Connections Between Language and Mathematics in the Elementary Classroom

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Abstract: Mathematical literacy, also defined as numeracy, enables learners to connect their mathematical skills to real-world applications. Success in numeracy requires learners to be proficient with literacy skills and background knowledge to develop and implement their understanding. Language in mathematics can present a challenge to all students, in particular for those who are learning English as an additional language. This literature review includes peer-reviewed studies which examine language in mathematics, vocabulary development for mathematical understanding, and dialogue to support student learning. Educators can implement strategies to strengthen numeracy for all students, including those learning English as an additional language. Further research is needed to explore the complexities of problem-solving, transfer of reading skills into mathematics, and student assessment tools to allow educators to understand where learners will benefit from targeted support.

Keywords: literacy; mathematics; numeracy; vocabulary; second language; English language leaner

Introduction

Media headlines making declarations such as "math scores continue deep slide" (Alphonso, 2023) or "math scores dipping for two decades" (Dabu, 2023), generate alarm about the future of mathematics education. These mainstream media news articles refer to the results from the 2022 Programme for International Student Assessment (PISA), which measures the reading, mathematics, and science skills of fifteen-year-old students in several countries around the globe (OECD, n.d.). Although educators and policymakers are being advised to warily consider the results (CMEC, 2023), some Canadians may be more inclined to question our school curriculum or the abilities of teachers to teach this subject effectively.

The term "mathematical language" is used here to describe words used in mathematics that hold specific meanings within this subject area, whereas "language" is more broadly defined to include all text in mathematics (Fesseha et al., 2020; Powell et al., 2020). Similarly, "mathematical literacy" is specific to understanding meaning within mathematics and "literacy" includes text across all subject areas (Karaali et al., 2016; new LearnAlberta, 2022; Steen, 2001).

The framework for the international assessment (PISA, 2022) addresses similar learning expectations as the provincial Mathematics Curriculum in Alberta (new LearnAlberta, 2022) and the National Council of Teachers of Mathematics (NCTM, 2024). Within each of these frameworks, the subject of mathematics is expanded to include new terms such as: "numeracy", "mathematical literacy", "mathematical reasoning", and "problem-solving". The importance of literacy across curricular areas has been widely recognized and acknowledged as a foundational aspect of student learning, especially in early childhood education. More recently, numeracy has been included as another foundational skill in the curriculum. Educational policies within Alberta have directed teachers to implement cross-curricular planning to provide additional opportunities for students to apply both literacy and numeracy across the school day (new LearnAlberta, 2021a; new LearnAlberta, 2021b).

In my urban school community, there are diverse classes consisting of students with a range of academic abilities, language proficiencies, and socioeconomic backgrounds. As an educator, I recognize effective teaching and learning strategies are vital for students to become proficient in both literacy and numeracy. Some students have the additional challenges of learning a new language at the same time as developing their mathematical skills (Vukovic & Lesaux, 2013). As one example, mathematics vocabulary contains homophones, such as some/sum, creating confusion among many students (Stevens et al., 2023). In consideration of the numerous languages represented in my classroom, I have wondered how I could improve my students' ability to strengthen their literacy and numeracy abilities within our Mathematics classroom. Are there meaningful connections between English and a student's home language(s) to support them in their meaning-making to achieve academic success in understanding mathematical concepts?

Method for Literature Selection Process

Throughout my experience teaching mathematics in elementary classrooms, I observed students often struggled with the language associated with this subject more than mathematical knowledge or skills. While this trend was observed with many of my students, it was more pronounced in those who found difficulty with reading comprehension or those who spoke languages other than English. My search for literature included the following keywords: "literacy", "mathematics", "numeracy", "vocabulary", and "second language" or "English language learner". My search was further limited to "peer-reviewed" scholarly articles. I searched broadly for research published between 2013 and 2023, using ProQuest Education Multi-Database, ERIC (via EBSCOhost), Google Scholar, and in scholarly mathematical journals published by NCTM and The National Numeracy Network. I selected several of these resources and used backward chaining to locate additional resources. To support my selection of articles I also evaluated the qualitative research articles against the "Big Tent" criteria (Tracy, 2010).

Using close reading strategies (Gallop, 2000), the selection of articles was organized by methodology, participants, findings, implications, and further research to determine central themes. A variety of research methods were used among the twenty-one articles selected: quantitative, mixed methods, case study, ethnography, action, interpretive, grounded theory, and typology to collect and analyze data. The participants in the research studies included students between preschool age and grade eight, pre-service teachers, and teachers. One article used typology methodology for the purpose of appraising children's picture books for mathematical content. Two of the articles included were not empirical studies: one being a critical review containing definitions related to numeracy and the other a highly cited position paper on teaching numeracy.

Findings

Literacy and numeracy, as understood by educators, are formative skills taught across all curricular areas (New LearnAlberta, 2021a, 2021b). Students benefit from representing their understanding through multimodal representations such as drawings, manipulatives, oral responses, or dialogue to explain their thinking (Cartwright, 2020; Franco et al., 2021; Merritt et al., 2017; Moffett & Eaton, 2019; NCTM, 2022b; Ward & Damjanovic, 2020). Language and mathematical language may be a source of misunderstanding and frustration for students, especially those learning English as an additional language (Barwell, 2020 and 2023; Fesseha et al., 2020). In this review, I will identify areas where students require language to develop numeracy and examine the implications of strengthening numeracy skills for classroom teaching and learning.

Mathematics, Mathematical Literacy and Numeracy

In the late twentieth century, mathematical literacy became identified as the mathematical equivalent to literacy (Karaali et al., 2016; Wilkins, 2015). Mathematical literacy is primarily the ability to understand and apply mathematical concepts in everyday situations to participate as a citizen with both computational and critical thinking skills (Karaali et al, 2016; new LearnAlberta, 2022; Steen, 2001). It is not limited to mathematics because it applies to all curricular areas in some form as they are connected to the content in all other subjects (Steen, 2001; Ward & Damjanovic, 2020; Wilkins, 2015). In the 2022 PISA test, mathematical literacy is identified as a key principle in their evaluation (PISA, 2022). Numeracy is synonymous with mathematical literacy and is the term more commonly used in Canada. Numeracy and mathematics are not the same concept; mathematics is more abstract while numeracy is more concrete and relevant to daily life (Steen, 2001). New LearnAlberta (2021b) defines numeracy as the application of mathematical knowledge and skills in practical situations within all subject areas. Mathematics and numeracy are both necessary for students to be successful in school and beyond (Steen, 2001).

Numeracy across curricular areas is an integral aspect of student learning, especially in early childhood education, because it lays the foundation for students to find success in later years (An et al., 2019; NCTM, 2022b; Ward & Damjanovic, 2020). For early learners, numeracy should be a connection between their lived experiences at home and school, building upon knowledge of language, culture, and numbers that is engaging and prepares a foundation for meaningful experiences with mathematics (NCTM, 2022b; Ward & Damjanovic, 2020). Providing students with rich early language and literacy opportunities will not only be reflected in literacy successes but is also necessary for achieving proficiency in numeracy (Fesseha et al.,

2020; Vukovic & Lesaux, 2013). Numeracy is dependent on students developing strong literacy skills for communication of mathematical thinking, reasoning, and problem-solving (An et al., 2019; NCTM, 2024). While the language ability required to be successful in numeracy can pose challenges for many, it increases the difficulty for those students who are also working to become proficient in English as an additional language (Fesseha, 2020; Powell et al., 2020; Vukovic & Lesaux, 2013).

Literacy and Numeracy

Early literacy skills of students are linked to success in mathematics in later grades and students learning English as an additional language have been identified as experiencing the greatest math difficulties (Fesseha et al., 2020; Powell et al., 2020; Vukovic & Lesaux, 2013). Data collected from the standardized Education Quality and Accountability Office (EQAO) in Ontario demonstrates a correlation between students in grade 3 struggling with reading and writing skills, and the likelihood of lower scores in mathematics in grade 6 (Fesseha et al., 2020). This suggests the importance literacy skills have in mathematics, especially when an assessment is fully reliant on reading abilities. Powell et al. (2020) report that if students are unable to build a proficient foundation in literacy and numeracy, then it may pose problems for their future success beyond elementary school.

Mathematical vocabulary often has different contextual meanings when compared to everyday language, requiring additional comprehension skills in both mathematical language and mathematical knowledge (Fesseha et al., 2020; Powell et al., 2020; Purpura et al., 2017; Stevens et al., 2023; Vukovic & Lesaux, 2013). Mathematical language can be recognized in formal and informal vocabulary: equivalent/same, subtraction/take away, multiplication/times. Moving between formal and informal vocabulary is one example of code-switching observed between peers during collaborative activities, and in discussions between a teacher and students in meaning-making to build mathematical knowledge and understanding (Arias de Sanchez et al., 2018; Merritt et al., 2017; Moffett & Eaton, 2019; Ward & Damjanovic). All students require a strong understanding of mathematical language and knowledge as they build their foundation of numeracy in the dominant language of instruction. Language in mathematics can be a barrier to student success for all students with any language background (Fesseha et al., 2020; NCTM, 2022a).

Literacy is not limited to reading and writing, as text provides the foundation of understanding across other curricular areas so that students may develop the skills necessary to participate meaningfully in society (Jewett, 2013; new LearnAlberta, 2021a). Text is not limited to a sentence with words but could also be intentional communication via “anything that conveys meaning” (Jewett, 2013, p. 23). In mathematics, this communicative text may take the form of symbols, images, numerical representations, or diagrams. Mathematics is referred to as “a universal language” according to the subject description in the Alberta curriculum (new LearnAlberta, 2022), however Ward and Damjanovich (2020) report evidence suggesting the opposite. In a preschool setting, teachers displayed mathematical text as represented by different cultures and languages, including English, and noticed the learners incorporated these different representations in their writing (Ward & Damjanovich, 2020).

Language Factors Contributing to Mathematical Difficulty

Mathematical literacy, mathematical vocabulary, and background knowledge each contribute to developing a student’s success in mathematics. Barwell (2020) noted that background knowledge and context take additional time for students to understand, but once comprehension has been established, students can apply the information to mathematical knowledge without difficulty. Powell et al. (2020) reported mathematics vocabulary was a significant factor in grade three students who had difficulty in mathematics following written assessment measures. Students who experience mathematical difficulties and who struggle learning another language share a common problem with knowing and understanding mathematics vocabulary (Barwell, 2020; Powell et al, 2020; Purpura et al., 2017; Vukovic & Lesaux, 2013). Standardized testing such as the EQAO assessment in Ontario fails to provide detailed information on specific areas where students are struggling, leaving educators and policymakers to speculate on possible reasons without concrete evidence (Fesseha et al., 2020).

Educators and students are not always confident about how to balance the main language used in the classroom with other languages used by students. There may be a linguistic tension which could be influenced by educational policies welcoming all languages yet also urging the dominant language of the culture to be used primarily (Barwell, 2020). It can be challenging for educators to maintain a healthy balance as all students who are learning to use mathematical language often rely on dialogue to create meaning through diagrams, gestures, known vocabulary, or other available resources (Barwell, 2020; Barwell, 2023). Mathematical understanding can be strengthened by code-switching or translanguaging, as a learner alternates between more than one language while speaking or writing. (Franco et al., 2021; Planas & Chronaki, 2021).

Additional Languages as a Resource

Using additional home languages is part of a student's lived experience and should not be viewed as a deficit (Barwell, 2020; Franco et al., 2021; Merritt et al., 2017; Planas & Chronaki, 2021; Ward & Damjanovic, 2020). Barwell (2020) noticed the practice of speaking languages other than English in multilingual classrooms could be wide-ranging. A language-neutral classroom, where other languages are rarely present and student learning is more subdued is on one end of the continuum. On another end, is a language-positive classroom, with additional languages present and students actively involved in learning. Increased student participation in learning activities can be enhanced by valuing multimodal and multilingual methods of communication (Barwell, 2020; Barwell, 2023; Planas & Chronaki, 2021).

The goal is twofold in our mathematics classrooms: ensuring students strengthen their mathematical literacies and supporting them in learning accurate mathematical language. Teachers and students speaking in languages other than English, code-switching, or translanguaging are beneficial for students developing an understanding and increasing confidence while learning a new language (Barwell, 2023; Franco et al., 2021; Merritt et al., 2017). Additional languages should be viewed as a resource with students' previous experiences contributing to learning (Franco et al., 2021). Providing the opportunity for students to use their first language as part of learning mathematical vocabulary is beneficial (Merritt et al., 2017).

Mathematical Vocabulary Development

Beginning in the early childhood years, formal mathematical language can be introduced and reinforced through activities to support vocabulary development (Moffett & Eaton, 2019; Purpura et al., 2017). Math vocabulary can be practiced through play, games, and explicit teaching experiences to connect the language to mathematical knowledge (Ward & Damjanovic, 2020). Picture books with rich vocabulary, accurate representations of numeracy, and engaging text have been used successfully to introduce and strengthen mathematical language development (Nurnberger-Haag et al., 2021; Purpura et al., 2017). Inclusion of mathematical vocabulary needs to be purposeful, recognizing that students will need some explicit practice to develop their understanding of the vocabulary (Moffett & Eaton, 2019; Purpura et al., 2017; Stevens et al., 2023).

Stories selected for mathematical thinking and having a connection to students' lived experiences can increase vocabulary to build contextual understanding (An et al., 2019). McCormick and Essex (2017) created an activity for their students to write short story problems with pictures to explain their understanding of multiplication and division. Building on students' prior knowledge allowed the teachers to accurately assess student learning. Stories written by students will provide valuable opportunities to generate discussions and offer additional representations of student mathematical thinking (McCormick & Essex, 2017; Merritt et al., 2017).

Classroom Dialogue as Learning

Often students struggle to explain their understanding in writing, whereas their oral skills are more advanced and provide better insight into their mathematical understanding and knowledge (Cartwright, 2020). Assessments don't always allow for students to use verbal or other multimodal strategies to explain understanding and could contribute to inaccurate test results (Powell et al., 2020). Increased student

participation in learning activities can be enhanced by valuing multimodal and verbal methods of communication (Cartwright, 2020; Merritt et al., 2017; Moffett & Eaton, 2019; Ward & Damjanovic, 2020).

Using teaching strategies and student activities which promote dialogue and peer conversations is helpful for students in developing mathematical language and numeracy skills. Meaningful math discussions will increase student engagement, build confidence, and contribute toward proficient mathematical language development (Barwell, 2020; Franco et al., 2021; Merritt et al., 2017; Moffett & Eaton, 2019). Dialogic reading, in combination with prepared questions and prompts to build inquiry, allows students to further develop their mathematical knowledge (Purpura et al., 2017). As students strengthen their oral language skills, their written skills will also improve (Cartwright, 2020).

Further Research

The research studies included in this literature review involve participants from preschool to grade eight, and are based in Canada, the United States, Northern Ireland, Spain, and Australia. This review contained a broad range of classroom communities where the benefits from certain instructional and learning practices may be unique to specific age groups. Canada has two official languages in comparison to research from some of the countries studied. A few articles provided data about additional languages in mathematics classrooms at the early elementary school age (Powell et al., 2020; Stevens et al., 2023; Vukovic & Lesaux, 2013). A preschool or after-school environment is different from an elementary classroom setting due to both structure and expectations (Arias de Sanchez et al., 2018; Franco et al., 2021; Purpura et al., 2017; Ward & Damjanovich, 2020). For example, vocabulary practice would require repetition in any grade, but not through the same teaching methods for kindergarten and grade three.

Throughout the evaluation of the literature, it was noted that there were a limited number of articles which suggest specific strategies to support students when solving word problems. Word problems have been recognized as an area of mathematics which has caused frustrations for many students. Some of the articles specifically noted the benefits of targeting vocabulary knowledge (Powell et al., 2020; Vukovic & Lesaux, 2013) or ensuring students grasp the contextual understanding of reading problems (Barwell, 2020). Most of the articles explored the research on linguistic functions of language without explicitly focusing on the application of these skills in everyday problem-solving. Therefore, targeting research to evaluate a foundational understanding of problem-solving may be an area of future study.

The early childhood years, kindergarten to grade three, are essential for building a strong foundation in literacy and numeracy. A significant amount of time is devoted to developing basic comprehension skills and increasing background knowledge across curricular areas during early elementary years. A focus on researching numeracy alongside problem-solving in this specific age group would be beneficial. Additional research is needed to determine how young students transfer their newly developed reading comprehension skills into mathematics. This would inform educational researchers which high-impact strategies will support young students who are also learning a new language to construct the connections between their lived experiences with school expectations. Ideally, it would also create an advantage for educators as they play a critical role in developing those early beliefs and attitudes of numeracy and mathematics.

Several articles in this literature review acknowledged oral responses, diagrams, gestures, and pictures as more valuable forms of assessment compared to traditional written tests (Cartwright, 2020; McCormick & Essex, 2017; Powell et al., 2020). Students were able to include greater detail and depth using these alternative testing methods. However, traditional written assessments continue to be administered and the data collected in a single evaluation is used to determine success in mathematics. It is important to understand where students require additional support and assessments should be used to provide data which supports student growth and achievement (Fesseha et al., 2020). This specific information could be applied to professional development for teachers to strengthen their classroom instructional practice (Fesseha et al., 2020). Ultimately, stakeholders in education are interested in every student achieving proficiency in numeracy and being able to participate successfully in society.

Conclusion

Mathematics requires literacy skills to learn the mathematical language in meaningful ways using diverse teaching and learning strategies (Merritt et al., 2017). Educators must be aware of the literacy skills (Purpura et al. 2017) required for a strong understanding of mathematical knowledge. Oversimplifying language (Moffett & Eaton, 2019) or limiting accessibility (Barwell, 2020; Cartwright, 2020; Ward & Damjanovich, 2020) for students to connect with mathematical language and develop a proficient understanding limits success for these students now and in the future. Some resources provide teacher development support for educators to improve their personal beliefs and attitudes about numeracy while also supporting students' academic achievement (Wilkins 2015; Moffett & Eaton, 2019). Embedding numeracy across multiple subject areas (Jewett, 2013) will benefit all learners by deepening their understanding and providing additional opportunities to experience and apply their mathematical knowledge.

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