AMERICAN UNIVERSITY OF BEIRUT

A GENRE-BASED APPROACH TO LANGUAGE LEARNING PROGRESSIONS ACROSS ELEMENTARY AND MIDDLE SCHOOL MATHEMATICS: AN ANALYSIS OF THE WORD PROBLEM GENRE IN THE LEBANESE NATIONAL MATHEMATICS TEXTBOOK

by
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A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Arts
to the Department of Education
of the Faculty of Arts and Sciences
at the American University of Beirut

Beirut, Lebanon
May 2026

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Date of thesis defense: May 7, 2026

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor, Dr. Rabih El Mouhayar, for his continuous guidance, insightful feedback, and unwavering support throughout this research journey. His expertise and encouragement have been invaluable in shaping this work.

I am also sincerely grateful to my committee members, Dr. Saouma Boujaoude and Dr. Tamer Amin, for their thoughtful comments, constructive suggestions, and time dedicated to reviewing this thesis.

On a personal note, I would like to thank my husband for his constant support, patience, and belief in me during this demanding journey. His encouragement has been a source of strength at every step.
To my son, you have been my greatest motivation and my source of strength and purpose. This work is as much yours as it is mine.

Finally, I extend my heartfelt thanks to my family for believing in me and for their continuous support. I am especially grateful for their help in taking care of my son during the many moments when I needed to focus on my work. Their love and support made this achievement possible.

ABSTRACT
OF THE THESIS OF

Razan Abbas Kachmar for Master of Arts
Major: Education

Title: A Genre-Based Approach to Language Learning Progressions Across Elementary and Middle School Mathematics: An Analysis of the Word Problem Genre in the Lebanese National Mathematics Textbook

The Lebanese education system operates within a multilingual context, where students learn mathematics in English or French, neither of which is their native language. This language barrier poses a significant challenge for both teaching and learning mathematics, particularly in students' ability to understand word problems, which constitute a major part of the curriculum in different grade levels. Despite the central role of word problems in teaching and learning, there is a gap in the literature on exploring the characteristics, structures and linguistic features of the word problem genre in Lebanese mathematics textbooks. This study examines the word problem genre in the Lebanese national mathematics textbook series, *Building Up Mathematics*, focusing on its function, structure, lexicogrammar, and mode of representation. Using a mixed-method design, the study analyzes the distribution of word problems across grades and conducts a qualitative analysis of a stratified sample from Grades 3, 6, and 9. Specifically, the study examines the progressions of language demands of the word problem genre across Lebanese Cycles I, II, and III. The findings show that while word problems consistently function to generate mathematical activity, their linguistic and structural features become increasingly complex across cycles. This progression is reflected in greater contextual sophistication, increased use of complex grammatical and lexical features, increased use of task-oriented structures, and higher representation density through the integration of multiple modes. These changes increase the interpretive demands placed on learners, particularly in multilingual contexts.

The study provides insights into curriculum design, textbook development, and classroom practice by highlighting how language demands are systematically embedded in word problem textbook tasks. It contributes to research on mathematical discourse and genre by demonstrating how the word problem genre develops across school cycles in response to increasing disciplinary demands.

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INTRODUCTION

Research background

Learning is a social process shaped by interaction with the cultural context. Language is not only a tool of communication but an essential component in cognitive development (Vygotsky, 1978). Collaborative learning, peer interactions and group work aid in opportunities of language proficiency (Moschkovich, 2010). Language also helps in developing thinking throughout the practice and learning of mathematics (Espinas & Fuchs, 2022). It is crucial to look at the key challenges of mathematical language. Not only do learners struggle with understanding specific mathematical terms, but also the abstract language, including the expressions and symbols, which hinder their ability in linking concepts together (Jourdain & Sharma, 2016). For instance, dealing with word problems is a common challenge, as students often find translating words into mathematical symbols difficult (Moschkovich, 2010). Moreover, the instructional language of the teacher and the cultural context of the mathematical problem create a barrier to understanding. This is because mathematical language differs from everyday language in several ways, thereby affecting engagement and comprehension of mathematical concepts. Those differences are categorized as specialized vocabulary, abstract symbols, syntax and structure, conditional language, and cultural context (Jourdain & Sharma, 2016; Kersaint et al., 2013).

From a general point of view, each field, such as science, mathematics, sports, etc, has its own vocabulary, writing systems, and expression ways. Considering computer science, law, football, medicine, or any other field, each has its own set of language characteristics that help participants communicate effectively about the objects particular to their activity and get things done regardless of whether people, strangers to the domain, will understand or not. Mathematics is often recognized for its specialized language. Studying mathematics shows a distinct linguistic environment distinguished by clarity, abstraction, and accuracy. The specialized language used in mathematics may make the subject appear unapproachable, yet it also acts as an effective and very important instrument for knowledge generation, reasoning, and communication. Mathematical language provides structured frameworks that foster logical thinking and enable the concise communication of complex concepts, in addition to many more benefits to the development of students' learning journey (Walshaw & Anthony, 2008).

While some individuals may find it difficult to engage in mathematics due to the ambiguity or abstractness of some elements of mathematical language, the practice of mathematics heavily relies on the use of its specialized forms of language, both for interpersonal communication and for the creation of new mathematics. This is where the issue of equality and inequality in mathematics education arises, reflecting on the opportunities for diverse learners. And these are influenced by language proficiency. Language proficiency plays a significant role in mathematics education as students, non-native in the language of instruction, struggle and face challenges in understanding complex mathematical concepts and terminology (Moschkovich, 2015). Language proficiency not only affects students' ability to understand mathematical concepts and terminology but also acts as a barrier to understanding and participation in the classroom. This negatively impacts students' engagement and confidence in the classroom, resulting in achievement gaps between native speakers and multilingual learners (Barwell, 2009). Educators can help in bridging this gap by implementing innovative strategies and differentiated practices that promote language development ensuring a more equitable and fair learning environment for all students (Walshaw & Anthony, 2008).

The mathematical register is the language of mathematics that refers to this specialized terminology, symbols, syntax and vocabulary (Wilkinson, 2019). Among its characteristics, the abstractness and ambiguity of mathematical language are widely recognized. Also, the terminology used in mathematics demands a high level of accuracy where each word and symbol have a precise and distinct meaning (Morgan, 1998). Mathematicians are effectively able to communicate complicated concepts straightforwardly and understandably due to the clearness and accuracy of the terms used. Concise mathematical statements employ the fewest words and symbols required to communicate ideas. This mathematical register reduces repetition and improves the effectiveness of mathematical communication (Herbel-Eisenmann et al., 2015). Furthermore, the mathematics register enables conveying intricate relationships and concepts in a concise manner. It would be challenging to explain abstract and logical concepts in everyday language without the use of mathematical notation and symbols (Peng et al., 2020). Common terms in mathematics frequently have distinct meanings from their ordinary usage. For instance, in the context of mathematics, phrases like "function," "variable," and "product" have exact meanings (Morgan, 1998). Finally, logical and abstract concepts are communicated using mathematical language. This involves representing mathematical relationships and structures with symbols, formulae, and diagrams (Schoenfeld, 2020). Understanding the mathematics register is crucial for supporting equity in education and bridging the everyday and academic language.

While mathematical register focuses on the specific language and symbols used in mathematics (Wilkinson, 2019), mathematical communication is also shaped by different styles and forms, known as genres. Pimm and Wagner (2003) argue that mathematics can be divided into several categories, such as geometry, algebra, calculus, analysis, and number theory. Additionally, mathematical writing can be divided into specific forms, such as definitions, theorems, lemmas, corollaries, conjectures, and proofs. These forms highlight the different functions of mathematical texts and how they contribute to knowledge construction.

Mathematical genres refer to these different forms used in the language of mathematics where each genre has distinct structure, function, and linguistic features that shape how mathematical ideas are understood (Schleppegrell, 2007). Bakhtin defines genres as "compositional structures embedded in and developing out of various spheres of human activity, with each sphere possessing its repertoire of speech genres that distinguish and increase as the sphere evolves and becomes more sophisticated" (Bakhtin, 1986, p.60). A recent and common definition attributed to genre is being a “style” or “form” that serves a certain purpose within a communication encounter and is distinguished by recognized characteristics (Pimm & Wagner, 2003).

Gerofsky (1999) defines genre as written and spoken forms used in academic discourse. The author also argues that genre analysis is a type of discourse analysis that provides new perspectives on teaching and learning. The exploration of genre in mathematics teaching and learning provides a source for innovation and renewal in mathematics education practices (Gerofsky, 1999). Previous studies revealed the implication of using genre pedagogy in classrooms to promote student proficiency in domain-specific language (Smit et al., (2017); Boscolo et al., 2023). For example, Smit et al. (2016) argue that the structure and linguistic features of a genre should be taught and learned explicitly in schools and particularly in multilingual classrooms. The authors discussed how focusing on the structural and linguistic features in interpreting line graphs, such as using specific mathematical terms like “steep” or “gradually”, using temporal prepositions like “between… and”, “at”, “in” to distinguish between moments and periods, helped students in better expressing themselves mathematically. The authors emphasized the importance of making genre features necessary in the teaching and learning process based on the grade level for achieving maximum student comprehension and mathematical communication. For instance, Boscolo et al. (2023) explained that while description and expository writing, in higher grades, arise from writing activities linked to objects, the narrative genre arises from writing activities connected to events. Children learn the fundamental genres through writing, and acquire the ability to identify and differentiate between them through reading (Boscolo et al., 2023).

Gibbon (2002) argues that a genre can be distinguished by its purpose, structure, linguistic features and culture. Similarly, Chapman (2002) explains that a genre reflects an interplay among the content being expressed, the form or structure of the text, the context, and the writer's intention, that represents the purpose or function of the text. Although researchers use different terminology to describe genre, there is consensus in the literature that genres are characterized by common underlying elements, including purpose, structure, linguistic features, and context.

There are several genres in mathematics, but the word problem genre is commonly spread and remains a central theme in education. The National Council of Teachers of Mathematics (NCTM) has continuously prioritized and focused on problem-solving in the field of Mathematics (NCTM, 2000). Word problems are "mathematical problems presented in the context of a story or real-life scenario" (Adams, 2003, p.6). Adams explains that the purpose of word problems in the curriculum is to help students in exploring mathematical challenges and transfer their mathematical understanding, concepts and symbols into different contexts like real-life or story-based contexts. Moreover, Gerofsky refers to word problems as "written in imitation not of life but of other word problems" (Gerofsky, 1999, p.37). Gerofsky argues that word problems have repetitive language, structure, and themes of existing word problems which makes it a kind of genre with its own features rather than only relating mathematics to real life. As such, she studies word problems through a linguistic and semiotic lens. This study explores the word problem genre and look at its features and characteristics.

Context of the problem

The multilingual educational system in Lebanon imposes challenges to students' understanding and performance in mathematics. Language proficiency is the main cause of difficulty in both teaching and learning mathematics as it affects the ability of grasping mathematical concepts and communicating mathematically.

In Lebanon, the school system is organized into four main educational stages: Kindergarten, Cycle I (elementary level, first), Cycle II (elementary level, second), Cycle III (intermediate level), and Secondary education. Lebanon has three languages being used: Arabic, French and English. While Arabic is the native language that is the main language of everyday communication, the language of instruction used in Lebanon to teach mathematics and science is either French or English. This multilingualism in Lebanon is due to historical and political factors. Due to the French mandate in the 20th century, French was the main language of the government and education. After independence and the globalization of English language, Lebanon adopted both French and English in its domains including the educational domain (Shaaban & Ghaith, 1999). The multilingual context creates barriers for students in learning mathematics as the subject relies on specialized vocabulary, symbols, and concepts. These challenges are usually faced by students from low socio-economic background or public schools due to their low proficiency in English or French, hindering their ability to understand and apply mathematical concepts (Younes, Salloum & Antoun, 2023).

Moreover, abstract mathematical concepts expressed in English and French often lack adequate scaffolding or equivalent terminology in colloquial Arabic, the native language of Lebanese students. For example, technical terms such as "derivative", integral", or "vector" carry well-established mathematical meaning in French, whereas their equivalents in Arabic —particularly in colloquial Arabic— often lack alignment with the formal mathematical context (Azrou, 2020; Al-Tarawneh, 2024). Azrou (2020) also argues that students panic and feel stuck when they encounter a new mathematical term that does not correspond to a known term in Arabic.

Another major issue facing the Lebanese educational system is that the national exams are conducted in French or English. Younes and her colleagues (2023) found that Lebanese students' low performance in TIMSS is associated with the extent to which they speak the language of the test at home. Their study showed that students who spoke the language of the test at home were more likely to perform better in mathematics. This highlights a clear language barrier in assessment, where students' mathematical abilities may not be accurately reflected due to limited proficiency in the language of the test.

In addition to the above, one of the key challenges arising from the Lebanese multilingual education system is student's difficulty in understanding the structures and genres of mathematical texts – an ability that requires language proficiency. Some mathematical genres such as word problems and proofs require students to interpret and construct meaning within specific contexts demanding comprehension of the written language. For example, students with limited language proficiency tend to face difficulties in word problems since they are required to link everyday language into mathematical concepts. Misunderstanding a word or sentence in a word problem can lead to an incorrect solution, even when the student understands the underlying mathematical concept related to the task. Similarly, students may face difficulties in mathematical proofs, which demand constructing coherent reasoning and the use of specific mathematical terminology and principles (Moschkovich, 2010). Mathematical proofs are often written in a language that is not the student's first language. This is particularly challenging at the middle, and secondary school levels, where proof-based reasoning becomes essential, as students must simultaneously master both the mathematical logic and the linguistic structures (Azrou, 2020). Furthermore, the need to engage in different mathematical genres along with learning mathematics in a foreign language requires both cognitive and linguistic flexibility. This dual demand can pose a challenge for students in leaning mathematics, especially for those who have not yet developed the required language skills, which can negatively impact their performance.

Another factor challenging the Lebanese education system is the lack of teachers' plans in addressing the linguistic needs of students while teaching mathematics. In many cases, teachers are trained in the subject rather than in language pedagogy so they focus on delivering the mathematical content rather than supporting students with overcoming the challenges of the language barrier. Research has shown that few teachers are adequately prepared for this challenge due to the lack of subject-specific professional development programs designed to support language-responsive mathematics classrooms (Prediger, 2019). Teachers must deal with language complexities during classroom talk since the language of instruction in mathematics classroom is different than the home language of students that they bring with them to class (El Mouhayar, 2022). Learning mathematics involves learning a specialized academic register that differs from everyday language in terms of vocabulary, syntax, and discourse structures (Schleppegrell, 2007). El Mouhayar (2022) shows in his study that the home language (Arabic) along with English is being used when Algebra is taught in English in middle school cycle. He argues that it is essential for teachers to be aware of patterns of linguistic practices and functions. Moreover, teachers rely on the traditional teaching methods that focus on memorizing rather than understanding and deepening thinking of the content, which hinders the ability of students to engage with the mathematical language. Younes et al. (2023) explained that the cause behind the overall low performance of students in mathematics is the traditional content-centered approach in teaching that targets lower-level learning. To bridge this gap, teachers should be having extensive professional development sessions where they learn new strategies for fostering language proficiency in mathematics and using appropriate pedagogical approaches to create a fair learning environment (Prediger, 2019). Moreover, the language and structure of mathematical textbooks have been shown to pose substantial comprehension challenges for learners, and current instructional materials often do not provide sufficient scaffolding or support for engaging with mathematical texts (Rezat, Malik, & Leifeld, 2022).

Bailey and Heritage (2014) argue that little attention has been given to the linguistic content, such as the sophistication of sentences. They argue that both instructed learning and the developmental process affect language growth. In mathematics, students require explicit instructional support to engage with the specialized language of mathematics because these structures are not acquired through everyday language exposure alone (Schleppegrell, 2007). Instructed learning involves the knowledge and skills that an individual acquires through exposure to different texts and the developmental processes such as problem-solving skills are related to physical, cognitive and socioemotional maturation (Bailey and Heritage, 2014). Bailey and Heritage (2014) describe language development through features such as coherence and cohesion, advanced relationships between ideas, sentence structure sophistication, vocabulary sophistication, verb form sophistication, and expanded word groups**.** Language progression can be observed in the increasing complexity of linguistic features, such as the shift from basic connectors like “and”, “so”, and “then”, to more complex causal connectors like “because’, “if”, “since”, and “as a result”. This successful evolution depends on the quality of teaching and learning, and assessment opportunities. As such, it is not only related to how language is progressively acquired, but also how teachers and students can support language learning (Bailey & Heritage, 2014).

Purpose of the study and Research questions

A research team led by Professors Tamer Amin and Rabih El Mouhayar at the Science and Mathematics Education Center (SMEC) at the American University of Beirut initiated a research project entitled “Meeting the Language Challenge in Science and Mathematics Education in Lebanon” to support the Lebanese students overcome the language proficiency challenges in science and mathematics. The main goal of the project is to develop an evidence-based curriculum and online instructional materials to develop foreign language proficiency for science and mathematics. The project is aimed at preparing a full set of modules targeted at the Lebanese curriculum over the cycles 1-3 (grades one to nine). The online modules and activities on subject-specific genres in science and mathematics that would be implemented on the Lebanese Alternative Learning (LAL’s) Tabshoura platform. This would help students in developing language skills needed for science and mathematics by adopting a genre-based approach. This study looks at the genres in mathematics education, with a focus on the word problem genre. The purpose of this study is to characterize the learning progressions with respect to the word problem genre characteristics by capturing the increase of sophistication of language demands in the Lebanese Cycles I, II, and III based on textbook analysis.

This study looks at the word problem genre in mathematics education, identifies the characteristics of this genre then examines the occurrence of this genre and its features within the Lebanese mathematics textbook series, *Building Up Mathematics*, from grades 1 to 9 with a focus on English as the primary language of instruction. In this study, the researcher maps the occurrence of word problem genre across the Lebanese curriculum based on the linguistic features and characteristics of word problems genre. The mapping is through coding the word problems in the Lebanese national textbook for grades 1 to 9 in terms of frequency and representing in frequency tables to show how these genres vary over the mathematical strands and the grade level in terms of repetition and complexity of the linguistic features hypothesizing that as students progress through grade levels, they are exposed to increasing sophisticated language that contributes to the development of higher levels of learning and language proficiency.

The following are the research questions of the present study:

(1) How does the frequency of the word problem genre vary across grade levels, school cycles and mathematical strands (numbers and calculations, algebra, geometry, measurement, and statistics) in Lebanese National mathematics textbooks?

(2) How do the linguistic characteristics of the word problem genre change across grade levels, and school cycles in the Lebanese National mathematics textbooks?

(3) What learning progressions can be identified in the linguistic characteristics of the word problem genre across Cycles I, II, and III in the Lebanese curriculum reflecting increasing levels of language complexity?

Significance

The language of mathematics has been an important topic of research in mathematics education for years. There has been extensive research on the language of mathematics, and identifying the challenges faced by learners in understanding and comprehending mathematical texts. Researchers have examined specific genres within mathematics, highlighting the characteristics and function of each and exploring the positive effects of genre-based instruction approach on students' learning (Marks & Mousley, 1990; Gerofsky, 1999; Bicknell, 1999; Morgan, 1996; Pimm & Wagner, 2003; Meaney, Trinick, & Fairhall, 2009; Bailey, 2017). Marks and Mousley (1990) identified and described different types of mathematical genres. Gerofsky (1999) reported that genre analysis, as a form of discourse analysis, can provide insights into mathematics teaching and learning. Her study focused on the word problem genre, unpacking its functions, forms, and linguistic characteristics. Bicknell (1999) examined teachers' and students' perspectives on writing explanation and justification genres in mathematics. Morgan (1996) discussed students' limited linguistic awareness in producing and comprehending mathematical texts. She suggested an analytical approach to these texts by examining the mathematical genres and register, drawing on the linguistic tools used in mathematical writing, based on the three meta-functions of language posited by Halliday. Meaney et al. (2009) investigated ways to improve the quality of students' mathematical writing by identifying the genres of writing in the mathematics classroom. Pimm and Wagner (2003) investigated the genre features in mathematics classrooms. In Lebanon, limited research was done on genre-based approach and its positive impact on the Lebanese education system (e.g. El Mouhayar & Barwell, 2025; Mehdi, 2024). Mehdi (2024) examined how genre-based approach combined with translanguaging can enhance writing explanations in science classes for sixth grade in Lebanon. El Mouhayar and Barwell (2025) explored the language socialization practices of geometric proof genre in in Lebanon in English by looking at the classroom interactions involved in interpreting and constructing geometric proofs. They identified four categories of socialization practices: guiding, obtaining information, deducing and attending to accuracy and precision (Mouhayar & Barwell, 2016).

The understanding and communication skills that students are able to develop because of the connection between language and mathematics not only positively impact their academic achievements but also boost their confidence and critical thinking abilities. When students are effectively able to engage with mathematical language, they are ready to assimilate new and complex mathematics ideas, properly decode problems, and openly communicate their mental processes (Lager, 2006). Indeed, educators are greatly responsible for aiding learners appropriately by easing the process of comprehending the language and language genres in mathematics. Building an inclusive environment for students is among the vital roles of educators where all students despite their language ability and cultural background are able to understand the mathematical language (Milner & Tenore, 2010).

Thus, it is important to include language-focused techniques in mathematics education to open the doors to fair learning outcomes and actively promote students' mathematical literacy.

This study's focus on a genre-based approach to analyze the Lebanese mathematics textbook is significant, particularly within the context of Lebanon's multilingual education system. It provides empirical evidence on the language learning progressions that Lebanese students are expected to achieve with respect to the word problem genre in mathematics education across Cycles I, II, and III. In particular, the study reveals that language demands in word problems become more complex across grade levels and school cycles based on textbook analysis. This research also offers valuable insights into how language proficiency influences the understating and communication of mathematical texts and content. Exploring characteristics of word problem teaching and learning of mathematics. This study traces the evolution of the structure and linguistic features of word problem genre across cycles, providing a clear picture of students' linguistic progression across grades, and school cycles in mathematics classrooms. This shows how mathematical language supports the cognitive development of mathematical thinking. In addition, this mapping to the Lebanese textbook supports teacher training on specific language pedagogy through the genre-based approach. Moreover, it shows specifically the mathematical skills embedded in word problems targeted in every cycle, offering guidance to both teachers and students. This can serve as a valuable resource for them that would promote an engaging learning experience targeting each student's need and pace. This can aid in bridging the language gap in multilingual mathematics classrooms, specifically when working with word problems.

Moreover, this study helps to identify the extent to which mathematical language is scaffolded across grades in the Lebanese textbook by examining whether textbooks are effectively building the linguistic tools required for students' engagement with mathematical concepts. It also identifies gaps in the textbooks and offer valuable recommendations for textbook development and teaching strategies. This study can serve as a reference for textbook designers in developing more targeted and language-specific word problems by taking into account the linguistic progression across cycles in mathematics textbooks.

Finally, this study contributes new knowledge to the field of mathematics education in Lebanon and multilingual and multicultural settings. It adds to the existing research on the role of language in mathematics education by focusing on a genre-based approach to analyzing word problems. Moreover, this study offers a framework that can be used to analyze mathematics textbooks, especially in countries with bilingual or multilingual classrooms. The findings may also raise new research questions on the effectiveness and the impact of word problems on students' learning, especially in Lebanese classrooms. Moreover, this study provides opportunities for future studies on other mathematical genres such as proofs, explanations, and descriptions. It may also support the development of instructional online modules based on subject-specific genres.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the researcher first reviews the sociocultural perspective on the role of language in the learning of mathematics through Vygotsky's sociocultural theory and examine the nature of mathematical language by looking at the mathematical register and the linguistic features of the language of mathematics. Then, this literature review explores the functional aspects of mathematical language by introducing Halliday's Systemic Functional Linguistics. This theory is used to support a subject specific genre-based approach, where the researcher presents the various mathematical genres found in the literature. This review focuses on the word problem genre and provides a detailed analysis and understanding of its function, structure, and linguistic features. Furthermore, this review explains how mathematical language increases in sophistication as learners progress in level and experience. This study also examines the role of the textbook in mathematics instruction and review previous studies on textbook analysis.

This literature review examines the existing research on language in mathematics education, with a focus on the role of genres in the learning process. By analyzing mathematical genres in the Lebanese mathematics textbook, specifically word problems genre, this study aims to fill a gap in the literature regarding the progression of linguistic features of word problem genre across grade levels. This contributes to a better understanding and support for the development of students' cognitive and linguistic capabilities in mathematics.

A Sociocultural Perspective about the Role of Language in Teaching and Learning of Mathematics

Researchers in mathematics education have been conducting research on the role of language in teaching and learning of mathematics for several decades; however, there is no consensus on its role: “Within the field of mathematics education, the central role language plays in the learning, teaching, and doing of mathematics is increasingly recognized, but there is no agreement about what this role (or these roles) might be” (Morgan, Craig, Schütte, & Wagner, 2014, p.843). In the current study, we adopt Vygotsky’s sociocultural theory, which provides a framework for understanding how language and social interaction shape cognitive development. Vygotsky (1978) argues that cognitive development is embedded in social interactions and shaped by the tools, language, and interactions that occur within a community. He believes that knowledge is constructed through social interactions and within a cultural context. The cultural tools that help in shaping the thinking process can be both physical tools such as computers or pens, and symbolic tools such as language, diagrams, and symbols. As such, culture has a crucial role in the understanding and communication of knowledge.

Vygotsky also believes that language is not only a mean of communication, but a tool for thinking. He argues that individuals initially learn through social interaction with those who are more knowledgeable like parents, teachers, peers. Then they internalize these interactions to become personal cognitive tools. As such, according to Vygotsky, language is a tool for social interaction and a medium for internalizing knowledge. This is because when students are engaged in conversations, whether self-directed talk or with others, they learn how to regulate and organize their thoughts, plan their actions, and solve problems. According to the socio-cultural theory, students’ ability to understand mathematical concepts is directly linked to the language used in solving mathematical problems. This process is shaped by the linguistic features used in mathematics and the social context in which the learning occurs, such as classroom interactions, textbook, language, and teacher guidance. Moreover, understanding mathematical concepts is not only shaped by individual effort, but also through collaborating with peers and teachers. This interaction occurs within their zone of proximal development (ZPD), where learners are supported beyond their current cognitive abilities. Vygotsky defines the Zone of Proximal Development (ZPD) and refers to it as the gap between what a learner can do independently and what he can do with someone else's assistance such as a teacher or a peer. He highlights that in order for learners to achieve higher cognitive functions, they should be supported through social interactions and cultural tools.

In mathematics classrooms, what bridges the gap between the current understanding and the harder or more complex mathematical concepts is the language of instruction. In the current study and based on the socio-cultural theory, we highlight the importance of scaffolding language in addition to the mathematical content to ensure that students develop both mathematical language and the language of instruction. This guidance can be achieved through scaffolding by the teacher or peer, where little support is provided to help the learner move through the ZPD. An example for teachers scaffolding new mathematical content is through demonstrating the steps involved, asking the students to repeat the procedure, then gradually reducing the support will result with independent application of the concept.

In countries like Lebanon, where Arabic is the home language, English and French are used as language of instruction, students face challenges in understanding and applying mathematical concepts due to students' limited proficiency in language (Younes, Salloum & Antoun, 2023). For example, the word for "sum" exists in Arabic (مجموع), in English (sum), and French (somme) and it represents the same operation, but students' comprehension of the term may depend on their level of proficiency in each language. For this reason, teachers need to understand and have a deep background on the nature and characteristics of mathematical language to be able to teach it. That is said, developing a learner's mathematical thinking requires the development of his mathematical language first.

Mathematics Register: Student Challenges and Linguistic Barriers

Researchers argue that mathematics is a language and has characteristics like modern languages (Visher, 2015; Adams, 2003; Kersaint et al., 2013; Usiskin, 1996). Adams (2003) argues that mathematics should be seen as a language rather than an action we do. Reading mathematics requires navigating the relationship between words, symbols, and numerals. Kersaint and his colleagues (2013) claim that mathematics itself is a language and has a register. He refers to this mathematical register as a "subset of language composed of meaning appropriate to the communication of mathematical ideas" (Kersaint et al., 2013). The discourse of mathematics is both oral and written and as any language, it includes vocabulary, syntax (sentence structure), and semantic properties (truth conditions). However, these are unique and different from other content-area registers which make math a complex language on its own (Visher, 2015; Kersaint et al., 2013; Marks & Mousley, 1990; Usiskin, 1996). One key assumption shared by several researchers on the nature of mathematics is viewing mathematics as a form of text. Both Marks & Mousley (1990) and Usiskin (1996) argue that mathematics not only include symbolic and numerical representations but also pictorial representations such as graphs that convey meaning the same way that word do in written texts. Halliday (1978) and Schleppegrell (2007) extend this idea by viewing mathematics as a semiotic system, a system of signs and symbols that works to making meaning. This view of mathematics as a semiotic system brings us to the concept of mathematical register that refers to the language features such as vocabulary, syntax and symbols used to solve mathematical problems within a context.

While mathematics is known as a universal discipline, it relies heavily on specific linguistic structures. These structures differ from everyday language, posing a particular challenge for learners, especially in multilingual contexts. These linguistic structures – such as specialized vocabulary, symbols, and syntax – are referred to as the mathematical register

(Adams, 2003; Schleppegrell, 2007). As with any other discipline, mathematics has its own specific set of language features, known as a register. Register is defined as “a set of meanings that is appropriate to a particular function of language, together with the words and structures which express these meanings.” (Halliday, 1978, p.195). The term ‘mathematics register’ refers to the use of language to express mathematical concepts and communicate mathematical ideas, rather than referring to mathematics itself (Halliday, 1978). The mathematics register includes the vocabulary used to express mathematical ideas and the sentence structures in which this vocabulary appears. “Specifically, the mathematics register includes unique vocabulary, syntax (sentence structure), semantic properties (truth conditions), and discourse (oral and written text) features” (Kersaint et al., 2013, p.43). Doing mathematics involves constructing mathematical knowledge such as oral and written language, symbols, and visual representations through the mathematics register that constructs the technical discourse (Schleppegrell, 2007). Schleppegrell identifies the features of the classroom mathematics register as multiple semiotic systems and grammatical patterns. The multiple semiotic systems include the mathematics symbolic notations, oral language, written language, graphs and visual displays while the grammatical patterns include the technical vocabulary, dense noun phrases, being and having verbs, conjunctions with technical meanings and implicit logical relationships (Schleppegrell, 2007).

Mathematical discourse is distinct from everyday language by numerous linguistic features including technical vocabulary, formal syntax, precision and clarity, logical reasoning, symbolism and notation that will be further explained (Usiskin, 1996). For instance, the grammar of mathematics includes technical vocabulary, dense noun phrases, being and having verbs, conjunctions with technical meanings, and implicit logical relationships. The technical vocabulary includes two kinds of vocabulary, such as the “sum” or “fraction”, and the other kinds that are not particular to mathematics but still have a technical meaning in it, such as “place”, or “borrow”. In addition to specific terminology used such as “integral”, “derivative” and even symbols such as “π” (pi) (Herbel-Eisenmannet al., 2015).

Pimm (1987) argues that learning mathematics is not just acquiring the mathematical concepts but also learning to speak like a mathematician, through acquiring the mathematics register (Pimm & Wagner, 2003). The mathematics register includes specialized vocabulary, syntax and discourse structures that are essential for students to engage meaningfully with mathematical ideas. To better elaborate, Halliday’s (1978) discussion of the mathematics register highlights the distinction between the informal, everyday language used in doing mathematics such as counting and measuring, and the formal, academic language used in the study of mathematics. Halliday’s view suggests that the students must be guided in the transitioning from these informal, everyday ways of constructing mathematical knowledge to the academic and technical ways required in mathematics discourse (Schleppegrell, 2007).

Although the everyday language is filled with the language of mathematics due to the use of telephone numbers, addresses, and monetary values, mathematics is seen as a foreign language for many children. Bertoch (2014) argues that this is because the language of mathematics is entirely used at school and not at home. Many children perceive mathematics as a foreign language since the symbols and expressions act as a significant barrier to understanding mathematical concepts (Meiers & Trevitt, 2010). Bertoch (2014) suggests that students would prefer to learn mathematics in the same way they would learn a foreign language, claiming that the exposure to certain ideas and concepts increases students’ chances of success. That is, the same way that language learners benefit from exposure to vocabulary, grammar, and usage of words, learning mathematics through being exposed to mathematics symbols, terms and structures is beneficial. As such, students face several challenges in learning the language of mathematics. Meiers and Trevitt (2010) along with

Jourdain and Sharma (2016), identified four key issues related to language and literacy: the use of specialized symbols and expressions in mathematical language; the use of everyday English terms that carry different meanings in mathematics classrooms; language-based factors affecting the solving of mathematical word problems; and overall communication in mathematics classrooms.

Kersaint and his colleagues categorize challenges in learning the mathematical language under five categories: vocabulary, symbolic representations, syntax, semantics, and linguistic features of discourse (Kersaint et al., 2013). Mathematics language includes many different types of vocabulary that can influence students' understanding. Specialized vocabulary - often technical and abstract - can be particularly difficult to comprehend. Terms such as Pythagoras, isosceles, hypotenuse, sine, cosine, tangent, and probability, present challenges for learners (Visher, 2015). Words like "congruent," "isosceles," or "quadrilateral" typically require special instructions. Even general vocabulary such as factor, frequency, line, curve can be confusing. In addition, students often struggle with everyday words that have different meanings in mathematics, including product, prove, difference, area, function, and expression (Visher, 2015). Some words also have multiple meanings within mathematics itself, such as base and median. Schleppegrell (2007) notes that students often find it easier to learn new mathematical vocabulary than to reinterpret technical meanings for words they already know in other contexts. Moreover, students must navigate mathematical concepts expressed through multiple semiotic systems. For instance, a function written as $y=5x+7$ can also be represented graphically as a straight line.

Symbols are used to express concepts and processes. So, students should not only be able to recognize the symbol, but rather they should be able to learn how to associate them in particular concepts. Rubenstein and Thompson (2001) identified several challenges regarding the use of symbols, specifically that some symbols require several words to verbalize the meaning, others have more than one way to say it, and so on. Therefore, the authors suggest that teachers should include the explanation of symbols explicitly in their instructions.

Students face several challenges related to the syntax of mathematical language. These difficulties are due to various factors. Among these factors is that mathematical texts are characterized with specialized syntax such that the sentence structure includes use of prepositions like by, into, of, if and then. These prepositions in mathematical texts define mathematical relationships such that "divided into" is different than "divided by" (Visher, 2015). Similarly, mathematics often relies on logical connectors such as “if-then” or “if and only if” to link abstract ideas. Students might face difficulties in understanding and applying those connectors correctly, specifically when faced with complicated problems. Additionally, mathematics often employs the passive voice, which is less familiar to English Language Learners (ELLs) who are more accustomed to the active voice. This mismatch can make it difficult for students to comprehend word problems or questions (de Araujo, Roberts, Willey, & Zahner, 2018). For example, the use of the word “which” in questions like “which is the largest among the following?” may refer to something that is not explicitly stated. (Visher, 2015). Another example of difficulties that students face related to the syntax of mathematical language is within the context of algebra, particularly when translating word problems into algebraic expressions. Linking between mathematical symbols and words is challenging for students. For example, in algebra, the number m is 10 less than the number n may be mistakenly written by students as m = 10-n if they follow the order of the sentence. However, the correct equation should be m = n-10 (Visher, 2015). As a matter of fact, for a student to translate “the number a is 7 times more than the number b” into a=b+7 is a challenge. Moreover, mathematical symbols have their own syntax such as 2^n is different than 2n.

“Semantics refers to the process of meaning-making from language” (Kersaint et al., 2013, p. 46). One difficulty related to semantics is: interpreting references within word problem statements, especially when similar terms serve different functions depending on context. For example, the word ‘base’ has a different meaning in the context of triangles that it does in powers. Another example is the concept of limits in mathematics, where students must understand that a function can approach a certain value without actually reaching it. For instance, one might state: "the limit of a function f(x) as x approaches a constant c is K”.

Discourse features refer to the ‘chunks’ of language—sentences or groups of sentences or paragraphs—that function together as textual units, each with a specific meaning and purpose of mathematics” (Dale & Cuevas, 1992, p. 337-338). Discourse in mathematics has two components: oral and written language. Students often struggle to understand oral language due to homophones that sound like common English words, such as plane vs plain, arc vs ark, and sum vs some (Kersaint et al., 2013). Adams (2003) notes that understanding written mathematical language is equally challenging since students are challenged to attain mathematical understanding fluently through the reading of numerals and symbols. In mathematics, there are notions, such as the concept of infinity, that are difficult to define and pose a challenge for students to understand. For example, decoding a statement such as "the limit of a function as x approaches a constant" requires students to connect mathematical concepts and variables with symbolic representations. Moreover, the specialized ways of communication in both written and oral forms are challenging for students in mathematical texts because students are expected to follow different directives such as find, calculate, evaluate, justify, define, prove, and simplify that are non-mathematical (Visher, 2015).

As discussed earlier, the students’ abilities to comprehend mathematics concepts, efficiently solve problems, and explain their thinking are very much linked to the language employed in mathematics learning. As a matter of fact, it is crucial to get the hang of specific register in mathematics such as mathematical vocabulary, grammar, syntax, discourse structures, etc., leading to successfully communicating with students. Hence, student comprehension is a factor of the language used in teaching in general and the understanding of its genres in particular (Bapna, Myers, & Sharma, 2023). Mathematics draws on multiple semiotic systems for constructing knowledge such as mathematics symbolic notation, oral and written language, graphs and visual displays. These systems do not function in isolation, rather, they function intersemiotically (O'Halloran, 2005, as cited by Moschkovich, 2010). As the discourse shifts from one semiotic to the other, mathematical meaning and knowledge expands (Moschkovich, 2010). For example, giving students a word problem with unfamiliar context makes the problem more difficult to access, so providing visual cues aids students in understanding the context and engage better in the problem (Jourdain & Sharma, 2016). A more complex language can be made accessible for all students by providing non-linguistic cues such as visual diagrams or drawings (Brown, Cady & Taylor, 2009, as cited by Jourdain & Sharma, 2016).

Mathematics symbolic notation is for expressing meanings that go beyond what ordinary language can express that is describing the pattern of relationships between the mathematical elements such as numbers, expressions, etc." (Schleppegrell, 2007, p. 4). For example, it can be used to describe relationships of parts of whole. Visual displays such as graphs and diagrams aid in presenting mathematics symbolism (Schleppegrell, 2007). For example, a diagram provides a connection between the material world like finding the distance between a cliff and a river where the mathematical process would be expressed in oral language in the classroom. Another example is the visual representation of the symbolic notation "linear equation" is a straight line. The graph provides an understanding of the mathematical relationship "rate of change" that is the slope m in the equation y = mx+c. On the other hand, the oral language in class helps in scaffolding and guiding students in the mathematical reasoning of the latter. As such, all the components of the multiple semiotic systems work together in classroom discussions between the teacher and the students. This gives further implications on the teaching and learning of mathematical language.

However, sometimes making connections across these semiotic systems might be challenging for learners. For students to develop fluency in mathematical symbols and representations, teachers should guide the process of understanding the relationship between mathematical notations, verbal explanations and pictorial representations in communicating meaning, such as interpreting a graph or working with algebraic expressions (Schleppegrell, 2007). For example, the transition from the graph of a straight line (visual graph) to the linear equation (symbolic notation) requires interpreting the features of the line i.e. the slope and the y-intercept and write it in algebraic language. This is challenging for students as it requires advanced cognitive skills and a well-developed knowledge of mathematical language and concepts. The author argues that this is considered a challenge since the oral language in discussions adds another layer of complexity since it does not capture relationships in the ways the written or symbolic language does. The author gives the example of the teacher treating "square root" in her/his oral speech as things to be manipulated, rather than a process or operation (Schleppegrell, 2007, p. 8).

As such, viewing mathematics as a semiotic system takes us to Vygotsky's theory on the importance of context in understanding the concept. Words in sentences can convey different meanings depending on their context, similarly do mathematical symbols. For example, plus sign in mathematics "+" means simple addition in simple arithmetic (like 3+2=5), but in algebraic expressions it means collecting like terms (like 2x + 3 +3x + 4 = 5x +7). However, in sequences, writing $u_{n+1} = u_n + 2$ indicates using the plus sign to refer to the next term (Radford, 2003).

Functional Aspects of Mathematical Language

Researchers in mathematics education refer to the systemic functional analysis of multisemiotic mathematical texts to analyze how language is used in teaching and learning of mathematics with a focus on how mathematical meaning is constructed through language (Morgan, 1996; Alshwaikh & Morgan, 2013; Alshwaikh, 2016; Rezat & Rezat, 2017; O'Halloran et al., 2018). For instance, Morgan (1996) used the systematic functional linguistics as a theoretical framework to analyze mathematical texts and genres. Morgan (1996) used three metafunctions posited by Halliday and discussed the linguistic tools that are used in mathematical texts based on the three functions (ideational, interpersonal, and textual). At the very heart of this systemic functional linguistics lies three essential functions including the ideational function, the interpersonal function, and the textual function through which language can be analyzed (Halliday & Martin; 1993). The ideational function is primarily concerned with the representation of content and experiences. The interpersonal focuses on how language is used to establish social interactions and express attitudes. The textual function is concerned with the organization of language and the structure to ensure the coherence and flow in communication.

The ideational function

The ideational/experiential function refers to the way in which language expresses one's experience and interpretation of this experience. The ideational function in mathematics language lies in the naming of mathematical objects and types of objects in the mathematical activity. The features of mathematical texts are the types of processes and the types of participants in these processes. The types of processes are mental, relational, material, behavioral, existential, and verbal. For example: the uses of the equal sign and the types of processes used in the expression of generalizations like mathematical relations.

The types of participants in these processes are such as the portrayal or suppression of agency through nominalizations, non-active forms of verbs, and the nature of the expression of casual relationships.

The ideational function of genres within SFL demonstrates information about the world such as events, participants, and circumstances in texts. Genres assist in structuring information in a certain way that leads to representing content effectively. For instance, research findings and experiments are represented in a specific format to validate mathematical theory. In addition, genres mirror the degree to which language portrays reality whether in descriptions, explanations, or narratives.

The use of nominalization in mathematical texts involves changing a verb or a process into a noun or an object such as rotation, permutation, or relation. Morgan argues that the use of nominals allows the description of not only a particular pattern but also a general relationship between a range of patterns. Moreover, it removes the grammatical need to specify the actor in the process as mathematics is a system that exists independently of human action. Morgan also argues that the correct and objective way of writing in mathematics is using passive rather than active forms of verbs. Morgan highlights that it is important to determine how causal relationships are represented in mathematical texts and this expression of causality takes place through the explanations and proofs in mathematics (Morgan, 2001).

The interpersonal function

The interpersonal function expresses the social and personal relations between authors and others (like the readers). Interpersonal relationships are expressed in a text through the use of personal pronouns, mathematical vocabulary and conventional forms of language such as imperatives, and the expression of certainty and authority in the modality of clauses. The plural pronouns refer to the group as a whole working on the activity in a text. The first-person pronouns (I and we) indicate the author's personal involvement in the text. The use of "we" implies that the reader is being involved in the doing of mathematics. When using "we" in school mathematics, the teacher might respond to the student's use of "we" in circumstances that do not refer to an activity done by a group as inappropriate. The second-person pronoun "you" in mathematical texts is used in expressing general processes rather than addressing individual readers. Morgan argues that students use "you" when they are struggling with formulating generalizations and communicating them. Morgan also discussed the use of imperatives in mathematics texts such as consider, suppose, define, and let x be in showing the relationship between the author and reader.

Social dynamics and interpersonal meanings in communication are shaped by language which is the main study point of the interpersonal function. Social roles, power dynamics, and relationships through language choices are all part of that function. Whether to express attitudes, emotions, beliefs, or gratitude, participants indirectly represent the interpersonal function of properly communicating with others. For instance, a student in a classroom saying: "I acquired the use of the Pythagorean Theorem, but have you considered using Sine?" not only demonstrates an understanding of the lesson but also suggests another method. The interpersonal function aims to foster mutual understanding, communication, and collaboration.

Morgan claims that the use of imperatives and specialist vocabulary in academic mathematics texts marks the author's claim to be a member of the mathematical community that uses the same special language. In the school context, the teacher and textbooks use these conventional forms of language to introduce students to the mathematical community. However, students in mathematics classrooms tend to have tension between being familiar with and able to use the conventional mathematical language and the need to satisfy their classroom demands (like showing their thinking process). The relationship of author, reader, and subject matter can be seen through the expression of certainty and authority in the modality of a text. This is expressed through the modal auxiliary verbs (must, will, could, etc.), adverbs (certainly, possibly), or adjectives (I am sure that...).

The textual function

The textual function is what makes language relevant in context and distinguishes a living message from an entry in grammar or a dictionary. It is concerned with the creation of a coherent mathematical text and the type of message it attempts to convey. This is through the thematic progression, the cohesiveness of the text, the ways in which reasoning is expressed, and the overall structure of the text. The thematic progression occurs in reports of mathematical activities by the presence of themes expressing reasoning such as hence, therefore, by theorem 1, which would show the text as a deductive argument. Temporal themes such as First, next, and then are used in constructing reports recounting what happened or used with imperatives to construct algorithms.

Mathematically speaking, this function is present through the use of numerous features discussed above such as logical connectors. For instance, using connectors like “thus”, or “if” help learners in their logical reasoning process. These connectors ensure that the flow of ideas is concise and logical. The structure in mathematics is very important as a trait of the textual function. Texts usually start with definitions couples with a theorem and then proofs, examples, and problem solving on each lesson. In addition to the connectors and the structure, the textual function encompasses visual representations in aiding textual words to promote better understanding and facilitate comprehension

Moreover, the cohesiveness of the texts can be achieved through the use of repeated or related vocabulary, connectors making links between sentences, and the use of words that refer backward or forward in the text. Reasoning can be expressed in the text through the use of conjectures (because, so), nouns (the reason is...), verbs (X cause Y), or prepositions (by, because of). The overall structure of the text can be organized by labeling, paragraphing, or changes in content matter or style.

From a social semiotic approach to register analysis, Halliday and Hassan (1985) argue that texts cannot be approached without referring to the context of the situation where texts are unfolded and being interpreted (Mehawesh, 2014). Throughout his theory of language, Halliday's discussed that the three metafunctions above are triggered by three social functions of language: field, tenor, and mode form the context of the situation of a text, which were elaborated upon as features of genres. The field relates to the topic matter or the events happening in the conversation. It refers to the general topic, content, and target of communication in a certain setting. The tenor refers to the social roles and relationships between the participants in the communication event. In this sense, formality, power dynamics, familiarity, and the social environment in which language is employed are to be considered. As for the mode, it symbolizes the way, the channel via which communication can effectively occur. Examples of modes include spoken language, visual texts, and written speech. It represents the physical aspect of communication and the impacts on the language employed. By understanding these three pillars, Hallidays' theory draws upon a framework for better understanding how language manifests in various social and communicative contexts (Halliday, 1999). This paves the way for the development of distinct genres that are understood to be recurring types of texts that arise to fulfil specific communicative purposes within particular fields (Meaney et al, 2012).

Exploring Word Problems as a Genre in Mathematics Education

Scholars (e.g. Pimm & Wagner, 2003, Meaney et al, 2012, Rezat & Rezat, 2017, Chapman, 2002; Bakhtin, 1986) define a genre in different ways. According to Chapman (1995), a genre refers to text types or ways of organizing or structuring discourse. Pimm and Wagner (2003) define a genre as a 'style' or 'form' which is used as a basis for distinction and classification. As for Meaney, Trinick, and Fairhall (2012), a genre fulfills a particular function within a communicative interaction and has recognizable features. Bakhtin defines genres to be “compositional structures embedded in and developing out of various spheres of human activity” (Chapman, 1995). “Each sphere of activity contains an entire repertoire of speech genres [oral and written] that differentiate and grow as the particular sphere develops and becomes more complex” (Bakhtin, 1986, p.60 as cited by Chapman, 2002, p. 5). This perspective emphasizes that genres are not fixed; they develop through practice and within specific social context. Rezat and Rezat (2017) emphasize that the context of the situation of a text determines the genre and the variations in the context of the situation lead to different kinds of genre. Meaney and his colleagues (2009) argue that any text is influenced by three components: what is being discussed (field), who is involved in the text (tenor), and the form the communication (mode).

Genres reflect an interplay between four bases: content, context, form, and intention. The content component refers to the meaning the writer expresses. Form deals with the structure, organization, or pattern of the text. Context represents the situation in which writing occurs, and intention symbolizes the writer’s purpose (function) (Chapman, 1995). Also, Rezat and Rezat (2017) discuss Gibbon’s (2002) four characteristics that distinguish a genre from another genre: a specific purpose, a particular overall structure, specific linguistic features, and shared by members of a culture (Rezat & Rezat, 2017). Sandig (1997) distinguishes between the linguistic function and the linguistic form of a genre. Sandig reports that a genre is constituted by a type of act and a text type. The former refers to “the properties of a genre in the sense of communicative functions and the context of situation (social function, the context in which it is used, the involved parties)” (Rezat & Rezat, 2017,p. 4195); and the latter refers to “the features of the genre in the sense of language structure and the corresponding linguistic means to realize the genre (speech acts, sequence pattern, formulation pattern, etc.)" (p. 4195). Rezat and Rezat (2017) in their turn argue that the relationship between the type of act and text type constitutes the genre. They state that "the type of act directs the expectation of the text type while the features of the text type indicate the type of act" (Rezat & Rezat, 2017, p. 4197). The authors match Gibbons' characteristics of a genre to the text type and type of act. The type of act involves the field that is the topic of the text; mode that is specific social purpose or function of the text; and tenor that is the relationship between involved parties (writer and reader). The text type is identifying the structure of the text and the language features. The structure of the text involves constitutive and facultative speech acts, sequence pattern or organizational structure. The language features are the lexical features such as technical language and the style, the grammatical features or grammatical constructions such as the connectives, adverbs, tense, etc (Rezat & Rezat, 2017). Halliday and Martin (1993) state that the genre approach originates from a systemic functional perspective on language.

As such, there is consensus in the literature on what characterizes a genre, however different terminologies are used. In other words, while different studies may describe the characteristics of a genre using different languages, they all recognize the same fundamental aspects such as purpose, structure, linguistic features, and context as essential components of a genre.

Mathematical Language has its own genres and discourse that are essential for understanding mathematical concepts. Understanding and engaging with these genres is essential for mastering the subject (O'Halloran et al, 2018). Researchers in mathematics education have distinguished between different genres in terms of structure, function and characteristics (Marks & Mousley, 1990; Morgan, 1998; Gerofsky, 1999; Bicknell, 1999; Adams, 2003; Meaney et al., 2009; Stephanowicz, 2014; Daroczy et al., 2015; Rezat & Rezat, 2017). For instance, Marks & Mousley (1990) distinguish between the recount genre and the procedural genre. The former involves recalling a sequence of events or telling a story or an event or an experience, whereas the latter includes the methods described or how something is done involving listing the sequence of events. Marks and Mousley (1990) identify other genres such as the report genre and explanatory genre. They highlighted that the report genre includes what an entire class of things is like. For instance, a circle is a shape with all points at the same distance from the center and a triangle has three sides. Explanatory genre is defined as the judgments outlined or the reason why a judgment has been made. Other researchers such as Meaney and his colleagues (2009) define the description genre. It corresponds to the activity that involves answering “what is it?” It refers to mathematical objects, facts, or situations that can be in words (verbal), or numeric facts written in symbols. This genre exists mainly in the definitions, theorems, charts, labels, etc. For example: this is a triangle, it has three sides and it has three angles. Other researchers (Meaney et al., 2009) referred to the justification genre in which students justify the obtained results answering: why is this best?. It is about explaining why something is done in a specific manner. It is providing grounds, evidence, or reasons to convince an argument or claim is true (Bicknell, 1999). A genre of proof is defined as “the occurrence of strings of statements thematizing both the fact that an act of reasoning is occurring (i.e. starting with words such as hence or but) and the previously established facts which act as the bases for the deductions” (Dye, 1991 as cited by Morgan, 1998, p. 17). A geometric construction genre includes a drawing and geometric construction texts that involve a step-by-step description of the construction (Rezat & Rezat, 2017). A word problem genre that is “mathematical problems presented in the context of a story or real-life scenario” (Adams, 2003, p.6).

In reference to all of the above definitions and features of a genre, this study adopts the definition of a genre as a form or type of text that is used as a mean of classifying or organizing a discourse that has a specific function and recognizable features within a communicative interaction. Halliday and Martin (1993) state that the genre approach originates from a systemic functional perspective on language. This study adopts a combination/link between Halliday's SFL and Gibbon's characteristics of a genre to unpack the features and characteristics of word problem genre as with previous studies that analyzed genre features (e.g. Chapman, 2002; Gibbon, 2002; Morgan, 1998; Rezat & Rezat, 2017). Gibbon identifies four characteristics that distinguish one genre from another: a specific purpose, a particular overall structure, specific linguistic features, and cultural sharing among members of a community. Accordingly, the field relates to the function or purpose of the text. The tenor influences the linguistic features by shaping how language is used in interactions between participants. The mode affects the structure of the text and how the context is presented. As such, this study also characterizes a genre based on its function/purpose (field), structure (mode), and lexicogrammar or linguistic features (tenor) including, keywords that relate to it (tenor), and the mode of representation (mode). This review explores the word problem genre, and look at its features and characteristics.

Mathematical word problems are defined as "mathematical problems presented in the context of a story or real-life scenario" (Adams, 2003, p. 3). Word problems in mathematics education "are written in imitation not of life but of other word problems" (Gerofsky, 1999, p. 37). There is familiarity in the form of word problems such that the sentence structure, sequence of the story elements, data, questions and the kind of stories used in word problems are similar. Students will translate these problems into mathematics over arithmetic, algebra, and geometry and the questions are solved in the taught methods. The data provided in the word problem is enough to solve the problem such that the problem solver may not demand more data. As such, Gerofsky argues that word problems are strongly imperative where it asks the problem solver to solve the problem using only the information provided and the methods he just learnt. The process of translating these word problems into algebraic or arithmetic expressions is challenging for many students (Gerofsky, 1999; Verschaffel et al., 2020). Barwell (2011) argues that extracting arithmetic operations or reading and understanding the word problem are not enough. According to the author students are expected to read between the lines and comprehend the mathematical tasks embedded within the problem. The main purpose of word problems is to generate a form of mathematical activity (Barwell, 2005). Barwell (2003) argues that word problems are a genre of mathematics problems that are recognized by named characters, a scenario, items of numerical information, and a question or task to be carried out. Solving a word problem represents reaching the final stages of the chapter as it is meant to test students' competence in recognizing problems related to that chapter (Gerofsky, 1999). Students are expected to translate the problems into diagrams and equations that can be solved using taught algorithm methods.

Gerofsky (1999) analyses word problems and focuses on the linguistic structure and organization of word problems. She explores how word problems are constructed, the linguistic features and the interaction of students and teachers with the problem. Gerofsky discusses the features of mathematical word problems and argues that word problems have a sequenced rhetorical structure of three components that are the story element, followed by data and then a question. The story set-up consists of characters' names and action verbs (driving, running, building…). The information part consists of quantities with units. The question part is about an unknown quantity; and often follows the "If…when" structure. The nouns used in word problems are ambiguous such that the word point to some other world than that of our conscious, lived, real-world experience (Gerofksy, 1999). This is also due to the lack of consistency in the use of verb tenses as the verb tenses are mixed in word problems. Gerofsky also argues that word problems are very poor quality, fiction at best. Daroczy and his colleagues (2015) also emphasized some of the linguistic features of word problems such as the use of conjunctions ("and" for addition), the use of adverbs ("left" for subtraction), the use of determiners ("each" for multiplication), the use of prepositional phrases, the presence of passive voice, and the use of complex clause structure (e.g. relative, subordinate, complement). For example, in the word problem "A 10 meters ladder is leaned against the wall, with the root of the ladder 3 meters from the wall" the passive voice is used and there are no people in it (Gerofsky, 1999, p. 44). "The set-up and information components are sometimes collapsed into one sentence by the use of subordinate clauses, or the information component and the question are collapsed into a single sentence using a subjunctive "if … then" structure" (Gerofsky, 1999, p.39). Barwell (2011) argues that students need to be aware and pay attention to three dimensions of word problems that are the genre, the mathematical structure, and personal experience. Barwell refers to the linguistic form of word problems as a three-part structure that are scenario, information, and question. Students are aware of the purpose of the word problem that holds a mathematical question within a scenario. To make this scenario meaningful, students link to their personal experience to understand and interpret the given scenario. This makes the numbers and the experience more realistic. Students need to be aware of the mathematical structure to be able to relate the words of a problem to mathematical operations. To be engaged in valuable and meaningful mathematical thinking, they should be aware of the operations and numbers used and how these numbers are related. As such, understanding the structure of the word problem is essential to mathematize the scenario (Barwell, 2011).

Rezat and Rezat (2017) discuss how a genre relates to language in texts. The authors suggest that frequent exposure to texts allows individuals to recognize the pattern and the style of these texts that they encounter regularly. Moreover, this familiarity and repeated experience aids in reading, understanding and producing similar texts as the individuals are more comfortable with the language, structure, and conventions of these texts. Through practice and repeated experiences individuals get more skilled in certain tasks (Rezat & Rezat, 2017). For this reason, the author of this review adopts a genre analysis approach in the current research. The author believes that one effective way to explore the relationship between language and mathematics is through a genre-based approach, which promotes different forms of communication in mathematics instruction (Gerofsky, 1999). Mathematical genres, such as word problems, proofs, explanations and descriptions, function as tools for the communication of mathematical knowledge (Marks & Mousley, 2009). Each genre has its own linguistic features and cognitive demands, which must be mastered by students to progress in their mathematical learning (Schleppegrell, 2007).

To this end, this literature review reveals variations in defining word problem genre, and unpacking its characteristics in mathematics education. The literature review nevertheless shows that there is limited research on how the characteristics of a word problem genre vary across different grade levels. The focus of this study is on exploring these variations by analyzing the National Lebanese mathematics textbook. The author analyzes textbooks because textbooks play a crucial role in shaping students' mathematical performance. The current study explores word problem genre in the mathematics national textbook. More specifically, the current research studies the characteristics of word problem genre, how these characteristics vary across mathematical strands and across grade level and school cycle from Grade 1 till Grade 9. We have selected word problem as a genre for our study because previous studies have characterized a word problem genre. In addition, the Lebanese mathematical curriculum emphasizes problem solving and in engaging students in word problems.

Language Learning Progression in Mathematics Education

As previously stated, mathematics is a critical subject in every school curriculum, contributing to the development of students' problem-solving skills, logical reasoning, and analytical thinking. Educators must understand and adapt to the development of mathematical skills and concepts in order to effectively assist students in their learning. Major developmental stages have been identified through mathematics education research, outlining how mathematical concepts and representations are organized and introduced across grade levels. These progressions span areas such as number sense, algebraic reasoning, geometry, and data analysis. A clear understanding of these progressions helps educators structure lessons and instructional materials at each level.

Learning progressions track the development of students' thinking and learning from simple and basic levels to successively more sophisticated levels (Bailey & Heritage, 2014). Bailey and Heritage (2014) argue that language can also develop in sophistication across levels, progressing from basic words, sentences, and discourse structures toward more complex and specialized forms. Although their work focuses on the development of students' language over time, the linguistic features they identify provide useful dimensions for examining how language may vary in complexity across educational materials and tasks. Bailey and Heritage (2014) examine how students' language develops in sophistication over time through their work on Dynamic Language Learning Progressions. They identified the features of language development as stamina, coherence and cohesion, advanced relationships between ideas, perspective taking, sentence structure sophistication, vocabulary sophistication, verb form sophistication, and expanded word groups.

The authors assess language growth across several dimensions, including quantity, quality, repertoire expansion, and accuracy, while also noting that language development may vary in rate and follow general patterns in the order of acquisition. These dimensions describe ways in which language may increase in complexity and sophistication. In educational contexts, such dimensions can also be used to identify linguistic features that signal increasing language demands across levels of instruction. They argue that language progresses through increasing in quantity of the use of topic-specific vocabulary and new terms.

Moreover, language progresses by quality when complexity or sophistication increases through more structured relationships between ideas. This includes the use of modal verbs like “should’, “could’, “would”, complex clauses and attempts at perspective taking. Such linguistic features reflect increasing discourse complexity, where ideas are connected through logical sequencing and more elaborated sentence structures. Language also progresses through the expansion of repertoires, makes use of a wider range of grammatical and discourse resources to express relationships between ideas. This progression is evident in the increasing use of connectors and relational expressions, move from using basic connectors like “and”, “so”, and “then’, to incorporating prepositions that express relationships, such as causal (“because”), conditional (“if”), contrastive ("even though"). It also includes replacing repetitive use of causal connectors like "because" with alternatives such as "since," "as a result of," and "consequence of".

Bailey and Heritage (2014) found that throughout the progression of language, the features of language tend to be used in increased accuracy or expected conventionality. For instance, more precise word choices were made to avoid ambiguity in meaning. Also, language functions were applied appropriately within context. Sophistication in verb use was marked by increased control over tense and the use of modal verbs. Such developments illustrate how grammatical forms and vocabulary may become increasingly precise and conventional as linguistic sophistication increases.

The concept of progression has gained importance, particularly through Bakhtin’s notion of genre. Bakhtin defines genres as “compositional structures embedded in and developing out of various spheres of human activity” (Chapman, 1995). “Each sphere of activity contains an entire repertoire of speech genres [oral and written] that differentiate and grow as the particular sphere develops and becomes more complex" (Bakhtin, 1986, p.60 as cited by Chapman, 2002, p. 5). This perspective emphasizes that genres are not fixed; they develop through practice and within specific social context. From this perspective, educational genres such as mathematical word problems can also evolve in structure and linguistic complexity as they are presented across different levels of schooling. This highlights the need for understanding how mathematical genres such as proofs or word problems in textbooks or instructional texts develop in response to increasing conceptual and communicative demands within the discipline.

Similar to how Piaget and Vygotsky emphasized the development of cognitive skills, Bakhtin's notion of genre progressions suggests that the forms of mathematical communication must also develop in response to growing sophistication in disciplinary practices. Consequently, the way that mathematical problems or solutions are written may change as the mathematical content and communicative expectations become more complex. This view allows us to explore how the genre evolves over time. In particular, this view supports the current research's aim to examine how the word problem genre varies across grade levels in the Lebanese curriculum.

Daroczy et al. (2015) argue that as students advance, word problems become increasingly challenging, particularly when it involves multiple steps. In the two-step problems, the difficulty often arises not only from algebraic complexity but also from increased linguistic demands, such as the inclusion of more phrases and semantic distractors. These findings highlight how the linguistic structure of word problems can contribute to their overall complexity. The successful progression of students' mathematical thinking depends on the quality of teaching and learning, and assessment opportunities. As such, it is not only related to how language is progressively acquired, but also how teachers and students can actively support language development in mathematics (Bailey & Heritage, 2014).

Jian-Xin Yao and Yu-Ying Guo's focus on the Phenomenon-Theory-Data-Reasoning framework reflects a larger interest in the methodical creation of progressions in mathematics education (Yao & Guo, 2018). The authors emphasize the relevance of scaffolding learning experiences through structured progressions that guide learners from basic to more complex forms of understanding. This method is consistent with current educational research, which calls for logical progressions in mathematics, emphasizing the need for clear routes that allow students to build on their prior knowledge and abilities.

As such, this study explores the language learning progression of the word problem genre across grade levels in the National Lebanese mathematics textbook. That is, this study compares and highlights the increasing sophistication of mathematical language in word problems across grades one to nine. This study looks at the progression of language based on the features of the development of language identified in the literature that are the sentence structure sophistication, vocabulary sophistication, verb form sophistication, and expanded word groups.

The Role of Textbooks in mathematics instruction

Textbooks are essential tools for delivering the curriculum and guiding the learning instruction. In Lebanon, textbooks are not only an instructional tool but play an essential role in reflecting the language linguistics and the culture of the Lebanese context. This is due to the multilingual nature of the educational system in Lebanon as textbooks are written in French or English. However, the complexity of language in these textbooks and the mathematical language itself can create challenges to the learners. Students are expected to interpret the instructions, understand abstract concepts, engage with the subject matter, and solve problems across different registers of language i.e. every day, academic and mathematical. Khoury and his colleagues (2023) compare three textbooks used in Lebanon over geometry content. They focused in their analysis on mathematical content, mathematical activity, complexity level, answer form, and context of tasks. In their study, they shed light on the importance of textbooks as an educational resource in the classroom as they consider it to be the main reference for teachers and students. Textbooks are a crucial part of the educational system as they are created and produced to convey the national curriculum and the educational goals. The examination of textbooks reveals the effectiveness of the implementation of the desired curriculum (Remillard, 2000, as cited in Khoury, Sfeir & El Rouadi, 2023). Textbooks serve as a mirror of the curriculum for parents, teachers and students. The design and organization of the mathematics textbook impacts the different pedagogical approaches used in the classroom as the organization of textbooks have an influence on how students are taught in the classroom and this is the case of Lebanon although the textbook is based on the national curriculum (Valverde, 2002, as cited in Khoury, Sfeir & El Rouadi, 2023). The linguistic challenges that students encounter through textbooks highlight the importance of designing the content to accommodate students' diverse linguistic needs. Moreover, by analyzing the characteristics of mathematics textbooks and understanding the structure and elements of the textbooks aligned with an organized strategy of unpacking the elements of the textbook, students can develop proficiency in the language and content of mathematics.

Morgan (1998) investigates numerous traits of the genre of mathematics textbooks, pointing out important elements to be considered that facilitate the learning and understanding of mathematical concepts. Morgan identified these characteristics of mathematical language as the vocabulary and symbolic context, the grammatical structures, and the level of density and consciousness used. Symbols and specialist vocabulary are used to name mathematical objects and concepts. The grammatical structures are used to express mathematical meanings like "the sum of the series to n terms." The density and consciousness focus on correctness of what is written rather than the richness of meaning.

Morgan says that the focus on more content words than grammatical words characterize scientific texts as having high level of lexical density. The author argues that school textbooks include the use of technical language, symbolic elements, graphic elements including tables, graphs, diagrams, plans, maps, pictorial illustrations where some of these elements are essential for the meaning of the text and others are for decorative purposes. Moreover, while the author analyzed the density and consciousness of these texts, the author noticed a redundant and repetitive structure which makes it easier for the reader to predict what will come next in the text. These repetitive structures were mostly found in the genres "examples and exercises". As such, these elements can be categorized into symbolic elements, graphical elements, and redundancy and repetitive structures. Moreover, the author highlights the presence of questions and instructions that involve the student as an active participant were found in practice exercises, testing student knowledge and in the sections designed to explain new ideas and concepts. These linguistic features are directly related to Halliday's three components of discourse: field, tenor, and mode. The vocabulary and symbolic context reflect the field of the discourse such that they represent the subject matter and types of mathematical activity used. The grammatical structure relates to the tenor since they shape the interaction between the text and the learner such that how this relationship is communicated. Finally, the level of density and consciousness along with the redundancy corresponds to the mode as it describes how the information is organized, how meaning flows within the text, and how cohesive the text appears to the reader.

This theoretical lens in textbook analysis is further seen in later work by Alshwaikh and Morgan (2013) by applying Halliday's SFL to investigate how mathematical meaning is constructed in the Palestinian mathematics textbooks. Throughout their study, they focus on the specialized mathematical discourse (field) and the learning agency in mathematical processes (tenor). They argue that the text in the textbook is highly specialized due to the extensive use of specialized and technical vocabulary such as “congruence”, “triangle”, “theorem” and conventional expressions such as “corresponding angles”, “congruence theorem”, etc. This is also due to the use of mathematical symbols that convey important meanings in the texts such as "$\angle ABC$", " $\equiv$ ". Moreover, the use of visuals and diagrams are specialized such as representing the triangle along with the marks and labels to indicate equal sides or angles. In their analysis of the learning agency (tenor) they argue that the learner engages in both material actions and mental processes. The engagement in material actions gives the learner the role of the scribbler such that they use the verbs “cut”, “draw”, “find”, while the engagement in mental processes give the learner the role of the thinker through the use of verbs like “show”, “prove”, “notice”, “consider”. Moreover, questions are used to encourage reflection such as “what do you notice” (Alshwaikh & Morgan, 2013). In the same vein, Alshweikh (2016) analyzed a chapter in the Palestinian geometry textbook and reached similar findings. However, in this study, he also looked at the visual elements in his analysis and discussed the structure of knowledge and text layout (mode). He concludes that the visuals are similar to the verbal contents such that the visuals mostly repeat or mirror the verbal content rather than elaborate or expand it. Moreover, some text like key facts have different text layouts such as colored, bold font, etc. Furthermore, the author notes that the use of nominalization and passive voice was evident as it conceals the role of the human agent and objectifies the process (Alshweikh, 2016).

Simpson and Cole (2015) elaborated that communication in mathematics is characterized by specific terms such as “integral”, “matrix”, “derivative”, “vector”, and many more. These keywords are vital for understanding specific concepts in mathematics and their understanding contributes to learners properly assimilating their lesson (Simpson & Cole, 2015). In addition, logical connectives are crucial in mathematical arguments that help to link between statements. As discussed by Shatfel, et al., (2006), connectors like “therefore”, “hence”, “if…then”, etc., are extremely important to construct mathematical proofs, explain, and solving problems. They assist in forming logical sequences properly clarifying and easing the reasoning process (Shaftel, Belton-Kocher, Glasnapp, & Poggio, 2006). Furthermore, the passive voice and the formal tone are regularly used in mathematics to preserve objectivity in the text and focus on the procedures, problems, and results and not on who’s performing those actions. Pimm and Wagner (2003) stated that the passive voice and the formal tone are used to maintain the universality and impartiality of the language (Pimm & Wagner, 2003). For instance, in mathematics, the form “the problem is solved as follows” instead of saying “we solved the problem as follows”; is done so to keep the focus on the act of solving the problem and not on who solved it.

Conclusion

In conclusion, this literature review presents a deep analysis of mathematical language used in textbooks and classrooms with a focus on language acting as a communication tool. As such, it looks at Vygotsky’s sociocultural theory, Halliday’s linguistic metafunctions and the challenges faced by students in understanding the mathematical register for improving communication and comprehension in mathematics classroom. Throughout this analysis, this research highlights that mathematical understanding is influenced by linguistic features including specialized vocabulary, syntax, and semiotics. The students’ abilities to comprehend mathematics concepts, efficiently solve problems, and explain their thinking are very much linked to the language employed in mathematics learning. As a matter of fact, it is crucial to get the hang of specific linguistic features in mathematics such as mathematical vocabulary, grammar, syntax, discourse structures, etc., leading to successfully communicating with students. Hence, student comprehension is a factor of the language used in teaching in general and the understanding of its genres in particular (Bapna, Myers, & Sharma, 2023).

Furthermore, this review looks at genre-based approach such that the different mathematical genres, such as justification, mathematical word problems, proofs, and geometric structures are the main structure of mathematical knowledge. In this review, the main focus was investigating the word problem genre, identifying its function, structure, characteristics and linguistic features. Recognizing and engaging with these genres allows students to get a more sophisticated perception of mathematical concepts and improve their problem-solving ability. This study also highlights the challenges that students face in studying mathematics in multilingual context like Lebanon, where textbooks serve as the medium of instruction. This review identifies a research gap on mathematical genres in textbooks and the development of the linguistic features across different grade levels. This suggests the need for further investigation into how linguistic features are present and evolve in mathematics education.

The main focus of the present study is to analyze word problems as genre based on textbook analysis. By analyzing the word problem genre in the Lebanese mathematics textbook, this study aims to fill a gap in the literature regarding the progression of linguistic features and mathematical knowledge of word problem genre across grade levels. This will contribute to a better understanding and support to the development of students' linguistic capabilities in understanding word problems.

CHAPTER 3

METHODOLOGY

In this chapter, we present the research methods that were used in this study to analyze and identify the key characteristics, including linguistic features, of the word problem genre in the Lebanese mathematics textbook. This study also examines how these characteristics vary across grade levels and school cycles. The following research questions are set to provide guidance on the paths to follow:

(1) How does the frequency of the word problem genre vary across grade levels, school cycles and mathematical strands (numbers and calculations, algebra, geometry, measurement, and statistics) in Lebanese National mathematics textbooks?

(2) How do the linguistic characteristics of the word problem genre change across school cycles in the Lebanese National mathematics textbooks?

(3) What language learning progressions can be identified in the linguistic characteristics of the word problem genre across Cycles I, II, and III in the Lebanese curriculum, reflecting increasing levels of language complexity?

Research Design

To answer the research questions, this study employs a content analysis approach based on textbook analysis by investigating the word problem genre and its characteristics present in the Lebanese mathematics textbook series "Building Up Mathematics" from Grade 1 to Grade 9. Content analysis is a research methodological approach that enables researchers to systematically examine texts to identify patterns and variations (Krippendorff, 2018). There are several types of content analysis. The current study conducts quantitative and qualitative content analyses. The quantitative content analysis involves counting the frequency of elements within text, while the qualitative content analysis focuses on interpreting meanings, functions, and contextual use of these elements within the text (Neuendorf, 2017). Moreover, the quantitative content analysis can provide numerical data for comparison while the qualitative content analysis provides contextual understanding.

Content analysis was used by several researchers in mathematics education for analyzing or comparing specific features in mathematics textbooks (Valverde et al., 2002; Li, 2000; Morgan, 1996; Morgan, 1998; Rezat & Rezat, 2017; Khoury et al., 2023). Valverde and his colleagues (2002) compared mathematics textbooks across nations using both quantitative and qualitative content analysis with a focus on differences in curricular focus. Li, (2000) also used content analysis to compare mathematical and contextual features between American and Chinese mathematics textbooks. In addition, Khoury et al. (2023) compared three textbooks used in Lebanon using a content analysis technique. In their study, the authors defined three types of textual analysis: "A priori textual analysis: Analyzing a text as a possible means of instruction; A posteriori textual analysis: Comparing learning results with the text; and Tempo textual analysis: Analyzing how teachers and learners use texts in the teaching-learning activities" (Khoury et al., 2023, p.349). The authors used the first type in their analysis, in which they coded and counted the frequencies of tasks on topics related to parallelograms. The authors also coded mathematical activities, complexity levels, structure, and context, and determined the frequency of each code. The current study adopted a similar analytical approach, focusing on one type of textbook: the Lebanese national textbook. To answer the first research question regarding variation of word problem genre in terms of frequency across grade levels, school cycles, and mathematical strands, the current study counts the occurrence of word problem genre per grade level, school cycle, and mathematical strands.

To address the second research question regarding variation of the characteristics of the word problem genre across school cycles, the current study analyzed the structure and linguistic features, including keywords and grammar, of the word problem genre in the textbooks. The analysis was conducted in a similar way to Morgan (1996;1998) and Rezat and Rezat (2017). Morgan (1996) conducted qualitative content analysis to analyze the characteristics and linguistic features of mathematics textbooks with a focus on particular mathematical texts. In the same vein, Morgan (1998) used quantitative and qualitative content analysis to investigate different genres of the textbook based on the structure of the textbook. For example, a redundant and repetitive structure in the genres “examples and exercises”. Rezat and Rezat (2017) also used a content analysis to analyze the features of geometric construction genre in mathematics textbooks. They investigated the linguistic features and sentence structure within geometry context.

To address the third research question, the study further examined how these linguistic and structural features progressed across Cycles I, II, and III in terms of increasing language complexity and sophistication. The analysis focused on identifying patterns of progression in the word problem genre, such as shifts in vocabulary sophistication, sentence structure complexity, logical relationships, and representational demands across school cycles.

Data Sources

The researcher analyzed the Lebanese mathematics textbooks to find the frequency of word problems and unpack its features in the textbook chapter by chapter, grade by grade, cycle by cycle and across the different mathematical strands within elementary and middle school cycles. The analysis of word problems was conducted on word problems from grades 3, 6, and 9, as the grades represent the end of each cycle. Moreover, this study analyzed the sophistication and development of the features across the cycles. The textbooks investigated are the official Lebanese national mathematics textbook series, *Building Up Mathematics*, mandated by the Lebanese Ministry of Education and Higher Education. These textbooks span the following grade levels and cycles: Cycle I from Grade 1 to 3, Cycle II from Grade 4 to 6, and Cycle III from Grade 7 to 9. This analysis aims to capture the progression of the characteristics of word- problem mathematical genre in early, middle and late stages of schooling with a focus on grades 3, 6 and 9. Our aim is to hypothesize the progression of linguistic characteristics of word problems and increased language complexity across school cycles in alignment with the Lebanese national curriculum guidelines.

Data Collection and Analysis Procedure

The present study identified the characteristics of the word problem genre within the Lebanese national mathematics textbook series, *Building Up Mathematics*, from grades 1 to 9 with a focus on English as the primary language of instruction. To conduct the analysis, this study used a coding framework using Gibbon's characteristics of distinguishing a genre from another, that draws on Halliday's systemic functional linguistics (SFL) with a focus on field, tenor, and mode (Halliday, 1978) to distinguish between the genres. Gibbon (2002, as cited by Rezat & Rezat, 2017) identifies four characteristics that distinguish one genre from another: a specific purpose, a particular overall structure, specific linguistic features, and cultural sharing among members of a community. Accordingly, the field relates to the function or purpose of the text. The tenor influences the linguistic features by shaping how language is used in interactions between participants. The mode affects the structure of the text and how the context is presented. In alignment with previous studies that analyzed textbooks with a focus on genre features (e.g. Chapman, 2002; Gibbon, 2002; Morgan, 1998; Rezat & Rezat, 2017), the author classifies the word problem genre according to its function (field), structure (mode), and lexicogrammar or linguistic features (tenor) including, keywords that relate to it (tenor), and the mode of representation (mode). We define the function, structure, lexicogrammar, keywords and mode of representation of the word problem genre based on the literature (Gerofsky, 1999; Adams, 2003; Barwell, 2003; 2005; 2011; Daroczy, Wolska, Meurers, and Nuerk, 2015).

The researcher refers to Gerofsky (1999) in the framing of the different dimensions that characterize a word problem genre. Even though different scholars have defined a word problem genre and identified its characteristics, we refer to Gerofsky (1999) because the author provides a detailed analysis of word problem genre with its function, linguistic features and grammatical structures, and sentence structure, and it was referred to by well-known researchers in mathematics education (e.g. Bawell, 2003; 2005; 2011). The main purpose of word problems is to generate a form of mathematical activity (Barwell, 2005). Word problems are mathematical problems presented in the context of a story or real-life scenario (Gerofsky, 1999). Gerofsky (1999) argues that word problems have a sequenced rhetorical structure of three components that are the story element, followed by data and then a question. The story set-up consists of characters' names and action verbs (driving, running, building…). The information part consists of quantities with units. The question part is about an unknown quantity; and often follows the "If…when" structure. The nouns used in word problems are ambiguous such that the word point to some other world than that of our conscious, lived, real-world experience (Gerofksy, 1999). This is also due to the lack of consistency in the use of verb tenses as the verb tenses are mixed in word problems. Daroczy and his colleagues (2015) also emphasized some of the linguistic features of word problems such as the use of conjunctions ("and" for addition), the use of adverbs ("left" for subtraction), the use of determiners ("each" for multiplication), the use of prepositional phrases, the presence of passive voice, and the use of complex clause structure (e.g. relative, subordinate, complement). For example, in the word problem "A 10 meters ladder is leaned against the wall, with the root of the ladder 3 meters from the wall" the passive voice is used and there are no people in it (Gerofsky, 1999, p. 44). Moreover, word problems involve unusual use of tense (e.g "eat, would eat, would eat" instead of "eat, would eat, do eat"). "The set-up and information components are sometimes collapsed into one sentence by the use of subordinate clauses, or the information component and the question are collapsed into a single sentence using a subjunctive "if … then" structure" (Gerofsky, 1999, p.39). Students are expected to translate the problems into diagrams and equations that can be solved using taught algorithm methods (Gerofsky, 1999).The keyword used in word problems are to convey causes and effects (e.g. comes from, leads to, because, so, thus, therefore, etc).

Table 1 presents the codebook used to identify and categorize word problems in this study. The coding framework presented in Table 1 was developed based on previous research on word problem genre (Gerofsky, 1999; Barwell, 2003, 2005; Daroczy et al., 2015) and grounded in a Systemic Functional Linguistics perspective (Halliday, 1978; Schleppegrell, 2007). The framework captures four key dimensions of the word problem genre: function, structure, lexicogrammar, and mode of representation. The table summarizes the defining features of word problems, including their function, structure, lexicogrammar characteristics, modes of representation, and a prototype example. This framework guided the systematic coding of problems in the textbooks, ensuring that each word problem was consistently recognized and analyzed according to established criteria from prior research.

Table 1
Word Problem Genre Features

	Word problems
Function (Gerofsky,1999; Adams,2003; Barwell, 2005)	The main purpose of word problems is to generate a form of mathematical activity - Word problems are imitations not of life but of other word problems. - Word problems are mathematical problems presented in the context of a story or real-life scenario.
Structure (Gerofsky, 1999; Barwell, 2003)	Word problems are a genre of mathematics problems that are recognized by named characters, a scenario, items of numerical information, and a question or task to be carried out. The structure of word problems is as follows: 1. *Story set-up*: sets the story context into which the problem will be embedded 2. *Information/data:* introduces the mathematical quantities that can be used to solve it 3. *Question:* indicates the quantity that needs to be determined "The set-up and information components are sometimes collapsed into one sentence by the use of subordinate clauses, or the information component and the question are collapsed into a single sentence using a subjunctive "if … then" structure" (Gerofsky, 1999, p.39)
Lexicogrammar (Gerofsky, 1999; Daroczy, Wolska, Meurers, and Nuerk, 2015)	- The story set-up consists of characters names and action verbs (driving, running, building…) - The information part consists of quantities with units - The question part is about an unknown quantity; often follows "If…when" structure - Conjunctions ("and" for addition) - Adverbs ("left" for subtraction) - Determiners ("each" for multiplication) - Prepositional phrases - Presence of passive voice - Complex clause structure (e.g relative, subordinate, complement) - Complexity of noun phrases (polysemous words) Unusual use of tense (e.g "eat, would eat, would eat" instead of "eat, would eat, do eat") - Keywords: Terms that convey causes and effects (e.g. comes from, leads to, because, so, thus, therefore, etc.), Mathematical Terms (everyday, transitional and technical terms)
Mode of Representation (Gerofsky, 1999; Schleppegrell, 2007)	The form of communication such as Text, diagrams (images) Visual displays such as graphs and diagrams aid in presenting mathematics symbolism.
Prototype example (Gerofsky, 1999)	Jake and Jerry went on a camping trip with their motorcycles. One day Jerry left camp on his motorcycle to go to the village. Ten minutes later Jake decided to go too. If Jerry was travelling 30 mph and Jake traveled 35 mph, how long before Jake caught up with Jerry? (Jonson, 1992, p. 28; as cited by Gerofsky, 1999).

The dimensions presented in Table 1 provided the conceptual basis for the development of the detailed codebooks (Tables 2, 3, 4 and 5) used in the analysis.

In this study, the researcher mapped the word problem genre across the Lebanese curriculum based on table 1 above that distinguishes the function, structure, and linguistic features of the genre in the literature using a quantitative content analysis approach to look at the frequency of word problem genre. The mapping was through coding the mathematical tasks that are word problems in the Lebanese national textbook for grades 1 to 9 in terms of frequency and representing in frequency tables to show the occurrence of this genre. The researcher coded every chapter in every grade level based on the division of the chapters, which is the structure of the unit analysis of the textbook.

The unit analysis in the textbook differs from one grade to another. In grades 1 to 3, each chapter is divided into a box that includes one or more activities, exercises, an evaluation rubric, and a game or research box. In grade 4, every chapter is divided into activities, subject, results, exercises, self-evaluation, problems, and just for fun. In grades 5 to 7, every chapter is divided into activities, text, focus, exercises, self-evaluation, problems, and just for fun. Grades 8 and 9 are similar to the latter but activities are divided into recall activities and preparatory activities. The frequency distribution was analyzed across grade levels and cycles using tables and bar charts to reveal distribution patterns based on the above structure of the unit analysis of the textbook. These word problems were counted and identified based on the structure, functions and linguistic features of the word problem genre. The total tasks in each chapter were also counted. A task was defined as any question requiring a student response. These questions fall under the following categories in the book: Recall Activities, Preparatory Activities, Activities, Self-Evaluation, Exercises, Problems, Just for Fun, and Game or Research box. Every question is considered a task. Questions with parts a, b, c are considered as 1 task. Moreover, word problems embedded within exercises were also counted as a word problem task. In addition to identifying the frequency of word problems across all grade levels (Grades 1–9), the study also examined the mathematical strands to which these problems belong (e.g., arithmetic, algebra, geometry, etc). This allowed the researcher to analyze how the distribution of word problems varies not only across grades and cycles but also across mathematical strands. These strands followed the textbook classification that includes numbers and calculations, algebra, geometry, measurement, and statistics. The arithmetic strand in mathematics is referred to as numbers and calculations based on the textbook. This helped in answering the research question: “How does the frequency of the word problem genre vary across grade levels, school cycles and mathematical strands (numbers and calculations, algebra, geometry, measurement, and statistics) in Lebanese National mathematics textbooks?”

This study also analyzed the function, structure, lexicogrammar, and mode of representation of the word problem genre in the Lebanese mathematics textbook across grades 3, 6, and 9, spanning the three cycles, focusing on similarities and differences to examine the complexity of the linguistic features. This qualitative content analysis allows the exploration of how the characteristics of the word problem genre vary across grade levels and school cycles and helps in understanding their progression. For the qualitative linguistic analysis, Grades 3, 6, and 9 were purposively selected as representative grades marking the end of Cycles I, II, and III, respectively, within the Lebanese curriculum. These grades serve as transition points between cycles and, therefore, provide meaningful comparison points for examining changes in the linguistic and structural characteristics of word problems across educational stages. This answers the research question: “How do the linguistic characteristics of the word problem genre change across school cycles in the Lebanese National mathematics textbooks?”

The findings from the frequency and linguistic analyses allow us to evaluate and assess the increasing sophistication of language, hypothesizing that language learning progression and high language proficiency are occurring throughout the grade levels. The comparison across these three grades enables the study to investigate progression in genre features and increasing linguistic complexity across cycles. In addition, a further layer of qualitative analysis was conducted on the sampled word problems to compare how linguistic and structural features evolved across Cycles I, II, and III in terms of increasing complexity and sophistication. This comparative analysis focused on identifying patterns of progression in the genre dimensions across the school cycles. This answers the research question: "What language learning progressions can be identified in the linguistic characteristics of the word problem genre across Cycles I, II, and III in the Lebanese curriculum, reflecting increasing levels of language complexity?"

To obtain a manageable yet representative sample of word problems for the qualitative phase of the study, a stratified random sampling procedure was conducted using IBM SPSS Statistics. The sampling was stratified by grade level to ensure proportional representation across the three targeted grades (Grades 3, 6, and 9), corresponding to the ends of Cycles I, II, and III in the Lebanese mathematics curriculum.

All word problems extracted from the mathematics textbooks were first entered into SPSS, yielding a dataset of 432 cases: 191 from Grade 3, 179 from Grade 6, and 62 from Grade 9. To generate an unbiased random selection within each grade, a uniform random number between 0 and 1 was generated for each problem using the RV.UNIFORM(0,1) function in SPSS. Word problems within each grade level were then sorted by this random value to produce a randomized ordering of cases inside each grade-level stratum.

After randomization, a rank variable was computed to assign an ordered index to each problem, beginning with 1 for the smallest random number and increasing sequentially within each grade. This ranking restarted at 1 for each new grade level, thereby preserving the stratification structure and ensuring that randomization was carried out independently within Grades 3, 6, and 9.

To determine the number of cases to be included in the sample, 10% of the total number of word problems was calculated separately for each grade. A ceiling rule was applied to ensure full inclusion when the percentage resulted in a decimal value by rounding the sample size upward to the nearest whole number. This process yielded the following sample sizes: 20 problems for Grade 3, 18 problems for Grade 6, and 7 problems for Grade 9. Finally, a filter condition was applied to retain only those cases whose rank values fell within the grade-specific thresholds (i.e., rank ≤ 20 for Grade 3, rank ≤ 18 for Grade 6, and rank ≤ 7 for Grade 9). The filtered dataset comprised a final random sample of 45 word problems, representing 10% of the population in each grade. This procedure ensured that the qualitative analysis was grounded in a rigorous and reproducible sampling method, while preserving proportional representation and minimizing selection bias across grade levels.

Following the sampling procedure, the selected word problems were exported and organized in an Excel spreadsheet for detailed qualitative analysis. Each problem was treated as a unit of analysis and coded individually according to four analytical dimensions: function, structure, lexicogrammar, and mode of representation.

The coding scheme used in this study was derived from a codebook developed for the analysis, which is presented below in this chapter. The codebook was informed by the relevant literature and the analytical framework adopted in this study. It provided definitions and descriptions of the coding categories and subcategories, along with examples to guide the coding process.

During the initial stages of coding, the researcher and second coder discussed the coding categories and criteria to clarify category boundaries and ensure consistent interpretation of the codebook. Based on these discussions, the coding scheme was refined iteratively before the final coding process was completed.

To ensure the reliability and consistency of the coding process, 20% of the sampled word problems from each of the three grades (Grades 3, 6, and 9) were independently coded by a second coder. The coded datasets were then compared to identify discrepancies between the two coders. Most differences occurred within the function dimension, particularly in distinguishing between imitation of school mathematics and imitation of real-life activity. These discrepancies were discussed until agreement was reached. As a result of these discussions, the two categories were treated as non-mutually exclusive, allowing a word problem to be coded simultaneously as both imitation of school mathematics and imitation of real-life activity when appropriate. This decision resolved the identified inconsistencies and ensured greater consistency in the final coding.

Once the coding process was finalized, the completed Excel coding sheets were transferred to IBM SPSS Statistics for quantitative analysis. Frequencies and percentages were calculated for each subcategory across the four analytical dimensions in order to compare the distribution of language features across the selected grades.

Codebooks Description

The analysis was guided by four codebooks: function, structure, lexicogrammar, and mode of representation. These codebooks were derived from the analytical framework presented in Table 1, which outlines the defining features of the word problem genre based on relevant literature. The function, structure, and lexicogrammar codebooks were informed by genre-based and systemic functional linguistic frameworks (e.g., Gerofsky, 1999; Barwell, 2003, 2005; Halliday & Martin, 1993; Martin & Rose, 2008), and their categories were adapted to suit the context of mathematical word problems in the Lebanese curriculum.
In contrast, the mode of representation codebook was developed iteratively through analysis of the data and was conceptually informed by semiotic and multimodal perspectives on representation (e.g., Schleppegrell, 2007). This dimension was therefore operationalized inductively to capture how mathematical information is distributed across different semiotic resources within word problems. Together, these codebooks combine theory-informed and data-driven categories, enabling a comprehensive analysis of both the linguistic and representational features of the word problem genre. The codebooks were refined iteratively through discussions between the two coders to clarify category boundaries and ensure consistency in the application of coding criteria. Each codebook provides definitions, inclusion and exclusion criteria, and illustrative examples to support systematic analysis.

The function codebook (Table 2) captures the purposes served by word problems and is informed by genre-based perspectives on mathematical discourse (e.g., Gerofsky, 1999; Barwell, 2003, 2005). The categories in this codebook apply these features by enabling the identification and evaluation of the presence of story or real-life framing and the extent to which tasks engage students in mathematical activity. These categories were adapted from the literature and refined through iterative analysis of the dataset to ensure alignment with the characteristics of word problems in the Lebanese curriculum. The definitions, as well as the inclusion and exclusion criteria, were operationalized by the researcher to support consistent coding and to clarify distinctions between closely related categories. This approach allowed the codebook to remain theoretically grounded while being responsive to patterns emerging from the data.

Table 2
Function Codebook Description

Primary Code	Subcode (Category)	Definition	Inclusion Criteria	Exclusion Criteria	Illustrative Example
Function Dimension	**Imitation of Real-Life Activity**	A word problem presents a scenario resembling everyday social or practical activity (e.g., shopping, sharing, traveling), intended to appear meaningful beyond school mathematics, even if simplified. May co-occur with "Imitation of School Mathematics."	Named characters; familiar settings; everyday objects or actions (buying, carrying, eating, traveling); quantities embedded in a plausible real-world activity.	Purely numerical tasks; no plausible real-world activity referent; abstract calculation prompts.	"A truck carries 125 cases of red apples…"
	Imitation of School Mathematics (Word problem Genre)	A word problem uses a real-life context but functions primarily as a routine school mathematics task, where the context mainly cues an operation rather than requiring interpretation. May co-occur with "Imitation of Real-Life Activity."	Context is thin, replaceable, and quantities directly cue an operation; solving does not require interpreting the situation; typical textbook phrasing ("how many in all," "how much is left")	Purely numerical tasks without any contextual framing.	"There are 65 persons on a bus. 43 are sitting. How many are standing?"
	Story or Real-Life Context Present	A narrative frame is used to situate the mathematical task, regardless of the authenticity or richness of the context.	Presence of characters, setting, event sequence (even minimal); contextualized quantities.	Bare numerical prompts without narrative framing.	"Mother bought three shirts…"
	No Story / Context-Free Task	The task is presented without any narrative or situational framing; it consists solely of numerical or symbolic expressions.	Numerical expressions, equations, or symbolic tasks only; no actors, actions, or settings.	Any reference to people, objects, actions, or situations.	"Calculate 884 ÷ 4."
	Mathematical Activity Generation	The problem invites engagement in a mathematical action (e.g., calculating, comparing, partitioning, classifying), rather than simple recall or application of a memorized fact.	Requires constructing a solution pathway; may involve multi-step reasoning, comparison, or organization of quantities.	Simple fact recall; isolated procedural drills with no decision-making.	"How many full tables were there?"
	Notes / Interpretation	Analytic memo capturing ambiguity, hybrid cases, or tensions between real-life appearance and mathematical intent.	Researcher reflection; justification of coding decisions; identification of borderline or mixed cases.	Descriptive restatement of the problem text; repetition of the definition.	"Although framed as real life, context is irrelevant to solution."

The function codebook corresponds to the function dimension of the word problem genre presented in Table 1 and is grounded in the literature on mathematical word problems (Gerofsky, 1999; Barwell, 2005). It captures key features related to the presence or absence of narrative context and the generation of mathematical activity, which are consistently identified as central characteristics of word problems.

The structure codebook (Table 3) examines the organization of word problems, including both canonical genre-based staging (e.g., set-up, information, and question) and variations in how these components are realized or combined. It is informed by genre theory (e.g., Gerofsky, 1999; Barwell, 2003) and adapted to the context of mathematical word problems. In particular, Gerofsky (1999) highlights that these components may be collapsed through the use of subordinate clauses or conditional (“if…then”) structures, a feature that is explicitly captured in this codebook. Moreover, some word problems take the form of task-oriented or activity-based structures, in which the focus shifts from narrative context to procedural instructions (Barwell, 2003). These problems are organized as sequences of actions (e.g., “calculate,” “compare,” “represent”), rather than as coherent story-based scenarios. The subcategories were further refined through iterative analysis of the dataset to capture structural patterns specific to the Lebanese curriculum, including both canonical and non-canonical forms. The definitions, as well as the inclusion and exclusion criteria, were operationalized by the researcher to support consistent coding and to distinguish between closely related structural configurations. This approach ensured that the codebook remained theoretically grounded while being responsive to patterns emerging from the data.

Table 3
Structure Codebook Description

Primary Code	Subcode (Category)	Definition	Inclusion Criteria	Exclusion Criteria	Illustrative Example
Structure Dimension	**Story Set-Up Present**	The problem includes a situational frame that introduces actors, objects, action verbs or settings that organize the task.	Named or implied actors; contextual opening ("In a bus…", "For a party…").	Purely numerical or symbolic tasks.	"A truck carries…"
	Minimal Narrative Structure	A thin or generic narrative cue is present but does not meaningfully structure the task. (may co-occur with story set-up)	Generic actors ("Ali", "a boy"), no situational development.	Rich narrative or fully context-free tasks.	"Ali has some apples…"
	Context-Free Mathematical Structure	The task is presented without any narrative or situational framing.	Numbers, symbols, or commands only.	Any reference to actors, actions, or settings.	"Calculate 884 ÷ 4."
	Information / Data Present	Explicit quantitative information is provided for solving the task.	Numbers, quantities, units.	Tasks without numerical data.	"125 cases", "65 persons".
	Question / Task Present	The problem explicitly states what is to be determined or done.	Interrogative or imperative goal.	Tasks without a clear goal.	"How many…?"
	Canonical Three-Part Structure	The problem follows a clear sequence: story set-up, data, and question.	All three components clearly separable.	Collapsed or activity-based structures.	Standard arithmetic word problems.
	Collapsed Structure	Two or more structural components are merged into a single clause, requiring unpacking to identify the question.	Subordination and conditional "if…then…" embedded questions.	Clearly separated components.	"If Jerry travels…, how long…?"
	Task-Oriented / Activity Structure	The task is organized as an activity or procedure rather than a single question.	Multi-step tasks, instructions (e.g. organize, compare), activity (color, complete a table..)	Single-question problems.	Color the stones that have the same difference to help Nada…
	Notes / Interpretation	Analytic memo documenting ambiguity or justification.	Researcher interpretation.	Simple restatement.	"Narrative present but secondary."

The structure codebook corresponds to the structure dimension of the word problem genre presented in Table 1 and is grounded in genre-based descriptions of word problems (Gerofsky, 1999; Barwell, 2003). It captures the presence of structural components such as the story set-up, information, and questions and variations in their organization within problems.

This codebook enables the identification of canonical structures, collapsed or task-oriented forms, allowing for the examination of how structural patterns vary across grade levels and reflect differences in the presentation of word problems in the textbook. Context-free tasks are expected to appear in both the Function and Structure dimensions, as they reflect the absence of context at both the level of purpose and linguistic organization.
The lexicogrammar codebook (Table 4) examines the linguistic features of word problems, including vocabulary, grammatical structures, and discourse-level markers. It is derived from the lexicogrammar dimension outlined in Table 1 and is informed by research on the mathematics register and linguistic characteristics of word problems (e.g., Gerofsky, 1999; Schleppegrell, 2007; Daroczy et al., 2015). In particular, prior studies have identified key linguistic features of word problems, such as action verbs, conjunctions, determiners, prepositional phrases, clause structures, and the use of technical vocabulary (Daroczy et al., 2015; Schleppegrell, 2007). The definitions, inclusion and exclusion criteria were further refined and operationalized by the researcher to ensure consistent coding and to distinguish between closely related linguistic features. This approach ensured that the codebook remained theoretically grounded while being responsive to patterns emerging from the data

Table 4
Lexicogrammar Codebook Description

Primary Code	Subcode (Category)	Definition	Inclusion Criteria	Exclusion Criteria	Illustrative Example
Lexicogrammar Dimension	**Characters / Story Vocabulary**	Presence of human or animate participants in the problem text or non-human participant	Named characters or implied participants (e.g., people, mother, buyer). Non-Human characters (truck)	Purely numerical or symbolic tasks.	"Mother bought three shirts…"
	Action Verbs	Verbs denoting actions performed by participants.	bought, carries, added, sitting.	Stative descriptions only.	"A truck carries 125 cases…"
	Verb Tenses	The dominant verb tense used to frame actions, conditions, or instructions in the word problem.	Present simple, past simple (completed actions), or mixed (no single tense dominates).	Isolated auxiliary verbs or tense shifts not framing the task.	"In a race, Naji covered the first part of the track in 30 s.." Past simple
	Quantities with Units	Linguistic expression of quantities associated with units ("65 persons").	Coded as Explicit: number with unit / Implicit: number without unit	Coded as None: no quantity or numbers	"10 packs of 24 pieces."
	Determiners (grouping/distribution)	Determiner-like elements that signal distribution, equal grouping, or rate relationships by specifying how quantities are assigned across units	each, every, per, and multi-word equivalents (e.g., for each, per day, per item), when they indicate equal distribution or rate.	Articles (a, an, the); general quantifiers (some, many, several); (twice, times); not indicating grouping or rate.	each pack; per day
	Determiners Notes	Indicating the Determiners if present	Indicate the determiner in the problem	No determiner	"per", "each"
	Prepositional Phrase Expressing Purpose	A prepositional or clausal construction that explicitly expresses intent, goal, or reason for an action within the problem situation.	Explicit goal-oriented phrases (e.g., for a party, to prepare, so that, in order to).	locative or situational phrases (in a bus, on a table, at school). General story framing without stated intent.	For a party, Rola bought 10 packs of 24…
	Prepositional Phrase Notes	Indicating the Prepositional Phrases if present	Indicate the Prepositional phrase present	No prepositional phrase	"for a party"
	Question Form / Task Cue	Linguistic form of the question or task: Interrogative or imperative form	Coded as Direct (How many) / Imperative ("color", "find")	Embedded (subject + verb, declarative statements)	"How many persons are standing?
	Conjunctions	Use of conjunctions linking quantities or clauses.	and, or, but	lists without conjunctions, or punctuations only list.	red apples and green apples
	Conjunctions Notes	Indicating the Conjunctions if present			

	Mathematical Linguistic Cue	Lexical cues signaling mathematical operations.	Additive (all)/ Subtractive (left)/ Multiplicative (each)/ Divisional (per)	No operational cues.	in all
	Clause Structure	Syntactic organization of clauses.	Coded as Simple/ Subordinate (embedded) / If–then (conditional).	Phrase-level expressions only.	"Since he paid.., he got a …" subordinate
	Sentence Length (Total Word Count)	Quantitative indicator of the total number of words used in the word problem text	All lexical items in the problem text are counted, including numerals, fractions, units, and repeated words.	Figure labels, and list markers (a, b, c) are excluded. Punctuation is ignored.	"In a bus, there are 65 persons." 7 words
	Sentence Length	Classification of the word problem based on total word count.	Short: ≤ 20 words Medium: 21–35 words Long: ≥ 35 words		Calendar task (62 words) Long
	Polysemous Words	A word that has an everyday meaning and a different math-relevant meaning, and is central to interpreting the task.	Words that: (1) have both everyday and mathematical meanings, (2) are essential for solving the problem, and (3) could plausibly create ambiguity	Unambiguous terms.	How many are left?
	Polysemous Words Notes	Indicating the Polysemous Words if present	(e.g., left, table, difference).		"difference"
	Noun Phrase Complexity	Degree of syntactic and informational complexity in noun phrases	Low: simple/single noun phrase Moderate: noun phrases with pre- or post-modification, quantifiers High: embedded phrases, multiple modifiers, or complex structure		10 packs of 24 pieces of cake – moderate
	Mathematical Terms	Level of technicality of mathematical vocabulary used in the word problem. Terms are coded by their position on a continuum from everyday language to formal mathematical terminology.	Everyday: common, non-technical ("more," "how many" or "total cost") Transitional: combine everyday terms with some maths vocabs ("fraction," "area," "height", "average") Technical: mathematical terminology ("parallelogram","angle of elevation")		Total number (everyday) Difference (transitional) Pythagoras (technical)
	Keywords – Logical Markers	Lexical items that signal logical relations such as addition, contrast, sequence, inclusion, or comparison between quantities, statements, or actions in the word problem.	Words or phrases that organize information logically (e.g., and, or, also, together, same, different). "Then" (logical sequencing) without explicitly indicating causation.	operation cues (times, each, per). Conjunctions that do not contribute to logical structuring (Listing "and"; procedural "then")	125 cases of red apples and 210 cases of green apples Stones with the same difference

	Keywords – Cause–Effect Markers	Lexical items that explicitly signal causal, conditional, or consequential relationships between events, actions, or quantities in the word problem.	if, if–then, so, therefore, due to, because	Temporal “then”; sequencing without causality; implicit reasoning	“She added 54 candies, so how many are there now?” “If each pack has 24 pieces, then how many pieces are there?”
	Math Keywords Used	Explicit lexical items that anchor mathematical meaning, quantities, relations, or operations in the word problem.	Units, rates, totals, or result-oriented words (pages, per day, total, remainder, percent).	Action verbs (read, bought); justification prompts (why); inferred operations without lexical realization.	pages; every day; one week; total; per
	Notes / Interpretation	Analytic memo capturing ambiguity or justification of coding decisions.	Researcher reflection.	Descriptive restatement only.	Context present but irrelevant.

The lexicogrammar codebook corresponds to the lexicogrammar dimension of the word problem genre presented in Table 1 and is grounded in research on the linguistic features of mathematical texts (Gerofsky, 1999; Schleppegrell, 2007; Daroczy et al., 2015). It captures a range of lexical and grammatical features that have been identified in the literature as characteristic of word problems. This codebook enables the systematic examination of how linguistic features vary across grade levels, supporting the analysis of patterns in the complexity and distribution of mathematical language in the textbook.

The mode of representation codebook (Table 5) examines how mathematical information is presented through different semiotic resources, including written text, visual representations, and symbolic forms. It is derived from the mode of representation dimension outlined in Table 1 and is conceptually informed by semiotic and multimodal perspectives on mathematical meaning-making (Schleppegrell, 2007). In particular, prior research highlights that mathematical meaning is constructed across multiple semiotic systems, including language, symbols, and visual representations, which interact to convey mathematical relationships (Schleppegrell, 2007). These aspects are operationalized in this codebook through the identification of representational modes and the density of information within and across these modes. The categories were developed iteratively through analysis of the dataset to capture how mathematical information is distributed and represented in the Lebanese textbook. The definitions and criteria were operationalized to ensure consistent coding while remaining responsive to patterns emerging from the data.

Table 5
Mode of Representation Codebook Description

Primary Code	Subcode (Category)	Definition	Inclusion Criteria	Exclusion Criteria	Illustrative Example
Mode of representation Dimension	**Representational Mode**	The dominant semiotic resource(s) used to present mathematical information.	Text only; text + image; symbolic expressions; mixed modes	Decorative images not needed for solving tasks	Text + calendar diagram
	Representation Density	Degree to which mathematical information (quantities, tasks) is concentrated or distributed	Low: single quantity / relation Medium: multiple clear quantities High: multiple relations embedded or distributed across representations or requiring unpacking.	Judgments based on difficulty rather than representation.	Multiple calendar-based questions
	Notes / Interpretation				

The mode of representation codebook corresponds to the mode of representation dimension of the word problem genre presented in Table 1 and is grounded in multimodal and semiotic perspectives on mathematical texts (Schleppegrell, 2007). It captures how mathematical information is conveyed through different representational modes and how this information is distributed within and across these modes. This codebook enables the systematic examination of variation in representational forms and information density across grade levels, supporting the analysis of how mathematical content is presented and organized in the textbook.

Table 6 presents a summary of the main steps of analysis conducted in the study. The analysis was organized into three phases: identifying word problems and analyzing their distribution across grade levels and mathematical strands, conducting a linguistic analysis of the sampled word problems, and examining language progression and increasing language sophistication across school cycles. These phases were designed to address the three research questions of the study.

Table 6
Summary: Steps of Analysis

Phase	Step
Identifying Word Problems	1) map word problems based on the framework per grade level, per chapter, and identify in what part of the textbook 2) Count the frequency and represent in frequency table per grade level, per cycle, and overall 3) Classify/sort based on the strands of math 4) Analyze using tables, barcharts to reveal distribution patterns
Linguistic Analysis	1) Analyse function, structure, lexicogrammar, and mode of representation of 10% of the word problems for each of grades 3, 6, and 9. 2) Analyse per cycle and identify similarities and differences
Language Learning Progression and Language Sophistication Analysis	1) Compare and contrast the linguistic features per cycle 2) Analyse the increase of level of language sophistication

Ethical Considerations

As this study only focuses on the national Lebanese mathematics textbook which is available, ethical approval is not required. However, proper acknowledgment of resources and adherence to academic integrity was ensured.

Validity and Reliability

Quantitative Content Analysis

Reliability. The coding framework used to identify the genre is consistent as it is a detailed and predefined coding framework based on the SFL (Halliday, 1978) and genre theory (Gibbon, 2002) which aligns with previous studies that analyzed textbooks with a focus on genre features (e.g. Chapman, 2002; Morgan, 1998; Rezat & Rezat, 2017). That is, the word problem genre was classified according to its function (field), structure (mode), lexicogrammar i.e. linguistic features (tenor), keywords that relate to it (tenor), and the mode of representation (mode). These characteristics and features of the word problem genre are adapted from the literature (Gerofsky, 1999; Barwell, 2003; 2005; 2011; Daroczy, Wolska, Meurers, and Nuerk, 2015). This ensures that identifying genres is consistent across all grade levels. Moreover, to ensure reliability, another coder coded 20% of the analyzed word problems in the study, and the data were then compared to evaluate intercoder agreement. In addition to that, the genre analyses and the frequency counts are explicitly documented. This allows other researchers to replicate the study under similar conditions (national Lebanese math textbook).

Validity. To ensure content validity, the genre frequencies were coded based on the characteristics of the word problem genre in the literature (Gerofsky, 1999; Barwell, 2003; 2005; 2011; Daroczy, Wolska, Meurers, and Nuerk, 2015) according to its function (field), structure (mode), lexicogrammar i.e. linguistic features (tenor), keywords that relate to it (tenor), and the mode of representation (mode) i.e. the SFL and genre theory (Halliday, 1978; Gibbon, 2002) ensuring that the data collected aligns with the study's focus on word problem genre.

Qualitative Content Analysis

Reliability. To ensure dependability, this study uses a transparent and systematic approach to analyze the linguistic characteristics of the word problem genre. The collection of examples from each grade in every cycle, along with an equal percentage (10%) of examples from each grade, was maintained to document the coding decisions throughout the process (Lincoln & Guba, 1985). To improve reliability, the findings are reviewed by peers or experts in mathematics education to verify the interpretations of qualitative data.

Validity. The linguistic characteristics analyzed are valid in theories of language use in mathematics education, where the analysis identifies these linguistic characteristics based on the grade levels, and look at the sophistication and variance and compare across cycles.

Trustworthiness of the study

This study adopts several strategies to ensure trustworthiness across both the quantitative and qualitative content analysis. Trustworthiness is defined as the quality of a study and its findings that makes it worthy of consideration by readers based on the degree of confidence in the data, interpretation, and methods used (Connelly, 2016). To ensure the trustworthiness of the study and its findings, there are four criteria: credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). The way to ensure these four criteria are prolonged engagement, persistent observation, peer examination, triangulation, and member checks, etc.

To ensure the trustworthiness of this study and its findings, triangulation was used. Triangulation is defined as the use of two or more methods of data collection in the study (Cohen et al, 2007). The integration of quantitative and qualitative content analysis strengthens the robustness of the findings by providing multiple perspectives on the data (Lincoln & Guba, 1985). Cohen and his colleagues (2007) refer to this as methodological triangulation as there is a use of different data collection methods. This adds to the credibility of the study and its findings. To add to the credibility of this study, the key examples used from the textbooks are included as evidence to support the qualitative findings. Transferability was also used to ensure the trustworthiness of this study and its findings. This is by describing the Lebanese mathematics textbooks and curriculum, the findings are made applicable to similar educational settings. Moreover, to ensure confirmability, the analysis process is documented in details to ensure that interpretations are data-driven and objective and not influenced by researcher bias. External reviewers may also examine the coding and interpretations.

CHAPTER 4

FINDINGS

This chapter presents the study's findings in relation to the three research questions. It begins by examining the distribution and frequency of the word problem genre across grade levels, school cycles, and mathematical strands in the Lebanese national mathematics textbooks (RQ1). It then examines how the linguistic characteristics of these word problems vary across grade levels and school cycles (RQ2). Finally, the chapter synthesizes the findings to identify language learning progressions in these linguistic characteristics across Cycles I, II, and III, highlighting shifts in language complexity throughout the curriculum (RQ3).

Across all sections, the findings are supported by a combination of quantitative summaries, such as frequencies and distributions, and qualitative analysis of representative examples, enabling an examination of both the prevalence and the nature of linguistic features within the textbook corpus.

Distribution of Word Problems Across Grade Levels, School Cycles and, Strands of Mathematics Problem Genre

RQ1: How does the frequency of the word problem genre vary across grade levels, school cycles and mathematical strands (numbers and calculations, algebra, geometry, measurement, and statistics) in Lebanese National mathematics textbooks?

To address Research Question 1, the frequency of word problems was analyzed across grades, school cycles, and mathematical strands in the Lebanese national mathematics textbooks.

Distribution of Word Problems across Grade Levels

Table 7 presents the distribution of word problems across grade levels, including the total number of tasks and the proportion of word problems in each grade. A task is any question requiring a student's response. As shown in Table 6, the proportion of word problems increases from Grade 1 (10.2%) to a peak in Grades 3 and 4 (37.4% and 36.3%, respectively), before gradually declining in the upper grades. This decline is particularly noticeable from Grade 7 onward, where the percentage drops to around 10% or below in Grades 7 and 8, with a slight increase in Grade 9 (12.3%). This pattern indicates a concentration of word problems in Grades 3 to 5, with relatively high levels maintained in Grade 6, followed by a marked reduction in the intermediate grade levels (Grades 7–9).

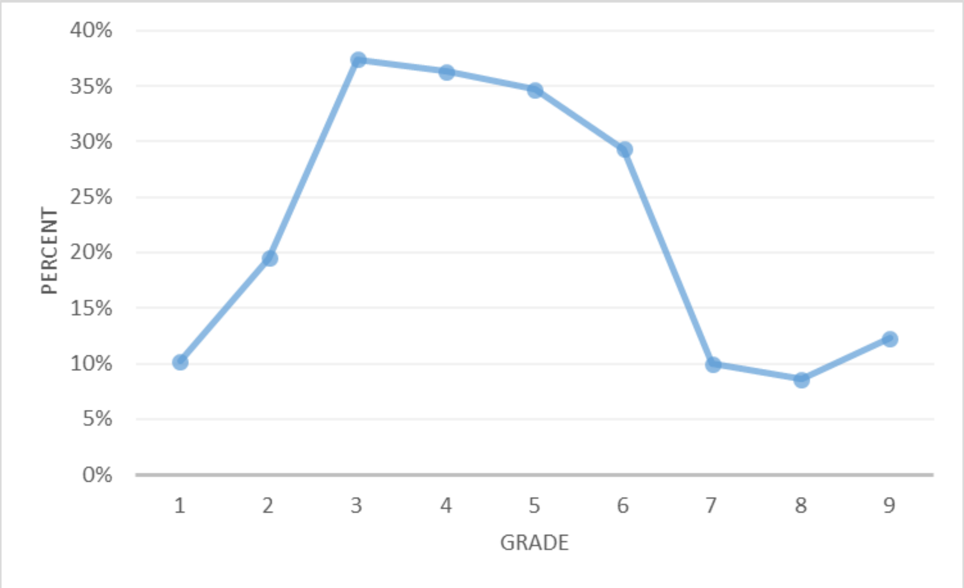
Table 7
Distribution of Word Problems across Grades

Grade	Word Problems	Total Tasks	Percentage of Word Problems
Grade 1	37	363	10.2%
Grade 2	138	708	19.5%
Grade 3	191	511	37.4%
Grade 4	303	835	36.3%
Grade 5	233	672	34.7%
Grade 6	179	611	29.3%
Grade 7	53	528	10.0%
Grade 8	56	651	8.6%
Grade 9	62	504	12.3%

Figure 1 visually represents the distribution of word problems across grade levels, complementing the numerical data presented in Table 7 by highlighting overall trends more clearly. The chart highlights a clear rise in the proportion of word problems from the early grades to a peak in the middle elementary levels, followed by a noticeable decline in the upper grades. This representation reinforces the concentration of word problems in Grades 3, 4, and 5 and makes the subsequent downward trend more explicit.

Figure 1

Percentage of Word Problems Relative to Total Tasks Across Grade Levels

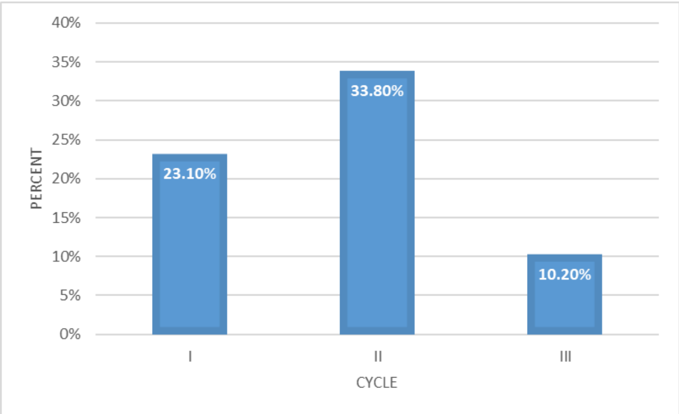


Distribution of Word Problems across School Cycles

When the data are grouped by school cycle, clear patterns in the distribution of word problems emerge, with a peak in Cycle II and a decline in Cycle III. The findings are presented in Figure 2. Cycle II (Grades 4–6) represents the highest concentration of word problems in the dataset, with approximately 33.8% of all tasks identified as word problems. This high frequency indicates that word problems play a central role during this stage of the curriculum. Cycle III (Grades 7–9) shows a decline in the percentage of word problems to 10.2%, indicating that the word problem genre is less prominent.

Figure 2 provides a visual representation of the average percentage of word problems across school cycles, highlighting the contrast between Cycles I, II, and III. The findings represent a progression in the distribution of word problems across school cycles in the Lebanese mathematics textbooks, such that students encounter a moderate proportion of word problems Cycle I, which increases to a peak in Cycle II. This is followed by a noticeable reduction in Cycle III.

Figure 2
Average Percentage of Word Problems across School Cycles



Distribution of Word Problems Across Strands of Mathematics

Word problems were also analyzed according to their distribution across mathematical strands at both the grade and cycle levels. The findings are represented in Table 8 and Table 9.

Table 8 presents the distribution of word problems across mathematical strands by grade level. The distribution in Table 8 reflects a shift from a strong emphasis on numerical word problems in the early grades to a more varied distribution across strands in the upper grades. The findings indicate that word problems classified under "Numbers and Calculations" dominate across all grades, accounting for the majority of word problems, particularly in the early grades where they constitute 100% in Grade 1 and remain above 60% through Grade 6. Measurement word problems appear from Grade 2 and increase in prominence through Grades 4 and 5 before disappearing in the upper grades (Grades 7-9). Geometry word problems are minimally represented in the lower grades but show a substantial increase in Grade 7 and remain present in subsequent grades. Statistics word problems emerge in Grade 4 and appear intermittently in later grades. Algebra word problems are absent in the early grades and first appears in Grade 6, with their proportion increasing in Grades 8 and 9. Overall, the distribution reflects a shift from a strong concentration on word problems in "Numbers and Calculations" toward a broader distribution across multiple strands in the upper grades.

Table 8
Distribution of Word Problems across Strands per Grade Level

Grade	Numbers & Calculations	Measurement	Geometry	Statistics	Algebra
1	100.0%	0.0%	0.0%	0.0%	0.0%
2	98.5%	1.5%	0.0%	0.0%	0.0%
3	83.7%	14.7%	1.6%	0.0%	0.0%
4	73.9%	21.5%	3.6%	1.0%	0.0%
5	70.8%	23.2%	1.7%	4.3%	0.0%
6	62.0%	19.6%	3.4%	3.9%	11.2%
7	50.9%	0.0%	17.0%	0.0%	32.1%
8	44.6%	0.0%	19.6%	19.6%	16.1%
9	22.6%	0.0%	32.3%	12.9%	32.3%

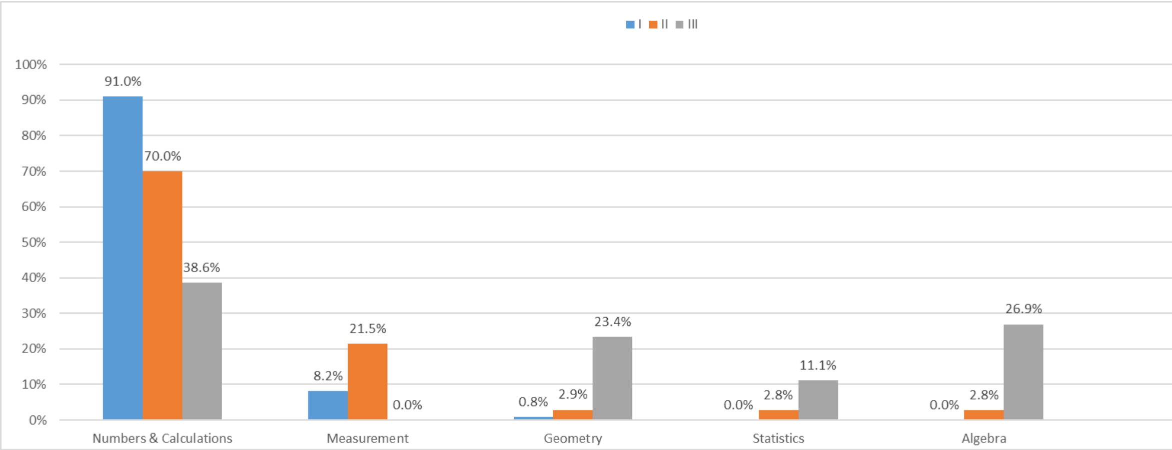
The distribution of word problems across mathematical strands by school cycle. Overall, the findings indicate a redistribution of word problems across strands as students progress through the cycles. Table 9 shows that word problems in Cycle I are highly concentrated in the "Numbers and Calculations" strand (91.0%), with limited representation of other strands. Measurement word problems appear at 8.2%, while Geometry word problems (0.8%), Statistics word problems, and Algebra word problems are nearly absent. In

Cycle II, the proportion of word problems in the "Numbers and Calculations" strand remains dominant (70.0%) but is accompanied by greater strand diversity. Measurement word problems increase to 21.5%, while Geometry (2.9%), Statistics (2.8%), and Algebra (2.8%) word problems begin to emerge. A major shift occurs in Cycle III where the proportion of word problems in the "Numbers and Calculations" strand decreases (38.6%), while Geometry (23.4%), Algebra (26.9%), and Statistics (11.1%) word problems increase substantially, and Measurement word problems are no longer represented.

Figure 3 provides a visual overview of the distribution of word problems across mathematical strands for all school cycles combined. The figure highlights the clear dominance of word problems in the "Numbers and Calculations" strand across the dataset, with substantially higher proportions compared to all other strands. In contrast, word problems in strands such as Measurement, Geometry, Statistics, and Algebra appear with noticeably lower and more varied proportions. By presenting all strands side by side, Figure 3 facilitates a direct comparison of the relative prominence of word problems across strands and underscores the uneven distribution of word problems across mathematical strands.

Figure 3

Distribution of Word Problems across Strands per Cycle



Figures 4, 5, and 6 illustrate the distribution of word problems across mathematical strands within each school cycle, providing a clear visual comparison of how the emphasis on word problems shifts across cycles. In Figure 4 (Cycle I), word problems are heavily concentrated in the “Numbers and Calculations” strand, with smaller contributions from Measurement word problems, and minimal representation in other strands. Figure 5 (Cycle II) shows that, although the proportion of word problems in the “Numbers and Calculations” strand remains dominant, the distribution becomes more diversified, with increased representation in Measurement word problems and the emergence of word problems in other strands. In Figure 6 (Cycle III), the distribution shifts more noticeably, with a reduced proportion of word problems in the “Numbers and Calculations” strand and greater representation in Geometry, Statistics, and Algebra word problems. Together, these figures make the shift in the distribution of word problems across strands more apparent and highlight differences in word problem distribution across the three cycles. Overall, they reveal a progression from a concentration of word problems in the “Numbers and Calculations” strand in the early cycles toward a more balanced and varied distribution across mathematical strands in later cycles.

Figure 4
Distribution of word problems across mathematical strands in Cycle I

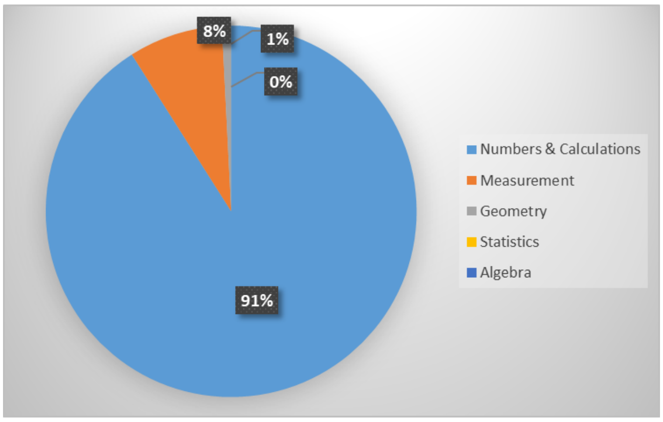


Figure 5*Error! Bookmark not defined.*
Distribution of word problems across mathematical strands in Cycle II

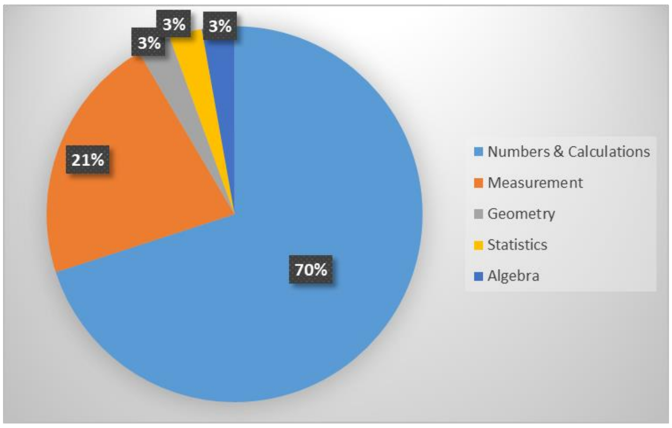
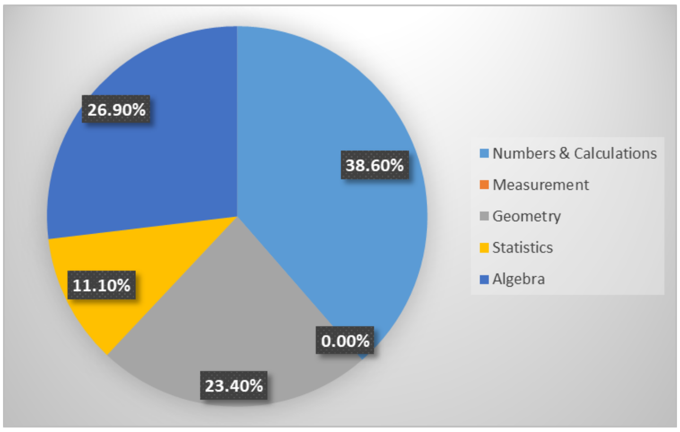


Figure 5
Distribution of word problems across mathematical strands in Cycle III



Linguistic Characteristics of Word Problems Across School Cycles

RQ2: How do the linguistic characteristics of the word problem genre change across school cycles in the Lebanese National mathematics textbooks?

To address research question 2, a sample of the word problems identified in the previous section were analyzed with a focus on four key dimensions: function, structure, lexicogrammar, and mode of representation through drawing on the codebooks presented in Tables 2, 3, 4, and 5. A sample of 10% of the word problems was analyzed from Grades 3, 6, and 9, representing the end of Cycles I, II, and III, respectively. The findings are organized by school cycles to highlight patterns of variation in how word problems are constructed across the curriculum. Through a combination of quantitative summaries and qualitative examples, this section identifies changes in these linguistic features and traces shifts in the complexity and form of word problems across the four analytical dimensions.

Distribution of function categories across Grades 3, 6, and 9,

Table 9 presents the distribution of function categories across Grades 3, 6, and 9, based on the coding framework outlined in Table 2. It shows the proportion of word problems classified according to their functional characteristics, including imitation of real-life activity, imitation of school mathematics, presence of story or context, and mathematical activity generation.

Table 9

Distribution of Function Categories Across Grades (% of Word Problems)

Function Category	Grade 3 (n=20)	Grade 6 (n=18)	Grade 9 (n=7)
Imitation of Real-Life Activity	80%	89%	100%
Imitation of School Mathematics	100%	100%	100%
Story or Real-Life Context Present	95%	89%	100%
No Story / Context-Free Task	5%	11%	0%
Mathematical Activity Generation	100%	100%	100%

As shown in Table 9, imitation of school mathematics and mathematical activity generation are present in all word problems across the three grades, each accounting for

100%. These categories were not assumed beforehand due to the mathematical nature of the tasks, but were identified through the coding process based on the codebook. Word problems were coded as “imitation of school mathematics” when the context is thin, replaceable, and quantities directly cue an operation, where solving does not require interpreting the situation, and as “mathematical activity generation” when the task required students to engage in mathematical processes such as calculating, comparing, organizing, or solving. The following word problem illustrates both imitation of school mathematics and mathematical activity generation: “Mother bought three shirts. Each shirt costs 26,750 L.L. What is the price of these shirts?” (Grade 3, P117). In this word problem, the purchase context is realistic and familiar, but it functions mainly as a numerical frame. The required mathematical activity involves multiplying the unit price by the quantity.

The function categories distinguish between the presence of context and the role that context plays in the task. “Story or real-life context present” refers to whether a narrative or situational frame is included in the problem, regardless of its role in solving the task, while “no story / context-free task” refers to problems without any contextual framing. Within contextualized problems, “imitation of real-life activity” identifies cases where the context reflects familiar everyday activities that students may encounter in daily life. In this way, the analysis differentiates between the presence of context and whether that context represents a real-life activity.

A high proportion of word problems also reflect imitation of real-life activity, increasing from 80% in Grade 3 to 89% in Grade 6 and reaching 100% in Grade 9. These word problems often involve familiar real-life activities that are done in daily life such as transport, sharing or shopping. Similarly, the presence of a story or real-life context is observed in most word problems, rising slightly from 90% in Grade 3 to full representation in Grade 9.

Grade 3 tasks often use narrative frame to situate the mathematical task. For example, the following word problem illustrates the presence of a story or real-life context without modelling a real-life activity: “In the calendar of the year 2000, color in red the months that are 31 days long and in blue the ones that are 30 days long. Then complete: There are ____ months 31 days long. There are ____ months 30 days long. There are ____ days in February.” (Grade 3, P12). This word problem uses a real-life artifact (calendar) to frame a task involving classification and counting, without representing an everyday activity.

In contrast, the following example illustrates both the presence of a real-life context and imitation of real-life activity: “For a party, Rola bought 10 packs of 24 pieces of cake each. How many pieces of cake did she buy?” (Grade 3, P72). In this problem, a party context is introduced (real-life context) to frame the problem, and a real-life activity of buying cakes. This task includes both a real-life context (a party) and an imitation of real-life activity, as it models a plausible situation involving purchasing quantities and determining totals.

In Grade 6, word problems that involve percentage discount calculations or geometric planning incorporate more procedural steps and multi-step calculations, while still using realistic contexts such as shopping, sharing or land measurement. The following word problem illustrates the presence of a story or real-life context: “A man bought 35 lambs for 135000 LL each. Since he paid the total amount in cash, he got a discount of 6%. How much did he pay?” (Grade 6, P311). This tasks involves a real-life purchase scenario where the task focuses on multiplication and percentage reduction. Here is another word problem that illustrates the presence of story or real life but incorporates multi-step calculations: “Rima ate 1/4 of 2/3 of a cake and her brother Adel 2/3 of 1/4 of this cake. a) What is the fraction of the cake that Rima and Adel ate? b) Who ate more cake?” (Grade 6, P288). A real life story of eating parts of the cake is present, along with the presence of multi-questions that require multi-step calculations.

In Grade 9, word problems use different real-life context but still framed as classic school word problems such as structured financial, architectural, or statistical contexts (e.g., right-triangle trigonometry or banking algebra tasks). The following word problem illustrates the use of real-life context: “The temple of Jupiter in Baalbek is 69.2 meters high. An observer looking at these columns views the temple at an angle of 40°. At what distance is he from the base of the temple?” (Grade 9, P416). This word problem involves a real monument context that is a typical right-triangle trigonometry problem.

In contrast, context-free tasks remain limited, accounting for 5% and 11% in Grades 3 and 6, respectively, and are absent in Grade 9. For example, Grades 3 and 6 involve word problems that are purely numerical mathematical riddles without a narrative context like “I am a number. When 6 is added to my ones-digit it becomes a ten. My tens-digit is the double of my ones-digit. My hundreds-digit is the half of my ones-digit. Who am I?” (Grade 3, P159). Here is another example that illustrates a context free word problem: “I think of a number then subtract 3.75 from it. I add 2 times 6.25, then I add 25 to the obtained result and the final number will be 100. What was my initial number?” (Grade 6, P341). This word problem involves an entirely numerical reasoning with no situational context or story.

Distribution of structural categories across Grades 3, 6, and 9

Table 10 presents the distribution of structural categories across Grades 3, 6, and 9, based on the coding framework outlined in Table 3. It shows the proportion of word problems according to their structural features, including the presence of story set-up, information and question components, as well as variations in overall organization such as canonical, collapsed, and task-oriented structures.

Table 10
Distribution of Structure Categories Across Grades (% of Word Problems)

Structure Category	Grade 3 (n=20)	Grade 6 (n=18)	Grade 9 (n=7)
Story Set-Up Present	95%	89%	93%
Minimal Narrative Structure	5%	6%	0%
Context-Free Mathematical Structure	5%	11%	0%
Information / Data Present	100%	100%	100%
Question / Task Present	100%	100%	100%
Canonical Three-Part Structure	75%	50%	57%
Collapsed Structure	5%	17%	0%
Task-Oriented / Activity-based Structure	20%	33%	43%

As shown in Table 10, most word problems across all grades include the core components of information/data and question/task, each present in 100% of cases. The following word problem illustrates the presence of components of information/data and question/task: "Rima has 55 pearls. She makes bracelets of 5 pearls each. How many bracelets can she make?" (Grade 3, P145). In this word problem, the data presented is the number of pearls (55 pearls) and number of pearls used to make each bracelet (5 pearls), the question/task for the students is to find the number of bracelets that Rima can make using the given information.

A story set-up is also highly prevalent, appearing in 95% of word problems in Grade 3, 89% in Grade 6, and 93% in Grade 9. Here is an illustrative example of a word problem that has a story set up: "Tamara is reading a novel of 87 pages. She decides to read 9 pages every day. Can she read the novel in one week? Why?" (Grade 3, P180). A personal activity (of readings a novel) and the character (Tamara) introduces the task, followed by data (number of novels she reads per day) and a question requiring justification (if she can read the novel in one week). The structure in this word problem is considered canonical three-part structure. However, in some cases, the context is minimal or decorative, such as the following word problem; "Color the stones that have the same difference to help Nada find her cat" (Grade 3, P29). This word problem has a character and story set-up, but it is a procedural puzzle-type task where the narrative is present but does not influence the mathematical procedure.

In contrast, context-free mathematical structure occurs less frequently across all grades. For example, Grade 3 problems commonly begin with a short narrative introducing a familiar situation, such as a shopping or sharing scenario, followed by numerical information and a question. In some cases, the context is absent, as in numerical tasks such as "I am a number…" where no story set-up is provided. For example: "I am a number. When 6 is added to my ones-digit it becomes a ten. My tens-digit is the double of my ones-digit. My hundreds-digit is the half of my ones-digit. Who am I?" (Grade 3, P159).

The canonical three-part structure is most prominent in Grade 3 (75%), decreases in Grade 6 (50%), and slightly increases in Grade 9 (57%). Collapsed structures are most common in Grade 6 (17%) and are minimal or absent in the other grades. For instance, many Grade 3 problems clearly separate the story, given information, and question, whereas Grade 6 problems combine these elements within fewer sentences. Here is an illustrative example of a word problem with collapsed structure: "An employee spends 8/9 of his monthly salary. If he spent 3/7 of his spent money on food, write a fraction to show how much he spent on food." (Grade 6, P287). This word problem is considered collapsed as data and the question are linguistically merged into one conditional construction. The reader needs to unpack the "if" condition to understand the data and the question. However, word problems such as "Fady bought 6 bottles of juice each 20 cm long. The price of each bottle is 250 L.L. How much did he pay?" (Grade 3, P79), follows a canonical three-part structure as a shopping situation frames the task, followed by numerical information and a question. Here is another example that illustrates canonical structure from grade 6: "A triangular table is covered with a glass sheet which costs 19 500 LL per m^2. What is the price of the sheet?" (Grade 6, P251).

In this word problem, a real-life object and pricing context is presented, followed by numerical data and a clear question. The structure follows the canonical three-part pattern.

Meanwhile, task-oriented or activity-based structures show an increasing presence across grades, rising from 20% in Grade 3 to 33% in Grade 6 and 43% in Grade 9. For example, some Grade 9 problems that involve diagrams or data tables are presented as activities requiring multiple tasks rather than a single explicit question, such as "organize this data in a table..., represent the frequencies in a bar graph..." Here is an illustrative example of task-oriented word problem:

> Here is a plan for Mr. Nader's garden. a) What is the area of this garden? b) What is the area of the vegetable garden? c) If the exact grass area surrounded by a green fence and he needs 4 fence each meter, how many meters of fence would he need? d) If each fence costs 700 LL, what is the cost of the fence? (Grade 6, P251).

A situational frame introduces the garden, but the task unfolds through multiple questions. The structure is activity-based rather than canonical. Here is another example of a task oriented / activity-based word problem:

> "Among twelve interviewed drivers, we found: 3 had no accidents, 1 had one accident, 2 had two accidents, 1 had three accidents, 3 had four accidents, and 2 had five accidents. a) Organize this data in a table showing the distribution of these drivers according to the number of accidents they had. b) Represent the frequencies in a bar graph. c) Calculate the relative frequencies in percentage form and represent them in a circle graph. d) Find the mean of this distribution." (Grade 9, P425).

In this word problem, data is presented narratively but organized as multiple statistical tasks (table, graph, mean) that categorize it as an activity-based structure.

Distribution of lexicogrammar features across Grades 3, 6, and 9

Table 11 and Table 12 present the distribution of lexicogrammar features across Grades 3, 6, and 9, based on the coding framework outlined in Table 4. Table 11 shows the proportion of word problems containing the presence of specific linguistic elements, including vocabulary related to characters and action verbs, grammatical markers such as determiners and conjunctions, and features associated with meaning-making such as polysemous words and logical or cause–effect markers. Percentages represent the proportion of word problems in which each lexicogrammar feature is present (coded as present/absent), and a single word problem may include multiple features.

Table 12 presents the distribution of lexicogrammar features across Grades 3, 6, and 9, focusing on verb tense, representation of quantities, question forms, clause structure, sentence length, noun phrase complexity, and the use of mathematical terms. These features were analyzed to capture how language complexity varies across grades and how it supports students' engagement with both quantitative and qualitative aspects of word problems.

Table 11

Distribution of Lexicogrammar Categories Across Grades (% of Word Problems)

Lexicogrammar Category	Grade 3 (n=20)	Grade 6 (n=18)	Grade 9 (n=7)
Characters / Story Vocabulary	85%	67%	100%
Action Verbs	95%	100%	100%
Determiners (grouping/distribution)	40%	28%	14%
Prepositional Phrase Expressing Purpose	10%	6%	14%
Conjunctions	30%	44%	72%
Polysemous Words	20%	11%	29%
Keywords – Logical Markers	45%	56%	72%
Cause–Effect Markers	0%	28%	14%

As shown in Table 11, characters or story-related vocabulary appear frequently across all grades, accounting for 85% in Grade 3, decreasing to 67% in Grade 6, and increasing to 100% in Grade 9. While the overall presence of characters remains consistently high, the analysis indicates a shift in how characters are represented and used within the problems. In

Grade 3, characters are typically familiar, concrete, and personalized, often represented through named individuals or everyday roles (e.g., Mother, Ali), serving to anchor the problem in recognizable, everyday situations. The following word problem illustrates the presence of characters (Rola): “For a party, Rola bought 10 packs of 24 pieces of cake each. How many pieces of cake did she buy?” (Grade 3, P72). Few word problems involve non-human characters (e.g. truck, printer). For example, “A printer made 37,826 business cards. He puts them in boxes of 6. How many full boxes does he fill? How many cards does he have left?” (Grade 3, P178). In Grade 6, named characters (e.g., Farha, Mr. Nader) continue to appear in combination with a wider range of situational contexts (e.g., a library, planet Mars), expanding the types of settings in which mathematical activity is embedded. However, several word problems do not involve characters such as “What is the price of an object labeled 10000 LL if you can benefit from a 30 % discount on its price?” (Grade 6, P316). By Grade 9, named characters still appear in combination with characters realized as generalized or role-based participants (e.g., an observer, interviewed drivers, an architect), where the focus shifts from individual identity to the function these participants perform within the mathematical task. Here is a word problem that illustrates the presence of generalized participants: “The temple of Jupiter in Baalbek is 69.2 meters high. An observer looking at these columns views the temple at an angle of 40°. At what distance is he from the base of the temple?” (Grade 9, P416). Taken together, these patterns suggest that while characters remain a consistent feature of word problems, their representation evolves from concrete and personalized to include more functionally defined and contextually embedded roles, reflecting increasing abstraction in the presentation of mathematical situations.

Action verbs are present in nearly all word problems across the three grades, reaching 95% in Grade 3 and 100% in both Grades 6 and 9. While their presence remains stable, a qualitative analysis highlights differences in how these verbs function within the problems. In

Grade 3, action verbs are primarily used to describe simple narrative actions, such as "Mother put 54 candies and Aunt Nadia added 239" and "Rola bought 10 packs of cake," where the verb directly corresponds to a concrete action that maps onto a single, straightforward calculation**.** This is also evident in word problems such as "A truck transports 125 kg of oranges in 5 boxes of same mass. What is the mass of each box?" (Grade 3, P174) where the verb "transports" situates the context but the mathematical procedure remains directly tied to a single operation. In Grade 6, action verbs remain frequent and appear across both narrative and procedural contexts, for example, "Ghada had the following receipt" and "find the exact total, then give its rounding," indicating a broader functional range in which verbs not only describe situations but also organize and guide the steps required to complete the problem. This can be seen in word problems such as "Due to a violent storm, water flowed on a rectangular porch whose width is 3.5 m and length 8.5 m. After the water was collected in an empty tank, its volume was 1500 liters. Calculate in mm the height of the water reached on the porch before it was emptied in the tank" (Grade 6, P351), where multiple verbs (e.g., "flowed," "collected," "reached") construct the situation, while the imperative "calculate" explicitly directs the mathematical procedure. In Grade 9, action verbs continue to be pervasive and are often embedded in more complex or multi-step situations, such as "a person bought, sold, and re-bought a car" and "we poured water in a cylindrical vase," where the verbs are part of extended sequences of actions . This is further illustrated in word problems where verbs such as "construct," "draws," "represents," and "place" contribute to a sequence of actions that frame a multi-step mathematical situation. The following word problem illustrates this:

> To construct a house similar to the one in the figure, an architect draws all the necessary plans. Below, a plan of the front view of this house is presented with some measurements. The adjacent figure represents the roof with an inclination of 30°. The

construction worker must place his posts at B and D. How high should AB and CD be set to assure a roof inclination of 30°? (Grade 9, P414).

Overall, while action verbs remain consistently present across grades, their role shifts from representing concrete, directly interpretable actions (Grade 3), to organizing procedural steps (Grade 6), to structuring more complex, multi-step reasoning (Grade 9).

The use of determiners related to grouping or distribution is moderate in Grades 3 and 6 (40% and 28%, respectively) but decreases notably in Grade 9 (14%). While these markers are present across all grades, their role in structuring the mathematical task shows a shift across grades. In Grades 3 and 6, determiners such as “each,” “per,” and “every” are used explicitly to structure quantities and signal how values should be distributed or grouped (e.g., “each box contains…”, “Fady bought 6 bottles of juice each 20 cm long”, “4 fences each meter”), providing clear linguistic cues that guide the interpretation of multiplicative or distributive relationships. In these cases, the determiner directly supports the identification of the required operation. In Grade 6, in addition to these determiners, word problems include a wider range of quantifying expressions, such as “the total number of books,” “all samples of A,” “some are 500 L.L. bills,” and “the number of yellow crayons,” as well as fractional constructions such as “1/4 of a cake” and “8/9 of his monthly salary.” These expressions also contribute to the structuring quantities, even when explicit grouping determiners are less frequent. In Grade 9, explicit grouping determiners appear less frequently, and quantitative relationships are more often expressed through numerical, relational, or technical constructions rather than through lexical markers such as “each” or “per.” For example, in problems such as “the radius of the sun… the radius of the moon… the distance TS is 150 million km” or “the distribution of these drivers according to the number of accidents,” relationships are expressed through technical and relational structures rather than explicit grouping markers. The analysis focuses on explicitly realized lexical markers. Therefore, the reduced presence of determiners does not necessarily indicate the absence of grouping or distribution, but rather reflects a difference in how these relationships are linguistically encoded. Overall, the findings indicate variation in how grouping and distribution are realized across grades.

Prepositional phrases expressing purpose remain relatively limited across all grades. In this study, such phrases are defined as prepositional or clausal constructions that explicitly express the intent, goal, or reason for an action (e.g., "for a party," "to help," "to show"). Across the dataset, only a small number of instances were identified. For example, in the Grade 3 word problem "For a party, Rola bought 10 packs of 24 pieces of cake each," the phrase "for a party" indicates the purpose of the action, while in "Color the stones that have the same difference to help Nada find her cat," the clause "to help Nada find her cat" expresses a clear goal. Similarly, in Grade 6, the phrase "write a fraction to show how much he spent on food" represents an explicit purpose linked to the task. In Grade 9, a comparable instance appears in "How high should AB and CD be set to assure a roof inclination of 30°?", where "to assure a roof inclination" expresses the intended outcome of the action. In contrast, other prepositional and clausal constructions (e.g., "in a race," "during a party," "due to a storm," "with respect to") express time, location, cause, or relation rather than purpose, and were therefore not included in this category. Overall, the findings indicate that purpose-related constructions are infrequent and play a limited role in the linguistic organization of word problems.

In contrast, conjunctions are present in 30% of Grade 3, 44% of Grade 6, and 72% of Grade 9 word problems. Across the three grades, the conjunction most frequently observed is "and," used to connect quantities or actions within the same problem. In Grade 3, this appears in examples such as "There were 125 pieces of candy in a candy box. Mother put 54 candies and Aunt Nadia added 239. How many pieces of candy are there in all?" (Grade 3, P32), where “and” links two actions contributing to the total. Similarly, in “A truck carries 125 cases of red apples, 210 cases of green apples, and 26 empty cases. How many cases does the truck carry in all?” (Grade 3, P9), “and” connects multiple quantities within the same problem. In Grade 6, conjunctions also connect quantities across categories, as in “A library passed 5 600 samples of a scholar by book A, 2 700 of book B and 4 200 of book C” (Grade 6, P231), where “and” links quantities associated with different categories. In Grade 9, conjunctions appear in similar linking contexts, for example “A person bought a car for 5000 dollars, then he sold it for 6000 dollars, and he finally re-bought it for 7000 dollars” (Grade 9, P397), where “and” links actions within the same problem. Conjunctions also appear in descriptive structures, as in “The points S (center of the sun), L (center of the moon), and T are collinear”, (Grade 9, P391) where “and” links multiple elements within a single statement such that more than one conjunction is used in the same problem. Across all grades, conjunctions are used to connect elements within the problem, with a higher proportion of problems containing conjunctions in Grades 6 and 9 than in Grade 3.

Logical markers are present in 45% of Grade 3, 56% of Grade 6, and 72% of Grade 9 word problems. In Grade 3, these markers appear in simple comparative forms. For example, “Color the stones that have the same difference to help Nada find her cat” (Grade 3, P29), where “same” signals comparison between quantities. In Grade 6, logical markers appear in tasks that require explicit comparison between results, for example “At the supermarket, Ghada had the following receipt… a) Using your calculator, find the exact total… b) Calculate the total by rounding the price of each item to the thousandth first. c) Compare the two results” (Grade 6, P246), where “compare” directs the relation between outcomes. In Grade 9, logical markers also appear in classification and distribution contexts. For example, “according to” organizes classification in the following word problem:

Among twelve interviewed drivers, we found: 3 had no accidents, 1 had one accident, 2 had two accidents, 1 had three accidents, 3 had four accidents, and 2 had five accidents. a) Organize this data in a table showing the distribution of these drivers according to the number of accidents they had (Grade 9, P425)

Similarly, in "Ziad has 26 money bills in his bank. Some are 500 L.L. bills and some are 1000 L.L. bills" (Grade 9, P397), the repeated use of "some… some…" signals distribution across categories. Moreover, the word problem "A person bought a car for 5000 dollars, then he sold it for 6000 dollars, and he finally re-bought it for 7000 dollars. Did he gain or lose?" (Grade 9, P388), uses "then" for logical sequencing. These examples show that logical markers are used across all grades to express comparison in early grades, then express classification, sequencing or distribution in higher grades, with a higher proportion of problems containing these markers in Grades 6 and 9 than in Grade 3.

Cause–effect markers are present in 0% of Grade 3, 28% of Grade 6, and 14% of Grade 9 word problems. No such markers are observed in the Grade 3 word problems. In Grade 6, these markers appear in both causal and conditional forms. For example, "A man bought 35 lambs for 135000 L.L. each. Since he paid the total amount in cash, he got a discount of 6%. How much did he pay?" (Grade 6, P311), where "since" expresses a causal relation explaining why the discount is applied. Similarly, in "Due to a violent storm, water flowed on a rectangular porch whose width is 3.5 m and length 8.5 m…" (Grade 6, P351), "due to" introduces the cause of the situation described. Conditional markers appear in word problems such as "Here is a plan for Mr. Nader's garden… c) If the exact grass area surrounded by a green fence and he needs 4 fence each meter, how many meters of fence would he need?" (Grade 6, P275), and "An employee spends 8/9 of his monthly salary. If he spent 3/7 of his spent money on food, write a fraction to show how much he spent on food" (Grade 6, P287), where "if" introduces a condition within the problem. In Grade 9, cause–

effect markers are observed in conditional constructions such as “Ziad has 26 money bills in his bank. Some are 500 L.L. bills and some are 1000 L.L. bills. How many of each does he have if he has a sum of 16 500 L.L. in all?” (Grade 9, P397), where “if” introduces a condition linking the given information to the question.

Overall, cause–effect markers are not present in Grade 3 and appear mainly in the form of the conditional keyword “if” in both Grade 6 and Grade 9, with additional causal markers such as “since” and “due to” observed in Grade 6.

The percentage of word problems that included polysemous words varies across grades, with 20% in Grade 3, 11% in Grade 6, and 29% in Grade 9. The occurrence of polysemous words in word problems include, “left”, “table”, “difference” in Grade 3, “area” in Grade 6, and “gain”, “lose”, “mean” in Grade 9. Polysemous words are present across all grades; however the words used differ with the use of more technical maths polysemous in later grades.

Table 12 presents the distribution of lexicogrammar features across Grades 3, 6, and 9, focusing on verb tense, representation of quantities, question forms, clause structure, sentence length, noun phrase complexity, and the use of mathematical terms. These features were analyzed to capture how language complexity varies across grades and how it supports students’ engagement with both quantitative and qualitative aspects of word problems.

Table 12

Distribution of Lexicogrammar Categories Across Grades (% of Word Problems)

Lexicogrammar Category	Grade 3 (n=20)	Grade 6 (n=18)	Grade 9 (n=7)
Verb Tense			
Past Simple	45%	28%	43%
mixed	0%	6%	14%
Present Simple	55%	67%	43%
Quantities w/ Units			
Explicit	90%	72%	100%
Implicit	10%	22%	0%
none	0%	6%	0%
Question Form			
Direct	80%	44%	71%
Imperative	20%	56%	29%
Embedded	0%	0%	0%
Of which Multi	10%	33%	29%
Clause Structure			
Simple	85%	39%	43%
Subordinate	15%	50%	43%
If-then	0%	11%	14%
Sentence Length			
Short	25%	11%	0%
Medium	60%	50%	29%
Long	15%	39%	71%
NP Complexity			
Low	25%	6%	0%
Moderate	70%	50%	57%
High	5%	44%	43%
Math Terms			
Everyday	65%	6%	14%
Transitional	30%	56%	14%
Technical	5%	39%	72%

As shown in Table 12, several patterns emerge in the lexicogrammar of word problems across grades. Regarding verb tense, Past Simple and Present Simple are the most common across all grades, while mixed tenses increase slightly in Grades 6 and 9. Here is a word problem with mixed verb tense in Grade 9:

> A person was observing the eclipse of the sun. Suppose this diagram represents this situation. The observer is at T. The points S (center of the sun), L (center of the moon), and T are collinear. The radius of the sun SO is 695 000 km. The radius of the moon measures 1736 km, and the distance TS is 150 million km. Calculate the distance TL (rounded to km). (Grade 9, P391)

This word problem includes past progressive “a person was observing the eclipse of the sun” then imperative “Suppose this diagram represents this situation”, then simple present in listing the data like “The observer is at T.”

The representation of quantities with units is primarily explicit in all grades, though Grade 6 shows a higher proportion of implicit quantities. However, in Grade 3 the units are “65 persons”, “three shirts”, “26,000 L.L.”, while in grades 6 and 9 more mathematical units emerge such as “19 500 LL per m^2”, “172 hr 21 min 41 s”, “inclination of 30°”, “diameter 5cm.”

Question forms vary across grades, with clear differences in distribution. In Grade 3, direct questions predominate (80%), typically realized through forms such as “what is,” “how long,” and “Can she,” while imperative forms are limited (20%). Here is an illustrative example of direct question form: “Fady bought 6 bottles of juice each 20 cm long. The price of each bottle is 250 L.L. How much did he pay?” (Grade 3, P79), where the question is direct “how much did she pay”. In Grade 6, this pattern shifts, with imperative forms becoming more frequent (56%) than direct questions (44%), as seen in instructions such as “calculate,” “compare,” and “write an algebraic expression.” Here is an illustrative example of an imperative question form: “Compare the volume of the earth to that of the moon, knowing that the radius of the earth is 3.8 times that of the moon. Taking into consideration that the earth and the moon are circular.” (Grade 6, P370), where the question form is imperative asking the student to “compare”. In Grade 9, direct questions increase again (71%) while imperative forms decrease (29%), indicating a more balanced distribution between question types. Embedded questions are absent across all grades (0%), suggesting that tasks remain explicitly framed rather than syntactically embedded. Additionally, multi-part questions increase in higher grades, rising from 10% in Grade 3 to 33% in Grade 6 and 29% in Grade 9, reflecting greater task complexity and the need for extended reasoning. Here is an illustrative example of multi-part questions: “We poured four liters of water in a cylindrical vase of radius 15cm. a) What is the height of the water? b) We immersed in this vase an iron ball of diameter 5cm. What will be the height of the water?” (Grade 9,P431) where there are multiple questions on the same given.

Overall, the findings indicate a shift from simple, direct questioning in lower grades to more instruction-based and multi-step task structures in higher grades.

Clause structure becomes more complex across grade levels. In Grade 3, simple clauses dominate (85%), with only limited use of subordinate structures (15%) and no conditional forms (0%), reflecting straightforward sentence construction. Here is an illustrative example of simple clauses: “In a bus, there are 65 persons. 43 of them are sitting. How many persons are standing?” (Grade 3, P20). In contrast, Grade 6 shows a clear increase in complexity, with subordinate clauses rising to 50% and the emergence of if–then structures (11%) such as “If each fence costs 700 LL, what is the cost of the fence?” This trend continues in Grade 9, where subordinate clauses remain high (43%) and if–then constructions increase slightly (14%), indicating more explicit conditional reasoning. Here is an illustrative example of subordinate clauses: “A man bought 35 lambs for 135000 LL each. Since he paid the total amount in cash, he got a discount of 6%. How much did he pay?” (Grade 6, P316), where “since” functions as a subordinate clause expressing cause, providing the reason for the main clause “he got a discount of 6%.” Here is an illustrative example of if-then (conditional) clauses where “if” represents a conditional clause: “An employee spends 8/9 of his monthly salary. If he spent 3/7 of his spent money on food, write a fraction to show how much he spent on food” (Grade 6, P287)..

This structural development is paralleled by changes in sentence length. In Grade 3, sentences are predominantly medium in length (60%), with relatively few long sentences (15%). However, in Grade 6, the proportion of long sentences increases to 39%, and in Grade

9, long sentences become dominant (71%), reflecting the inclusion of more information and multi-step instructions within a single problem. Here is an illustrative example of a long word problem formed of 74 words:

> A library passed 5 600 samples of a scholar by book A, 2 700 of book B and 4 200 of book C. The library sold 4 800 samples of A, 1 350 of B and 3 000 of C. a) Give the fraction that represents the number of books A sold with respect to all samples of A. b) Same question for B and C. c) What fraction of the total number of books do the samples sold of book A represent? Of book B? Of book C? (Grade 6, P231).

Similarly, noun phrase complexity increases across grades. While low-complexity noun phrases appear in 25% of Grade 3 problems, they decrease to 5% in Grade 6 and disappear entirely in Grade 9 (0%). In contrast, high-complexity noun phrases rise from 5% in Grade 3 to 44% in Grade 6 and 43% in Grade 9, such as "the distance between the centers of the sun and the moon." Here is an illustrative example of high noun phrase complexity:

> A person was observing the eclipse of the sun. Suppose this diagram represents this situation. The observer is at T. The points S (center of the sun), L (center of the moon), and T are collinear. The radius of the sun SO is 695 000 km. The radius of the moon measures 1736 km, and the distance TS is 150 million km. Calculate the distance TL (rounded to km). (Grade 9, P391)

This word problem exhibits high noun phrase complexity through the use of extended noun phrases with multiple modifiers and embedded elements, such as "the points S (center of the sun), L (center of the moon), and T" and "the radius of the sun SO," which include technical terms, prepositional phrases, and parenthetical information.

Similarly, the use of mathematical terms shifts across grade levels. In Grade 3, everyday terms predominate (65%) such as "total", "bought", "price", with some use of transitional terms (30%) like "4 times", "half", "difference", and minimal technical terminology (5%) like “same mass”, reflecting a reliance on familiar, accessible language. In Grade 6, this pattern changes significantly, with transitional terms becoming the most frequent (56%) such as “fractions”,”meters”, “discount, while everyday terms drop sharply (6%) and technical terms begin to emerge (39%) like “parallelogram”, “bar diagram,”, “rotations”. By Grade 9, technical terms are dominant (72%) such as “radius”, inclination”, “frequencies”, “mean”, or “cylindrical vase”, whereas both everyday and transitional terms are much less frequent (14% each), indicating a shift toward more specialized and discipline-specific language. Overall, the findings show clear progression from informal, everyday vocabulary in lower grades to increasingly formal and technical mathematical language in higher grades.

Distribution of mode of representation features across Grades 3, 6, and 9

Table 13 presents the distribution of modes of representation in word problems across Grades 3, 6, and 9, focusing on the use of textual and visual elements as well as the density of information presented. This analysis highlights how the form and richness of representation in word problems changes across the school cycles.

Table 13
Distribution of Mode of Representation Categories Across Grades (% of Word Problems)

Mode of Representation Category	Grade 3 (n=20)	Grade 6 (n=18)	Grade 9 (n=7)
Representational Mode			
Text only	90%	61%	57%
Text + image	10%	39%	43%
Representation Density			
Low	10%	6%	0%
Medium	70%	50%	57%
High	20%	44%	43%

As shown in Table 13, the majority of word problems in Grade 3 are presented as text only (90%), with a small proportion including both text and images (10%). By Grade 6, the use of both text and image increases to 39%, and in Grade 9, it reaches 43%, indicating a gradual integration of visual representation across grades. Here is an illustrative example of a word problem that needs both text and image:

> To construct a house similar to the one in the figure, an architect draws all the necessary plans. Below, a plan of the front view of this house is presented with some measurements. The adjacent figure represents the roof with an inclination of 30°. The construction worker must place his posts at B and D. How high should AB and CD be set to assure a roof inclination of 30°? (Grade9, P414).

In this word problem the figure is crucial to answer the question as it has the measurements and provides the visualization to understand the problem.

Regarding representation density, most word problems in Grade 3 are of medium density (70%), with low- and high-density forms appearing less frequently. In Grades 6 and 9, medium and high-density representations become more common such that 50% medium and 44% high representation density in Grade 6 and 57% medium and 43% high in Grade 9. For example, Grade 9 problems include visuals of geometric diagrams and plans that makes the representation dense.

Overall, these findings indicate that word problems in later grades tend to incorporate more visual elements and higher representation density, supporting more complex reasoning and multi-step problem-solving tasks.

Language Learning Progressions across School Cycles

RQ3: What language learning progressions can be identified in the linguistic characteristics of the word problem genre across Cycles I, II, and III in the Lebanese curriculum, reflecting increasing levels of language complexity?

To address research question 3, the author builds on the findings presented for Research Question 2. This section identifies language learning progressions in the linguistic characteristics of word problems across Cycles I, II, and III. The analysis was conducted by comparing and contrasting the findings obtained for each cycle in Research Question 2 in order to identify patterns of progression and increasing language sophistication across the school cycles. These progressions are examined across the four dimensions of the word problem genre: function, structure, lexicogrammar, and mode of representation based on the distributions presented in Tables 9–13, where clear patterns emerge that reflect increasing levels of linguistic and structural complexity across the three cycles.

Progression in Function Categories

Across the three cycles, word problems consistently function as mathematical tasks while maintaining the presence of real-life contexts. In Cycle I, word problems are strongly grounded in familiar everyday contexts such as shopping, sharing, or everyday situations, with clear narrative support. Tasks imitate real-life activities but primarily function as simple numerical frames. A small number of context-free tasks also appear (e.g., "I am a number…").

In Cycle II, real-life contexts are maintained, including situations such as discounts, fractions of cake, and land measurement. However, tasks become more procedural and often involve multiple steps, with mathematical procedures becoming more prominent within the context. Some context-free numerical problems remain.

In Cycle III, real-life contexts are still present but are embedded within more academic or disciplinary situations, such as geometric or statistical contexts. Problems continue to function as imitation of school mathematics and real-life activity, and context-free tasks are no longer observed.

Progression in Structure Categories

Across cycles, word problems show a progression in structural organization. In Cycle I, problems are predominantly organized using a canonical three-part structure (story-data-question), with clearly separated components. For example: “Mother bought three shirts. Each shirt costs 26,750 L.L. What is the price of these shirts?” (Grade 3, P117). This problem presents a familiar context, simple sentence structure, and a direct relationship between the given information and the required calculation.

In Cycle II, structural variation increases. Canonical structures decrease but are still present, while collapsed structures emerge, often through conditional forms. For example: “If he spent 3/7 of his spent money on food…” (Grade 6, P287) Similarly, in: “Here is a plan for Mr. Nader’s garden… If each fence costs 700 LL, what is the cost of the fence?” (Grade 6, P275), the if–then structure represents a conditional relationship and a collapsed structure where information and question are linguistically integrated. In addition, task-oriented structure with multi-part tasks become more frequent.

In Cycle III, structures become mixed between canonical and task-oriented involving multiple steps. For example, the following problem illustrates task-oriented structures with multiple instructions, where information is distributed across several steps rather than presented in a single question:

> “Among twelve interviewed drivers, we found: 3 had no accidents, 1 had one accident, 2 had two accidents, 1 had three accidents, 3 had four accidents, and 2 had five accidents. a) Organize this data in a table showing the distribution of these drivers according to the number of accidents they had. b) Represent the frequencies in a bar graph. c) Calculate the relative frequencies in percentage form and represent them in a circle graph. d) Find the mean of this distribution.” (Grade 9, P425)

Lexicogramar: Progression in Lexicogrammar Features

In Cycle I, vocabulary is primarily everyday, and mathematical relationships are often expressed through basic connectors that are operation-based, using terms such as “in all,” “left,” “each,” “times,” “half,” and “how many,” Linguistic features at this stage indicate simple clause structures dominating and minimal use of logical or cause–effect markers. Logical markers are limited to basic connectors such as “and”. Noun phrases are generally simple and refer to concrete quantities (e.g., “55 pearls”). Verb usage is generally consistent within single tense forms, reflecting limited verb form sophistication and shorter sentence length. Overall, word problems at this stage rely on explicit contextual support and lower linguistic complexity, and limited repertoire of linguistic resources.

In Cycle II, linguistic features become more varied. Vocabulary includes transitional and emerging technical mathematical terms such as “fraction,” “percent,” “ratio,” “area,” and “discount.” There is a noticeable increase in conjunctions and logical markers, along with the introduction of cause-effect relationships, reflecting increased coherence and cohesion. Sentence structures become more complex, with a higher proportion of subordinate clauses and the emergence of conditional (“if–then”) constructions indicating increased sentence structure sophistication (e.g., “If each fence costs…”, “Since he paid…”)**.** Sentence length increases, and information is increasingly embedded within clauses, reflecting noun phrase complexity. In addition, verb usage shows increased variation, with the emergence of mixed tense forms alongside single-tense constructions. These patterns indicate progression toward greater linguistic sophistication, reflecting more linguistically demanding word problems.

In Cycle III, lexicogrammar features become more complex and dense. Vocabulary is predominantly technical reflecting a shift toward discipline-specific language, including terms such as “radius,” “diameter,” “inclination,” and “mean.” Lexicogrammar features show further development, with more frequent use of conjunctions, logical markers, and cause-effect relationships, reflecting increased coherence and cohesion**.** Clause structures remain complex, including both subordinate and conditional forms, and longer sentences are more common, often involving multiple clauses and embedded information. Noun phrase complexity also increases, contributing to more complex noun phrases within single clauses. Verb usage continues to show variation, with mixed tense forms appearing more frequently.

Mode of Representation: Progression in Multimodality

In Cycle I, problems are predominantly text-only, with limited use of visual elements. Representation is generally low to medium in density, with information presented explicitly. In Cycle II, visual elements such as diagrams and plans become more common, and tasks increasingly require interpretation of both textual and visual information. Representation density increases accordingly. In Cycle III, word problems incorporate greater representation density and more frequent integration of visual elements, indicating more complex presentation of mathematical information including geometric diagrams and statistical graphs. For instance, word problems problems involving diagrams and multiple quantities require information to be interpreted across both textual and visual representations within a single task.

Table 14 presents a detailed summary of the linguistic characteristics of word problems across Cycles I, II, and III, organized according to the four dimensions of the word problem genre: function, structure, lexicogrammar, and mode of representation.

Table 15 presents a category-level analysis of the progression in linguistic characteristics across cycles. It highlights how specific elements within each dimension, such as vocabulary, clause structure, logical markers, etc, develop from Cycle I to Cycle III, indicating shifts in linguistic complexity, structural variation, and representational demands.

Table 14

Summary of Language Learning Progression in Linguistic Characteristics Across Cycles

Dimension	Cycle I (Grades 1–3)	Cycle II (Grades 4–6)	Cycle III (Grades 7–9)
Function	Word problems are strongly grounded in familiar everyday contexts such as shopping, sharing, and calendars, with clear narrative support. Problems imitate real-life activities and school mathematics. A small number of context-free tasks appear.	Real-life contexts are maintained (e.g., discounts, fractions of cake, land measurement) but tasks become more procedural and multi-step. Context continues to frame the task, though the mathematical procedures become more prominent. Some context-free numerical problems remain.	Real-life contexts are still present but embedded within more academic or disciplinary situations (e.g., temple measurement, trigonometry, statistics). Problems remain imitating real-life activities and school mathematics. and context-free tasks are no longer observed.
Structure	Problems are predominantly organized using a canonical three-part structure, with clearly separated components Task-oriented structure are limited.	Canonical structures decrease, while collapsed structures emerge through conditional forms. Task-oriented structure become more frequent.	Problems are often canonical and task-oriented, involving multi-part questions. The question may precede data, and tasks are condensed and integrated across components.
Lexicogrammar – Vocabulary	Vocabulary is predominantly everyday and operation-based, using terms such as "in all," "left," "each," "times," "half," "how many". Mathematical meaning is expressed through familiar language.	Vocabulary shifts toward transitional and emerging technical terms, including "fraction," "percent," "ratio," "area," "discount". Everyday vocabulary decreases, and mathematical meaning becomes more explicit.	Vocabulary becomes predominantly technical and discipline-specific, including terms such as "radius," "diameter," "inclination," "mean," "cylindrical vase". Mathematical relationships are expressed through specialized terminology.
Lexicogrammar – Sentence & Clause Structure	Sentences are mostly simple and short to medium in length, with minimal subordination (e.g., "There are 65 persons…"). No conditional (if–then) structures are present.	Sentence complexity increases, with more subordinate clauses and the emergence of conditional structures (e.g., "If each fence costs…", "Since he paid…"). Sentences become longer and more information-dense.	Sentences are predominantly long and complex, maintaining subordinate and conditional structures. Multiple clauses and embedded information are common, reflecting multi-step reasoning.
Lexicogrammar – Cohesion & Logical Relations	Logical markers are limited and mainly express simple comparison or addition, using terms such as "same," "more than," "and". No cause–effect markers are present.	Logical markers increase and expand in function, supporting comparison and procedural relationships (e.g., "compare," "then"). Cause–effect markers are introduced (e.g., "since," "due to," "if").	Logical markers are more frequent and used for classification, sequencing, and distribution, such as "according to," "then," "some" Cause–effect relationships are maintained, through conditional structures.
Lexicogrammar – Noun Phrases & Density	Noun phrases are mostly simple, referring to concrete quantities (e.g., "55 pearls"). Information is presented explicitly with limited embedding.	Noun phrase complexity increases with more quantifying expressions and embedded information (e.g., "the total number of books").	Noun phrases become highly complex, including multiple modifiers and embedded structures (e.g., "the distance between the centers of the sun and the moon"), contributing to dense information packaging.
Mode of Representation	Problems are mostly text-only, with limited use of images (10%). Representation is generally low to medium density, with information presented explicitly in text.	Use of text and image increases (diagrams), and representation density becomes medium to high, requiring interpretation of both textual and visual elements.	Problems increasingly integrate text and visuals with high representation density, requiring interpretation across multiple representations within a single task.

Table 15
Category -Level of Language Learning Progression in Linguistic Characteristics Across Cycles

Dimension	Category	Cycle I	Cycle II	Cycle III	Progression
Function	Real-life context	Familiar everyday contexts	Every day Context/ procedures	Academic/disciplinary contexts	Increasing contextual sophistication
	Context-free tasks	Present	Present	Absent	Decreasing context free
Structure	Canonical structure	story data, question	Reduced; more variation	Present but reduced	Decreasing reliance
	Collapsed structure	Rare	Emerging (if–then forms)	Minimal	Emerges in Cycle II
	Task-oriented structure	Limited	Increasing (multi-step)	Frequent (multi-step tasks)	Increasing frequency
Lexicogrammar	Mathematical vocabulary	Everyday	Transitional/technical	Predominantly technical	Increasing specialization
	Action verbs	Concrete (e.g., *bought, added*)	Procedural (e.g., *calculate, compare*)	Disciplinary (e.g., *construct, represent*)	Increasing functional complexity
	Characters / participants	Concrete individuals	Mixed contexts	Generalized roles	Increasing abstraction
	Determiners (grouping)	Explicit (*each*, *per*)	Expanded forms (*1/4 of…*)	Less explicit	Decreasing explicit marking
	Conjunctions (and)	Present/minimal	Increasing range	Frequent	Increasing cohesion
	Logical markers	Simple comparison	Comparison & relations	Classification & sequencing	Increasing complexity
	Cause–effect markers	Absent	Introduced (*if*, *since*)	Maintained (if)	Emerges in Cycle II
	Clause structure	Mostly simple	Subordinate + conditional	Complex clauses	Increasing complexity
	Sentence length	Short–medium	Medium–long	Long	Increasing length
	Noun phrase complexity	Low	Medium	High	Increasing density
	Verb tense use	Single tense	Emerging mixed	Greater variation	Increasing variation
Mode of Representation	Text vs visual	Mostly text-only	Text and visuals	More Text and visuals	Increasing multimodality
	Representation density	Low–medium	Medium–high	Medium–high	Increasing density

Overall, the linguistic characteristics of word problems show a clear progression across cycles. Word problems progresses from canonical three-part structures, simple clauses, and everyday mathematical terms in Cycle I, to more collapsed and task-oriented structures, increased use of subordinate clauses, if–then structures, cause–effect markers, and transitional terms in Cycle II, and finally to greater noun phrase complexity, technical mathematical terms, task-oriented structures, and higher representation density in Cycle III. These patterns demonstrate a systematic increase in linguistic and structural complexity across the textbook.

CHAPTER 5

DISCUSSION

This chapter discusses the findings of the study in relation to the three research questions and interprets them in light of the literature on mathematical language, genre, and language learning progression in mathematics education. The discussion is guided by the following research questions: (1) How does the frequency of the word problem genre vary across grade levels, school cycles and mathematical strands (numbers and calculations, algebra, geometry, measurement, and statistics) in Lebanese national mathematics textbooks? (2) How do the linguistic characteristics of the word problem genre change across school cycles in the Lebanese National mathematics textbooks? (3) What language learning progressions can be identified in the linguistic characteristics of the word problem genre across Cycles I, II, and III in the Lebanese curriculum, reflecting increasing levels of language complexity?

Using a genre-based and Systemic Functional Linguistics (SFL) framework, this chapter examines both the distribution and linguistic features of word problems, with particular attention to how these evolve across the curriculum. Special attention is given to the linguistic demands of word problems in Lebanon, where mathematics is taught in a language of instruction that is different from students' home language. The discussion begins with an analysis of the distribution of word problems across grade levels, school cycles, and mathematical strands, and then examines the linguistic features of word problems and how these features progress through Cycles I, II, and III. This chapter is organized into four parts: (a) a discussion of the findings in relation to the research questions and theoretical framework, (b) the study's limitations, (c) implications for future research and practice, and (d) conclusion.

Discussion of the Findings

Distribution of the Word Problem Genre Across Grade Levels, School Cycles, and Areas of Mathematics

The findings for Research Question 1 demonstrate that the distribution of word problems across grade levels, school cycles, and mathematics strands is uneven and follows a clear pattern of concentration and redistribution within the curriculum.

At the grade level, as shown in table 6, the proportion of word problems increases from Grade 1 to a peak in Grades 3 and 4. It remains relatively high in Grades 5 and 6, then sharply decreases in Grades 7 to 9. This pattern suggests that the middle elementary grades represent a key phase in which engagement with the word problem genre is most explicitly emphasized. The focus on word problems in Grades 3 to 6 likely reflects a point in the curriculum where students are expected to interact more with this genre and apply mathematical operations in structured text.

Looking at the school cycle level, this pattern is further reinforced, with Cycle II showing the highest percentage of word problems, while Cycle III shows a noticeable decline. This concentration suggests that word problems play a central role during Cycle II, where they are more frequently used as a primary format for mathematical tasks. In contrast, their reduced presence in Cycle III indicates that they become less dominant as students progress to higher grade levels.

This pattern can be interpreted in relation to how mathematical content is organized across the curriculum. In earlier and middle grades, word problems appear to serve as a key means of engaging students in applying numerical procedures within structured tasks. As students progress to higher grades, the decrease in frequency suggests a shift toward other task formats, such as symbolic or diagrammatic representations, which may be more suitable for expressing increasingly abstract mathematical concepts. This interpretation aligns with the observed decline in word problem frequency alongside the expansion of content in strands such as algebra and geometry in later grades.

The distribution of word problems across mathematical strands further supports this shift in the role of word problems throughout the curriculum. In the early grades and cycles, word problems are highly concentrated in the Numbers and Calculations (Arithmetic) strand, with minimal representation in other strands. In Cycle II, although this strand remains dominant, there is increased representation in measurement and the emergence of geometry, statistics, and algebra. In Cycle III, although this strand becomes more balanced, with a reduced proportion in numbers and calculations (arithmetic) and increased representation in geometry, statistics, and algebra. This redistribution indicates that word problems are not confined to numerical operations but are increasingly used to support a wider range of mathematical content as students progress through the curriculum.

From a genre perspective, these findings suggest that exposure to the word problem genre is staged across the curriculum rather than uniformly distributed. Word problems appear to be emphasized at particular stages, especially in Cycle II, before becoming less frequent but more integrated across different mathematical strands. This supports the view of word problems as a specific form of mathematical discourse (Gerofsky, 1999), whose use varies depending on curricular goals and content emphasis.

In relation to previous research, studies have highlighted the central role of word problems in school mathematics as a means of linking mathematical procedures to contextualized tasks and identifying their characteristics (e.g., Gerofsky, 1999; Barwell, 2005). However, fewer studies have examined how their frequency varies systematically across grade levels and strands. The findings of this study contribute to this area by showing that the use of word problems is not constant but concentrated in specific phases of the curriculum and redistributed as mathematical content becomes more specialized. This suggests that students' exposure to this genre is structured and selective rather than continuous.

In the Lebanese context, where mathematics is taught in a second language (English or French), this uneven distribution may have implications for students' opportunities to engage with extended written mathematical tasks. It may also reflect a shift in focus toward other mathematical genres that emerge more prominently in later grades, such as geometric constructions, proofs, and procedural forms of mathematical activity, resulting in a more selective rather than continuous use of the word problem genre across the curriculum.

Taken together, these patterns show that the distribution of word problems across grade levels, school cycles, and mathematical strands is structured rather than uniform. Word problems are concentrated in the middle elementary grades, particularly in Cycle II, before declining in later grades, while also shifting from a strong emphasis on Numbers and Calculations to a more varied distribution across Geometry, Algebra, and Statistics. These findings extend previous research on word problems, which has primarily focused on their role and characteristics, by demonstrating how their frequency varies systematically across the curriculum. In particular, the results highlight that exposure to the word problem genre is staged across different phases of schooling and varies according to mathematical content. This provides a clearer understanding of how word problems are positioned within the structure of the curriculum.

Linguistic Characteristics of Word Problems Across School Cycles

The findings for Research Question 2 show that the linguistic characteristics of the word problem genre vary across school cycles while maintaining several consistent genre features. These variations are interpreted through a genre-based and SFL perspective, where word problems are shaped by their function, structure, lexicogrammar, and mode of representation. The results indicate that while the overall function of word problems remains stable, variation occurs in how problems are structured, how linguistic features are used, and how information is represented across grades. These patterns highlight differences in the organization of tasks and the linguistic and representational features used in word problems across school cycles.

Function: Stability of Function Across Grades

The findings show that word problems consistently function as imitation of school mathematics and mathematical activity generation across all grades. This indicates that the primary function of word problems remains stable across school cycles, with all tasks designed to engage students in mathematical activity within a school-based framework.

At the same time, the consistently high proportion of story or real-life context and imitation of real-life activity across grades suggests that these contexts are not merely decorative. The findings show that real-life contexts are consistently present across grades and form a regular feature of the genre. However, the presence of context does not change the underlying function of the task. In all cases, the context serves to frame a mathematical problem that requires the application of specific procedures or operations.

This interpretation is consistent with Gerofsky (1999), who describes word problems as a school-based genre structured according to internal conventions. The findings support this perspective in that all problems ultimately function as mathematical tasks. However, unlike an interpretation that contrasts school mathematics with real life, the results show that imitation of school mathematics and imitation of real-life activity occur together across all grades. This suggests that real-life activity/contexts do not replace the school-based nature of word problems but operate within it. This indicates that real-life contexts function as a means of situating mathematical activity that functions as a bridge between everyday experience and formal mathematical reasoning.

Similarly, the consistent presence of mathematical activity generation across all grades aligns with Barwell's (2005) argument that word problems are designed to generate mathematical activity, even when framed through familiar situations. The findings show that this function is maintained regardless of the type of context used, whether narrative, or minimal.

From an SFL perspective, this reflects stability in the field of the discourse, where the purpose of engaging in mathematical activity remains consistent, while the context functions as a supporting frame. Across school cycles, variation is therefore not observed in function itself, but in how this function is realized through other dimensions, such as structure, lexicogrammar, and mode of representation.

Structure: Variation in the Organization of Components

The structural findings confirm that word problems maintain their core components: story set-up, information/data, and question, across all grades, reinforcing the three-part canonical structure described by Gerofsky (1999) and Barwell (2003). However, the key development lies in how these components are organized and integrated.

In earlier grades, these components are typically presented in a clear and sequential manner, allowing for direct extraction of information and question. In later grades, however, there is a shift toward collapsed structure and task-oriented structures where information and question are embedded within clauses or distributed across multi-step tasks presented within a single problem. This shift from canonical to more collapsed and task-oriented structures require students to actively interpret how information and question are organized, rather than simply extracting it.

From an SFL perspective, this shift reflects increasing complexity in the textual metafunction, where meaning is no longer organized through simple sequencing but through more embedded and multi-step structures. As a result, students are required not only to perform mathematical operations, but also to interpret how information is structured within the problem. Structural variation therefore reflects increasing demands on the interpretation of textual organization, rather than changes in the presence of core genre components.

Lexicogrammar: Variation Across Linguistic Features

The findings show variation across multiple categories (features) of lexicogrammar dimension of word problems across Grades 3, 6, and 9, while some features remain consistently present. In particular, action verbs appear in nearly all word problems across grades, and characters or story-related vocabulary remain frequent, although their form and role vary. At the same time, differences emerge across grades in the use of conjunctions, logical markers, cause–effect relations, clause structure, sentence length, noun phrase complexity, and mathematical vocabulary. These variations indicate changes in how information is expressed and organized linguistically across school cycles.

This variation is characterized by an increased use of conjunctions, logical markers, and cause-effect markers across Grade 3 to Grade 9. Similarly, clause structure becomes more complex, with a shift from predominantly simple clauses in Grade 3 to greater use of subordinate and conditional (if–then) structures in Grades 6 and 9. These features allow relationships between quantities to be expressed more explicitly within the text. Rather than presenting information in separate, simple statements, higher-grade problems more often connect ideas within and across sentences, requiring students to interpret relationships such as comparison, condition, and sequence.

In addition, the increase in sentence length and noun phrase complexity further contributes to higher linguistic density. The proportion of long sentences increases substantially in higher grades, and noun phrases become more complex, with greater use of modifiers and embedded elements. The increasing presence of such features in higher grades suggests that word problems require students to process more information within single sentences or phrases, and students must process multiple pieces of information within the same linguistic unit. This differs from Grade 3 problems, where information is more often distributed across shorter and simpler sentences.

In addition, the findings show variation in the use of determiners related to grouping and distribution. These markers (e.g., “each,” “per”) are more frequent in

Grades 3 and 6, where they explicitly signal how quantities are organized, but appear less frequently in Grade 9. In higher grades, grouping and quantitative relationships are more often expressed through numerical or relational structures rather than through explicit lexical markers. This indicates a shift in how quantitative relationships are linguistically encoded across grades.

The use of mathematical vocabulary also varies across grades. In Grade 3, everyday terms are more common, while Grades 6 and 9 show an increasing presence of transitional and technical mathematical terms. This reflects a shift toward more specialized and discipline-specific language in higher grades. In addition, the occurrence of polysemous words varies across grades, with different types of words appearing at different levels, including more technical meanings in higher grades.

These patterns align with the concept of the mathematics register (Halliday, 1978; Halliday & Martin, 1993; Schleppegrell, 2007), where meaning is constructed through specialized vocabulary and grammatical structures. From a SFL perspective, these changes reflect development in the ideational metafunction, where more complex relationships between quantities and processes are encoded linguistically. The increased use of conjunctions, logical markers, and more complex clause structures allows relationships between quantities to be expressed more explicitly within the language of the problem.

At the same time, the increased use of imperatives (e.g. suppose) relate to how the problem positions the reader in carrying out the task. This can be interpreted in relation to the interpersonal metafunction, as these forms explicitly direct the actions that students are required to perform. Rather than framing the task as a question, imperatives guide students toward specific procedures, particularly in multi-step problems. While previous research (Morgan, 1998) has noted the use of directive language in mathematical texts, the findings in this study show how this feature varies across grades, with a higher proportion of imperatives in middle grades. This suggests that directive forms are used differently across school cycles to organize increasingly procedural tasks.

Overall, the findings show that variation in lexicogrammar across grades is reflected in changes in specific linguistic features rather than a single unified pattern. While some features remain stable, others vary in frequency and form, contributing to differences in how information, relationships, and tasks are expressed in word problems across school cycles.

Mode of Representation: Increasing Multimodal Complexity

The findings also indicate a shift in the mode of representation across school cycles due to the increase in the use of text and images (visuals) and higher representation density in higher grades. While Grade 3 problems are predominantly text-based, Grade 6 and Grade 9 problems increasingly integrate diagrams, plans, and graphical (visual) representations.

This reflects the multisemiotic nature of mathematical discourse, where meaning is constructed through the interaction of language, symbols, and visual representations (Schleppegrell, 2007; O'Halloran, 2005). From a SFL perspective, this corresponds to the mode of communication, where information is distributed across different semiotic systems.

As representation density increases, tasks require learners to interpret information across different forms, such as diagrams, tables, and written text, which adds to the overall complexity of the task. This is because understanding the problem requires integrating linguistic and visual information. As such, higher demands are placed on learners that require them to interpret and coordinate multiple sources of information.

Language Learning Progressions in the Linguistic Characteristics of Word Problems Across School Cycles

The findings for Research Question 3 indicate that the linguistic characteristics of word problems follow systematic patterns of progression across school cycles, reflecting increasing levels of language complexity in the textbooks. These progressions are examined across the four dimensions of the word problem genre: function, structure, lexicogrammar, and mode of representation. In this sense, progression is reflected in the increasing complexity of the linguistic and representational resources of word problems.

This pattern aligns with the concept of language learning progression as described by Bailey and Heritage (2014), who argue that language develops in sophistication across dimensions such as vocabulary sophistication, sentence structure sophistication, verb form sophistication, coherence and cohesion, and expanded word groups. While their work focuses on student language development, the findings of this study extend their perspective by showing that these dimensions are also embedded within textbook design. This suggests that language learning progression is not only reflected in students' language development, but is also constructed within curriculum materials where linguistic and structural demands are progressively intensified across cycles. Furthermore, this progression reflects Bakhtin's (1986) view that genres evolve in response to increasing complexity within a discipline. The word problem genre, therefore, develops across school cycles through increasingly complex linguistic, structural, and representational forms. The discussion below examines this progression across the four dimensions of the word problem genre. I organize my discussion into four parts, corresponding to the four dimensions of the word problem genre: function, structure, lexicogrammar, and mode of representation.

Progression in the Function Dimension

The findings show that word problems consistently function as imitation of school mathematics and mathematical activity generation, while maintaining the presence of real-life contexts and imitation of real-life activity across cycles. The progression in the function of word problems is reflected in changes in how real-life context is presented and related to mathematical activity The observed shift in context suggests a progression in how situations are represented, rather than in their presence. In cycle I and II, contexts represent familiar, concrete, and personalized scenarios that closely reflect everyday experiences. In cycle III, contexts become more generalized, institutional, and discipline-specific, reducing reliance on personal narratives.

This shift indicates that mathematical meaning becomes more aligned with disciplinary forms of reasoning. The progression is also accompanied by a shift in how context functions within the task. In earlier cycles, context primarily serves as narrative support, providing a familiar frame for interpreting the problem. In later cycles, however, context becomes increasingly integrated with the mathematical procedures, particularly in multi-step tasks where it structures and sequences the required operations. As a result, solving the problem requires not only identifying numerical information but also interpreting how the context organizes the mathematical activity.

The progression in the function dimension is reflected in increasing contextual sophistication rather than a change in purpose. This pattern aligns with Bakhtin's (1986) notion that genres evolve in response to the complexity of the spheres of activity in which they operate. In this case, the context of word problems shifts from familiar, everyday narratives toward more formal and discipline-specific situations, reflecting changes in the types of mathematical activity represented across grades.

Furthermore, these findings support and extend Barwell's (2003, 2005) argument that word problems are designed to generate mathematical activity. While this function remains consistent across grades, the results show that the role of context becomes more closely aligned with the mathematical activity it is intended to support. As a result, context not only provides a setting for the task but also plays an increasingly important role in shaping how mathematical activity is interpreted and carried out.

Progression in Structure Dimension

Across Cycles I, II, and III, the canonical elements of story, information, and question remain present; however, the progression is reflected in increasing structural complexity in how the problem is organized. In Cycle I, the story set-up, information, and question are clearly separated components, which are explicitly stated. Later in Cycles II and III, more collapsed structure emerges. Meaning is therefore less directly signaled and more dependent on how information and questions are connected within clauses and across different parts of the task. In particular, the organization of mathematical activity into task-oriented structures reflects a move toward multi-step tasks, where the task is carried out across multiple steps rather than presented as a single, explicitly framed question. This indicates that word problems require readers to interpret more complex relationships between ideas, as information and tasks are increasingly organized across multiple steps rather than presented in a single, clearly separated structure.

As a result, structural complexity lies in the organization of relationships, particularly through how components are connected, embedded, and distributed within the problem. Learners are required to move beyond identifying given information toward interpreting how different components relate to one another across the structure of the task. From SFL perspective, this reflects increasing complexity in the textual metafunction across school, where meaning is organized through more integrated and multi-layered structures rather than simple sequencing. In terms of language learning progression, this aligns with Bailey and Heritage’s (2014) notion of increasing sentence structure sophistication and more complex relationships between ideas, where meaning is progressively constructed through embedded and interconnected forms. This pattern is also consistent with Daroczy et al. (2015), who show that multi-step problems increase linguistic difficulty by requiring learners to interpret relationships across multiple components rather than respond to a single explicitly structured task.

These findings extend existing literature (Bailey & Heritage, 2014; Daroczy et al., 2015) by showing that increasing complexity in sentence structure and relationships between ideas is not only reflected in student language development, but is also systematically built into the textbook, where the organization of meaning becomes progressively more complex across cycles. The word problem genre does not change in its core structure, but develops through more complex ways of organizing meaning across its components.

Progression in Lexicogrammar Dimension

The findings show that progression in the lexicogrammar dimension is realized through systematic changes in how specific linguistic features are used across Cycles I, II, and III.

Across Cycles I, II, and III, vocabulary moves from everyday to transitional/technical to predominantly technical. that is increasingly specialized and discipline-specific forms of expression. Rather than simply introducing new terminology, this shift reflects a reorganization of meaning through language, where concepts are expressed using more precise and technical forms. This pattern reflects the development of the mathematical register (Morgan, 1998), where meaning is increasingly encoded through specialized vocabulary and discipline-specific ways of expressing relationships. This also reflects increasing vocabulary sophistication discussed by Bailey and Heritage (2014), where interpreting the problem relies less on familiar terms and more on understanding discipline-specific wording within the task.

Clause structure shifts from mostly simple to subordinate and conditional to consistently complex and embedded across Cycles I, II, and III. Word problems in Cycle I rely on simple clauses and direct structures that present information sequentially, enabling straightforward interpretation. In Cycles II and III, meaning is increasingly encoded through more complex grammatical constructions, including subordination, conditional structures, and multi-part task formulations. This indicates that complexity is not simply a matter of longer sentences, but of how relationships are embedded within grammatical structures. This reflects increasing sentence structure sophistication, where relationships are no longer presented across separate sentences but are encoded within clauses, requiring interpretation of conditions and relations inside the sentence itself.

Logical and cause–effect markers shift from limited or absent in Cycle I to introduced and expanded in Cycle II to frequent and functional in Cycle III. This reflects increasing coherence and cohesion, where relationships such as sequence, comparison, and condition are no longer simply indicated through basic connectors, but are increasingly organized through a wider range of discourse markers, including causal (*since*), conditional (*if*), and relational expressions. This shift reflects an expansion in the linguistic repertoire used to express relationships between ideas. Rather than relying on simple connectors, conjunctions, logical markers, and conditional structures are used to construct more structured and relational connections across clauses. As a result, coherence is not only a matter of clarity, but a dimension of complexity, where understanding depends on navigating relationships between multiple elements within the problem. This aligns with literature on cohesion and logical relations in discourse, where conjunctions and relational markers function as key resources for organizing relationships between ideas (Gerofsky 1999; Schleppegrell, 2007; Daroczy et al., 2015;), and with the mathematical register, where meaning is expressed through specialized ways of linking quantities and conditions (Morgan, 1998). From a progression perspective, these findings extend Bailey and Heritage's (2014) emphasis on increasing coherence and cohesion by showing that these relational resources become increasingly frequent, varied, and functional across textbook cycles.

Noun phrase construction shifts from simple, concrete references in Cycle I, to expanded and quantified forms in Cycle II, to highly embedded expressions in Cycle III.

This reflects the use of expanded word groups, where more information is packed into single units, increasing density and requiring learners to process multiple elements within one phrase. This contributes to increased linguistic density, where relationships between quantities are embedded within nominal structures rather than expressed across multiple sentences. From an SFL perspective, it also aligns with the development of the mathematics register, where meaning is increasingly expressed through dense and specialized linguistic forms.

Determiners for grouping shift from explicit marking (e.g., *each, per*) in Cycles I and II, to less explicit use in Cycle III. This means that grouping is no longer directly signaled by a lexical item, but must be inferred from how quantities are structured within the expression, increasing interpretive demand. This aligns with the mathematical register (Morgan, 1998), where relationships between quantities are increasingly encoded through linguistic and symbolic forms rather than explicitly stated. From a progression perspective, this extends Bailey and Heritage's (2014) account of increasing linguistic sophistication by showing a shift from explicitly marked relationships (determiners) toward forms that require greater inference across textbook cycles.

The progression in verb forms suggests increasing variations. In Cycle I, word problems are dominated by consistent tense forms and direct question structures, typically relying on simple present or past tense verbs. In Cycles II and III, the findings show an increased use of mixed verbs, as well as increased use of imperative question forms in complex instructions requiring the interpretation of multiple actions and steps. This reflects increasing verb form sophistication, where language is used to organize context and steps, particularly in multi-step tasks. This aligns with Bailey and Heritage's (2014) dimension of verb form sophistication, where language involves more varied and flexible use of grammatical structures to express relationships and processes.

Taken together, these shifts reflect increasing complexity in how relationships are encoded within the language of the problem, where understanding depends less on individually marked cues and more on interpreting how linguistic features interact within sentences and across the task. This pattern aligns with Bailey and Heritage's (2014) view that language develops through increasing complexity in the use and interaction of linguistic resources, and is consistent with Daroczy et al. (2015), which shows that such linguistic complexity increases the interpretive demands of word problems.

Progression in Mode of Representation Dimension

The progression in the mode of representation dimension is characterized by a shift from single-mode (text only) to increasingly multimodal task design across cycles. In Cycle I, word problems are predominantly text-only, with low representation density and all information presented within a single mode. In Cycle II, additional representations such as diagrams and tables are introduced, resulting in tasks that combine text with one additional mode. In Cycle III, tasks more consistently integrate multiple representations, including geometric figures, tables, and graphical forms, leading to higher representation density and more complex representational configurations.

This progression reflects increasing complexity not only in the number of representations used, but also in how they are combined within the task. As representations become more integrated, learners are required to interpret and relate information across modes, rather than rely on a single source. This aligns with the multisemiotic nature of mathematical discourse (Schleppegrell, 2007; O'Halloran, 2005; Duval, 2006), and highlights a shift toward tasks that require coordination between textual and visual representations.

Progression in the Language of the Textbook

Taken together, these pattens indicate that the linguistic characteristics of word problems reflect a structured progression across school cycles, characterized by increasing abstraction, sentence structure sophistication, vocabulary sophistication, expansion of linguistic repertoires, coherence and cohesion, and multimodal representation. These patterns closely align with the dimensions of language progression identified by Bailey and Heritage (2014).

This indicates that progression in mathematics textbooks involves a systematic increase in the demands of the mathematics register, requiring learners to engage with more complex and specialized forms of mathematical language. This is in addition to interpreting increasingly abstract contexts, processing more complex sentence structures, and engaging with dense and multimodal representations. In this sense, word problems function as a key site where linguistic and mathematical development intersect.

Importantly, this extends the literature by showing how language progression is not only a feature of student development, but also embedded within the structure of curriculum materials. In this sense, the word problem genre evolves across grade levels in ways that reflect increasing disciplinary and communicative demands, highlighting the central role of language in shaping access to mathematical meaning.

Limitations of the Study

This study provides a systematic analysis on the linguistic characteristics of word problems in the Lebanese national mathematics textbook and its increasing complexity. However, this study is subject to several limitations that should be acknowledged. First, the study focuses exclusively on textbook content and doesn't examine how students interpret or engage with word problems in classroom context. Since the aim of this study is to identify the linguistic features of word problems in the textbook and how they progress across grade levels, the findings provide insight into the language demands that the students are exposed to, rather than how these demands are developed by learners. As such, future research could extend this work by examining how students engage with linguistic features in practice.

Second, the qualitative analysis was conducted on 10% sample of word problems from Grades 3, 6, and 9. Although the sampling was random and captures a grade level in each cycle, it may not capture the full range of linguistic variations present in all word problems within the textbooks.

In addition to that, another limitation is that the sample size in Grade 9 was lower than other grade levels since the 10% sample resulted with only seven word problems. This small sample size may have limited the extent to which the full range of linguistic features is represented. As such, there might be other demanding features that weren’t captured or highlighted in this study.

Moreover, this study focuses in the linguistic analysis and linguistic progression on Grades 3, 6, and 9 as these grade levels represent the end of every cycle. While this approach allows for a comparison across cycles, it may not capture the full range of linguistic features present within each cycle. Other grade levels may include additional or transitional linguistic patterns that are not reflected in the selected sample. Particularly, in the grade levels where the frequency of word problems is high, like Grade 4, there could be a broader range of linguistic features present. As a result, the findings provide a cycle level perspective on progression but may not fully represent the variation within a cycle.

Finally, this study examines a single textbook series within the Lebanese curriculum. While the *Building Up Mathematics* series is the national textbook used, the findings may not be generalizable to other curricula or educational contexts. However, the study could be replicable on other textbooks.

Implications of the Study

The findings of this study have important implications for curriculum design, textbook development, and classroom practice in mathematics education, particularly in contexts where mathematics is taught through a second language.

Implications for Curriculum Design

The findings indicate uneven distribution of word problems across grade levels and mathematics strands. A higher concentration of word problems was captured in Cycle II and a decline in word problems count but more varied across mathematical strands in Cycle III. While word problems appear prominently in earlier cycles, later grades may increasingly emphasize other mathematical genres, such as geometric constructions, proofs, procedural tasks, etc., reflecting changes in the linguistic and disciplinary demands of the curriculum. Understanding these shifts can support curriculum designers in examining how different mathematical genres are introduced and developed across grade levels and how the linguistic demands associated with these genres evolve throughout the curriculum.

In addition to that, the findings show that linguistic complexity increases across cycles. This suggests that curriculum design should not only consider the sequencing of mathematical concepts, but also the progression of the language demands embedded within the tasks. Scaffolding this progression could support more coherent alignment between mathematical content, and linguistic expectations and demands. This may also support curriculum developers in designing curriculum objectives that explicitly integrate the progression of mathematical language and genre features alongside mathematical concepts and skills across school cycles.

Moreover, the findings of this study may support the design of instructional material and online learning modules based on word problem genre and language progression. Such resources could help students progressively develop the linguistic and discourse skills needed to engage with word problems across different school cycles.

Implication for Textbook Development

This study shows that word problems maintain stable genre features such as the function and structure, their linguistic and representational complexity increases across grades. This has important implications for textbook development, as the findings reveal a systematic progression in the language demands of word problems across the Lebanese mathematics textbook series.

The progression observed in sentence structure sophistication, vocabulary sophistication, coherence and cohesion, and multimodal representation suggests that linguistic complexity is introduced gradually across school cycles in ways that align with increasing mathematical demands. These findings may support textbook developers in further examining how language progression can be made more visible and explicitly connected to students' engagement with mathematical discourse. For example, textbooks may incorporate activities that help students recognize the features of word problems, interpret information, unpack mathematical relationships, and mathematize contextual situations. Guided prompts and structured support within word problems may also help students engage more effectively with increasingly sophisticated mathematical language.

In addition, the increasing abstraction of context and linguistic density observed in later grades highlights how textbooks progressively prepare students to engage with more advanced forms of mathematical discourse. Understanding these patterns of progression may support future textbook design efforts aimed at maintaining coherent and developmentally appropriate transitions in language complexity across grade levels.

Implications for Teaching and Classroom Practice

The findings highlight that word problems are not only mathematical tasks, but also linguistic and semiotic constructs. This suggests that teaching practices should explicitly address the language of mathematics, rather than assuming that students will implicitly acquire it.

From a pedagogical perspective, teachers may need to support students in interpreting the linguistic features of word problems including complex sentence structures, specialized vocabulary, logical relationships between ideas, and integration of visual and textual information. This is particularly important in contexts where students learn mathematics through a second language. The increasing linguistic and multimodal demands identified in this study suggest that students may face challenges that are not purely mathematical but also linguistic.

As such, integrating language focused strategies such as unpacking word problems, highlighting key linguistic structures and features, and supporting interpretations of diagrams, can help the students access the mathematical meaning embedded within the tasks.

There could also be a need for cross-curricular alignment between Mathematics and English curricula, particularly in supporting the explicit teaching of the linguistic features required for interpreting word problems. At specific grade levels, this may include structures such as conditionals, logical connectors, comparatives, and quantifiers. Such alignment can support students in developing the language resources necessary to access mathematical meaning, rather than encountering these features implicitly within tasks.

Implications for Language and Mathematics Integration

The findings reinforce the importance of viewing mathematics as a language-based discipline. The progression observed across school cycles aligns with the development of the mathematics register, where meaning is constructed through specialized vocabulary, grammatical structures, and discourse patterns.

This suggests that language development should be considered an integral part of mathematics learning. Approaches informed by Systemic Functional Linguistics (Halliday, 1978; Halliday & Martin, 1993) and genre pedagogy (Gerofsky 1999; Martin & Rose, 2008) can provide useful frameworks for supporting students in understanding how mathematical meaning is constructed through language in relation to the increasing linguistic complexity identified across school cycles.

In this sense, mathematics instruction can benefit from explicitly addressing how language functions within word problems, helping students move from everyday language toward more specialized forms of mathematical expression.

Implications for Future Research

This study highlights the role of textbooks in shaping the linguistic demands of mathematical tasks. Future research could extend this work by examining how students engage with these linguistic features in classroom contexts, and how teaching practices mediate access to the mathematics register.

In addition, further research could explore linguistic progression across a wider range of grade levels and curricula, as well as the progression within a specific school cycle. Moreover, future research could investigate how different languages of instruction influence the development of mathematical discourse.

Building on these findings, future research could also focus on the design and development of curricula that explicitly integrate linguistic progression alongside mathematical progression. Such studies could examine how linguistic features, such as sentence structure, vocabulary sophistication, coherence and cohesion, and multimodal representation, can be systematically introduced and scaffolded across grade levels. In particular, intervention-based studies could be conducted to implement such linguistically informed curricula in classroom settings and examine their impact on students' understanding of word problems and their ability to engage with mathematical discourse. This would provide empirical evidence on how addressing linguistic complexity in curriculum design can support students' access to mathematical meaning.

Future research could also build on the findings of this study to design assessment tools and language-focused evaluation frameworks based on the linguistic progression of the word problem genre across school cycles. Such tools could be used to assess students' understanding of increasingly sophisticated mathematical language and genre features, as well as to examine students' progress in engaging with mathematical discourse over time. In addition, intervention studies could investigate the effectiveness of these assessment tools and instructional supports in improving students' comprehension of word problems and their participation in mathematical communication.

Future research could also replicate this study across different textbook series and educational contexts to examine whether similar patterns of linguistic progression are observed. Such comparative studies would provide further insight into how curriculum design, language of instruction, and educational contexts influence the development of the word problem genre.

Conclusion

This study examined the word problem genre in the Lebanese national mathematics textbook, focusing on its distribution across grade levels and mathematical strands, as well as the progression of its linguistic characteristics across school cycles. Drawing on a genre-based approach and Systemic Functional Linguistics, the study highlights the central role of language in the construction of mathematical meaning.

The findings show that word problems are unevenly distributed across the curriculum, with greater concentration in the middle grades and variation across mathematical strands. At the same time, while the core function of word problems remains stable as generators of mathematical activity, their linguistic and structural features vary systematically across grades. Most importantly, the study demonstrates that the linguistic characteristics of word problems follow a clear progression across school cycles. This progression is reflected in increasing abstraction of context, greater sentence structure sophistication, more specialized vocabulary, expanded linguistic repertoires, increased coherence and cohesion, and more complex multimodal representations. These patterns indicate that progression in mathematics education is not only conceptual, but also linguistic.

In the Lebanese context, where mathematics is taught through a second language, this progression in linguistic demands is particularly significant. The study therefore highlights the importance of considering language as an integral component of mathematics learning, as well as the role of textbooks in shaping access to mathematical discourse. By foregrounding the role of language in mathematics textbooks, it provides a foundation for supporting students' engagement with increasingly complex forms of mathematical meaning.

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