specific words are defined as "words that have a meaning only in mathematical language" (Lee, 2005, p. 15). Some researchers named it as discipline-specific words, technical vocabulary words or technical terms (Pierce & Fontaine, 2009; Skinner, Pearce, & Barrera, 2016). Examples of math-specific words could be perimeter, hexagonal, edge, hypotenuse, isosceles, coefficient, etc. Prior researches pointed out why students struggled with mathematical terms is because they only hear them in mathematics classroom and don't consider them as their primary discourse (Aflahah, 2018; Rubenstein, 2007; Kotsopoulos, 2007). Moreover, Ingram & Andrews (2018) explained another reason-- because math-specific words are used in a narrow range of topics and only be met when a topic is reviewed, therefore, it may be easier for students to misuse or misunderstand the definitions. In addition, data showed that students using math-specific terms orally more often than writing it down (Borgelt, 2008; Schoenberger, 2007). It means students may not know the correct spelling of these terms, identify these words, or connect terms with the concepts and operations in assignments and assessments. Besides, Lane, O'Meara, and Walsh (2019) demonstrated that pre-service mathematics teachers misuse and lack understanding of certain basic mathematics terminology. This may cause their students' misunderstanding on mathematics register and hamper students' learning progress. The study showed that pre-service mathematics are not fully prepared for vocabulary teaching, and universities did not prepare relative courses for them to teach mathematics literacy.

Multiple-meaning words. Lee (2005) defined multiple- meaning words as "words that have different meanings in mathematical language and natural language" (p. 15). It is also known as semi-technical terms, words shared with other disciplines (Rubenstein, 2007; Skinner et al., 2016). Table 2 listed some multiple-meaning words in the domains of number and quantity, algebra, functions, geometry, and statistics and probability. For example, the word "even" in ordinary English is an adjective and an adverb. Example sentences may be "The floor is even", "Breathing develops an even rhythm during sleep", and "Even a three-year-old child knows the answer" (California State Board of Education, November, 2013; p. 15). However, the word “even” means differently in the mathematical context. Even numbers refer to the numbers that are multiples of two (i.e.: 2, 4, 6 and so on). An even function means any function.

The main challenge of multiple-meaning words learning is that students are struggling in inferring multiple-meaning words more accurately and fluently from different oral and written contexts (Nel, 2012; Kotsopoulos, 2007). “Sometimes we encounter problems when the technical words we use, as formal parts of mathematics, conflict with an everyday understanding or use of the same word, or related words” (Gough, 2007, p. 7). Halliday (1978) found it an easier job for students to develop the usage of language in new ways to serve new functions through schooling. Teachers should use oral language to unpack and explain the meanings in mathematics symbolism.

Other challenges. In addition, there are other challenges that were discussed in prior researches: (1) Extra time would be needed in teaching vocabulary or vocabulary teaching is not focused or fully prepared (Bay-Williams, & Livers, 2009; Blessman & Myszczak, 2001; Georgius, 2008; Solomon, 2009). Aflahah (2018) argued that teachers encountered challenges in providing vocabulary acquisition because “their university education did not fully prepare them to teach them explicitly in this way” (p. 60); (2) Students have low confidence and self-esteem in the area of mathematics learning (Adams, 2008; Borgelt, 2008; Winsor, 2007); (3) Students misunderstand the definitions or cannot connect the words to the operation (Adams, 2008; Sepeng & Madzorera, 2014); (4) Students meet cultural difference and/or have low English Language proficiency (Barwell, 2008; Borgelt, 2008; Hebert & Powell, 2016; Meier & Trevitt, 2010; Smith & Angotti, 2012).

Table 2: Multiple-meaning words in mathematics and everyday situations

Number & Quantity	Algebra	Functions	Geometry	Statistics & Probability
Even Odd Operation Order Prime Produce Power Reminder	Variable Relation Power Expression Domain Formula Notation	Function Relationship Base Exponent Outlier	Degree Right (angle) Measure Similar Reflection Regular Imaginary Extreme	Mode Average Median Range Probability

Effective Strategies in Mathematics Vocabulary Learning

Mathematics vocabulary is closely bound with mathematical conceptual understanding so it should be taught as a partial requirement in class (Dunston & Tyminski, 2013; Orton, 2004). Visualization strategy, class interactions, and intra-personal learning strategies were three main methods discussed in the prior researches. The prime strategy that researchers discussed and that appeared effective is visualization strategy. Visualization strategy is a general instructional method via visual tools such as color coding, graphic organizers, word lists, etc. It provides visual aids for students to understand abstract terms and concepts. Adams (2008) applied graphic organizers to help students connect technical terms with other words, which in turn helped students feel that the contents and concepts are meaningful and useful rather than isolated. The result showed that students' confidence of mathematics and the use of the math language appear to have grown. Borgelt (2008) examined how the vocabulary lists affected students' mathematics learning in using specific vocabulary precisely and improving their self-confidence. The author employed an action research for a 8th grade class and self-reflected, "if I write the vocabulary word on the board as I work with the problem, the students will look up and use it as they discuss the problems - I think I will keep writing them up there" (Borgelt, 2008, p. 35). Apparently, the repetition of hearing and seeing provided more access to students.

Moreover, Edgren (2008) examined whether improving vocabulary acquisition would increase students' ability to communicate mathematically and attempt word problems via a variety of strategies. This action research reported that word wall, as a visual aids, is useful and would be kept, with its usage getting varied. Also, other strategies, such as grouping, association, physical activities, and journal, are effective in both improving students' technical words acquisition and helping them solve word problems. In addition, Aflahah (2018) proposed that gestures could also be applied as one of the visual aids in math classes in consideration of the shortage of school supplies.

Besides, research studies showed the effectiveness of combining visual tools to other teaching strategies. The intervention of using graphic organizers and mathematical vocabulary dictionary illustrated a positive effect on students' mathematics vocabulary building. Jennifer & Beverly (2001) demonstrated that there was an increasing of 15% and 47% students exhibiting a high level of understanding of the vocabulary checklist one and checklist two respectively. Moreover, the usage of direct methods via using text cards, word lists, graphic organizers and word games in contextual learning illustrated its effectiveness in mathematics classes. Contextual learning enables "students to witness the process and actions behind the vocabulary, allowing students to create a mental image" (Bicer, et al, 2015, p. 71). The study employed a t-test to assess student vocabulary knowledge and the results showed that this PBL instruction displayed a statistically significant improvement in the mathematical vocabulary knowledge of students. Therefore, combining visualization strategy to class interactions and/or intrapersonal tools are also effective in vocabulary learning in the mathematical context in the foundation phase.

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