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Graphing of Functions and Graphical Aspects in Lessons of Secondary School Mathematics Textbooks in Nepal: A Problem Analysis Approach

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Abstract

To assess students' achievement in graphing functions and understanding various mathematical concepts, we analyzed exercises from secondary-level mathematics textbooks (grades 9-12) in Nepal. The focus was on the concept of functions, their graphs, applications, and related problems. Each problem was categorized based on its context, expected response, and cognitive demand using a mixed-methods approach. The findings reveal a significant lack of emphasis on problem types crucial for developing graphing skills and applying functions in problem-solving contexts. Instead, there is an overabundance of certain problem types, underscoring the need for a more balanced distribution of exercises across different learning dimensions. This paper discusses the implications of these findings for curriculum developers and textbook authors.

Keywords: Functions and their Graphs; High School Mathematics; Mathematics in Nepal; Textbook Analysis

Introduction

Nepal's modern education system began in 1951 with the establishment of a state-run system (Wood, 1951), followed by the introduction of curricula in 1971. Despite these efforts, students' academic achievement lags behind global standards due to systemic issues, particularly the shortage of trained teachers. A 2020 report by the National Assessment of Student Achievement (NASA) revealed that many students fail to meet minimum learning objectives, with the national average for mathematics dropping from 500 in 2017 to 483 in 2020 (Ministry of Education, 2022; 2018). In science, the average was 470, 30 points below the national mean (NASA, 2018). Nepal's global ranking in mathematics remains low (Olympiad, 2023).

Research on math education in Nepal has primarily focused on socio-political and infrastructural issues, with limited studies on curricula, teaching, and assessment of specific mathematical topics (Belbase & Panthi, 2017; Koirala, 1991; Jones & Basyal, 2019). Curriculum reform, including textbook revisions, is a recognized strategy for addressing local needs (Gouëdard et al., 2020; Wedell & Grassick, 2017). The Ministry of Education has periodically updated the high school curriculum, introducing functions in grades 9 and 10 in 2001, and a dedicated lesson on graphing functions in grade 11 for the first time in 2011.

Given these changes, this paper analyzes current mathematics textbooks from a graphical perspective, quantifying how well they promote graphing skills and the exploration of graphical aspects in calculus and differential equations.

Rational for the Study

A substantial body of literature (Fuson et al., 1988b; Schmidt et al., 1999; Son, 2012; Son & Senk, 2010; Stigler et al., 1986; Valverde et al., 2002) emphasizes the strong link between curricula, textbooks, and student learning. Textbooks often serve as the most visible form of curriculum in classrooms, significantly influencing what is taught and what students learn (Swafford & Findell, 2001; Valverde et al., 2000). As Swafford and Findell (2001) note, "The choice of textbook often determines what teachers will teach, how they will teach it, and how their students will learn." This dependence on textbooks is not unique to Nepal; globally, teaching practices are heavily textbook-centered. A UNESCO report indicates that teachers in Nepal are "fully dependent" (Wagle et al., 2008, p. 102) on textbooks, with one teacher stating, "We never go out of the textbook" (p. 103), highlighting the textbooks' dominant role in instruction.

Mainali and Heck (2017) found that textbooks are often the sole teaching resource in many Nepali schools. The Nepal School Sector Development Plan (2016-2023) also mentions that many consider textbooks the definitive curriculum, leading to teaching practices that often emphasize memorization (Ministry of Education, 2016). Thus, textbooks are crucial for teaching and learning in Nepal, as teachers use them for lesson preparation, homework, and exams, while students rely on them for definitions, examples, and practice problems.

Research Questions

This paper aims to examine the quantity, formulation, and variation of problems related to functions, their graphs, and applications in secondary school mathematics textbooks in Nepal. It assesses whether these textbooks sufficiently meet learning expectations regarding functions and their graphical representations, including an analysis of their applications in topics like calculus and differential equations.

The study addresses the following research questions:

1. What fraction of problems related to functions, graphs, and graphical aspects is allocated to different learning categories in each textbook?
2. Are the exercises distributed adequately to help students develop cognitive skills related to graphing functions and understanding other graphical aspects of mathematics?
3. Is the distribution of problems balanced enough to meet diverse student learning needs?

Important of Functions and their Graphs

Functions are fundamental concepts in mathematics education (Romberg et al., 2012). Dubinsky and Guershon Harel (1992) assert that functions are crucial for both understanding and application. The introduction of algebraic and graphical representations marks a significant moment in learning, enabling students to use one symbolic system to grasp another (Leinhardt et al., 1990).

The duality between algebraic and graphical representations is vital; they are interconnected rather than isolated, forming a communicative system that conveys mathematical concepts. Students proficient in graphing or solving algebraic problems often struggle to apply their knowledge in scientific contexts (Hitt, 1998; Knuth, 2000; Leinhardt et al., 1990), as mastery in one area does not ensure knowledge transfer to others (Dreyfus & Eisenberg, 1982; Even, 1990; Greeno, 1989). Thus, functions and graphs are critical from both learning and instructional perspectives.

Many college students lack a solid understanding of functions and graphs due to insufficient emphasis on graphical aspects in school, often stemming from ineffective teaching practices (Durant & Garofalo, 1994). Even those who study these topics extensively in high school struggle to develop proper understanding (Markovits et al., 1988; Leinhardt et al., 1990).

Teaching and utilizing graphs should be prioritized in mathematics and science. Shuard and Neill (1977) emphasize that "all pupils can and should have some literacy in graphical work," as the inability to read graphs hampers individuals in society. It is essential to examine whether teachers' practices align with this idea and explore discrepancies that may hinder effective teaching (Booth, 1981). Graphs serve multiple purposes; as noted by Shuard and Neill (1977), children aged 11 and 12 can use graphs to represent information about numbers and quantities. Furthermore, graphs depict functions and relationships, which is especially significant for mathematicians and scientists, as they argue that "Graphical representation is...predictive, making it more than just a descriptive tool."

Analyzing textbooks can yield valuable insights into varying levels of student achievement (Usiskin & Willmore, 2008; Valverde & Schmidt, 2000). This study investigates the nature of exercises in several textbooks to explore factors contributing to student performance.

Research Methods

An analysis of problems from a few lessons of eight mathematics textbooks from grade 9-12 was conducted, and such problems were categorized and coded for the purpose of understanding the nature of these problems in terms of their numbers, formulation, variations from different cognitive demand to measure the overall resourcefulness for developing skills such as graphing of functions and graphical aspects in areas such as algebra, calculus, and differential equations of mathematics textbooks of grade 9-12. The problem analysis framework of the research method is given in Table 1.

Approach	Research question	Area of investigation
Problem analysis	• How many problems are listed in the targeted exercises of each textbook? • What type of problems related to functions and their use are presented in various lessons of each textbook? • What kind of learning objectives are trying to be achieved based on cognitive expectations from the exercises of each textbook? • What type of functions are used to develop graphing and graphical skills?	• Number of problems • Contextual characteristics • Response type • Cognitive expectation • Type of functions

Table 1. Problem Analysis Framework

Textbook Selection

In Nepal, the Curriculum Development Center (CDC) publishes textbooks for grades 1 through 10 and approves those from private publishers but does not publish for grades 11 and 12. Instead, various private entities publish these higher-grade textbooks, which the CDC approves. For this study, we selected two textbooks for each grade from 9 to 12: one textbook from the CDC and another from a private publisher for grades 9 and 10, while both textbooks for grades 11 and 12 are from private publishers. These textbooks were chosen due to their widespread use among schools and teachers in Nepal. Additional details about the selected textbooks are provided in Table 2.

Table 2. Textbook Information

Grade	Name of the Book	Publisher/Code
9	*Optional Mathematics*	Curriculum Development Center (CDC9)
	Maths Links	Readmore (RM9)
10	*Optional Mathematics*	Curriculum Development Center (CDC10)
	Maths Links	Readmore (RM10)
11	*Foundation of Mathematics*	Asmita Publication (AP11)
	Basic Mathematics	M.K. Publishers and Distributors (MK11)
12	*Foundation of Mathematics*	Asmita Publication (AP12)
	Basic Mathematics	M.K. Publishers and Distributors (MK12)

Topic Selection

Several lessons from the textbooks in Table 2 were selected for investigation, focusing on the problems in their exercises. Both quantitative and qualitative analyses were conducted, with results presented in tables to clarify the number and characteristics of the examined problems. Questions related to functions in various representations were counted and categorized, along with problems involving function applications. The study also explored problems on computing limits, assessing continuity or discontinuity of functions, and analyzing their graphical representations. Additionally, it examined problems designed to develop explicit graphing skills for different functions. Finally, the study connects differentiation, integration, and differential equations to their geometric interpretations and the application of function graphs in calculus. Relevant topics for this study are outlined in Table 3.

Table 3. Contents selected from the textbooks (9-12) for the analysis

Grade	Lessons
9	Relation and Function
	Polynomial
	Concept of Limit
10	Functions (Including Trigonometric)
	Polynomial
	Quadratic equations and graph
	Continuity of Function
11	Function
	Curve Sketching
	Limit and Continuity
	Derivatives and its application
	Application of antiderivative
12	Derivatives and its application
	Antiderivatives
	Differential equation

Problem Analysis

Problem analysis criteria are categorized in several ways: (1) mathematical features (e.g., number of steps) (Stigler et al., 1986); (2) contextual features (e.g., purely mathematical vs. illustrative context) (Li, 2000; Son, 2012); (3) response types (e.g., numerical answers vs. explanations) (Son & Senk, 2012); (4) cognitive expectations (e.g., knowledge and skills needed—procedural practice, problem-solving, representation, reasoning) (Son, 2012); and (5) cognitive demand (e.g., levels of difficulty) (Stein & Kim, 2011).

This study focuses on three primary criteria: contextual feature (purely mathematical vs. illustrative context), response type (graphical vs. non-graphical), and cognitive expectation (knowledge and skills required). We analyze mathematical problems related to functions (including polynomials, exponential, logarithmic, rational, and trigonometric functions) from two textbooks for each grade (9-12), evaluating each problem based on these criteria outlined in Table 4. Problems classified as "Graphical" are further categorized by "type of functions," such as linear or quadratic. The results are presented in Table 9, with the complete framework for problem analysis provided in Table 4.

Table 4. Framework used for the textbook problem analysis

Feature	Category/Code
Context	Purely mathematical context in word or equation form (PM)
	Illustrative context in words, graphs, diagrams, or combined (IC)
Response	Graphical (G)
	Nongraphical (NG)
	Procedure practice (PP)
	Problem solving (PS)
Cognitive Ability	Representation (R)
	Mathematical reasoning (MR)

To conduct this problem analysis, we will use a framework similar to that of Son and Hu (2015), categorizing problems based on the criteria in Table 4. Each problem will be analyzed according to two contextual features: mathematical and illustrative, focusing on illustrative problems that require graphing skills. Response types will be classified as graphical (requiring graphing a function) or non-graphical.

For cognitive expectations, problems will be categorized as follows: procedural practice for those requiring a rule or algorithm; problem-solving for those applying mathematical knowledge to real-life situations; representation for problems involving sketching graphs from algebraic information or using graphs to determine function characteristics; and mathematical reasoning for those needing interpretation, estimation, or evaluation. Table 5 includes sample problems categorized according to this framework.

Table 5. Sample problems and their classification from the textbooks

Example	Coding		
	Context	Response Type	Cognitive Expectation
1. Find the domain and range of $y = x^2 + 1$.	PM	NG	PP
2. Draw the graph of the function in question 1.	PM	G	R
3. You hike a 3-mile trail, starting at an elevation of 8000 feet. Along the way, the trail gains elevation at a rate of 650 feet per mile.	IC		
(a) Create a linear equation representing the situation?		(a) NG	(a) PS
(b) Draw the graph of the linear function.		(b) G	(b) R
(c) Does this model seem realistic?		(c) NG	(c) MR
4. Find the zeros of $f(x) = x^2 + 3x - 4$ by using the graph of f.	PM	G	R/PP
5. Find the limit of $\lim_{x\to\infty} \frac{3x^2-4}{4x^2}$. Provide the graphical meaning of the limit.	PM	NG	MR

Problem Analysis Results

In grades 9 and 10, the privately published textbook *Readmore* includes significantly more problems than the government-issued CDC textbook. In grades 11 and 12, the differences are smaller: Asmita Publications (AP12) offers more questions in grade 12 than MK, while MK has more in grade 11. Despite these variations, both textbooks maintain consistency in contextual features, response types, and cognitive demands. A total of 3,342 problems were analyzed.

Contextual Feature

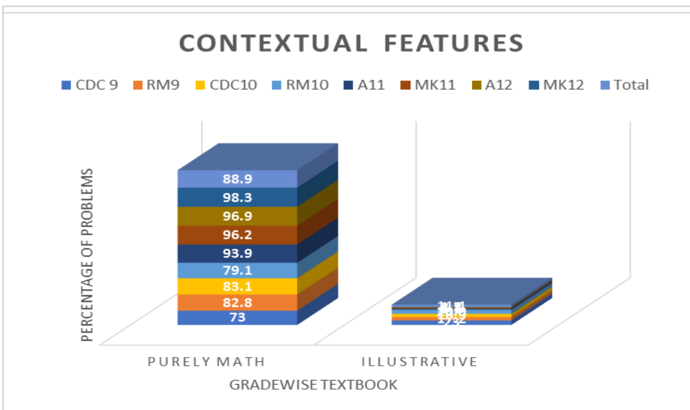
The problem analysis results are summarized in Table 6. The *Readmore* 9th-grade textbook includes 314 problems, with 17% having an illustrative context, while the CDC textbook contains 163 problems, with a higher percentage of illustrative problems (23%). In grade 10, *Readmore* features 622 problems compared to CDC's 203, with 21% of *Readmore*'s problems and 15% of CDC's being illustrative. In grade 11, Asmita's textbook (AP11) contains 804 problems versus MK11's 715, but both have very few illustrative problems (1.5% and 4%, respectively). Similarly, in grade 12, only about 2% of problems are illustrative. Overall, of the eight textbooks analyzed for grades 9-12 (n=3,324), around 9% are classified as illustrative, revealing a significant lack of emphasis on such problems, which are essential for developing skills in graphing functions and other graphical aspects of mathematics.

Textbook	Purely Math Context	Illustrative context	Total
CDC9	119 (73%)	44 (23%)	163
RM9	261 (83.1%)	53 (16.9%)	314
CDC10	168 (82.8%)	35 (17.2%)	203
RM10	492 (79.1%)	130 (20.9%)	622
AP11	795 (98.8%)	9 (1.2%)	804
MK11	688 (96.2%)	27 (3.8%)	715
AP12	327 (97.6%)	8 (2.4%)	335
MK12	183 (98.3%)	3 (1.7%)	186
Total	3033 (90.75)	309 (9.25%)	3342

Table 6: Distribution of Problems based on contextual feature

Graph below represents the data of table 6.

Figure 1.

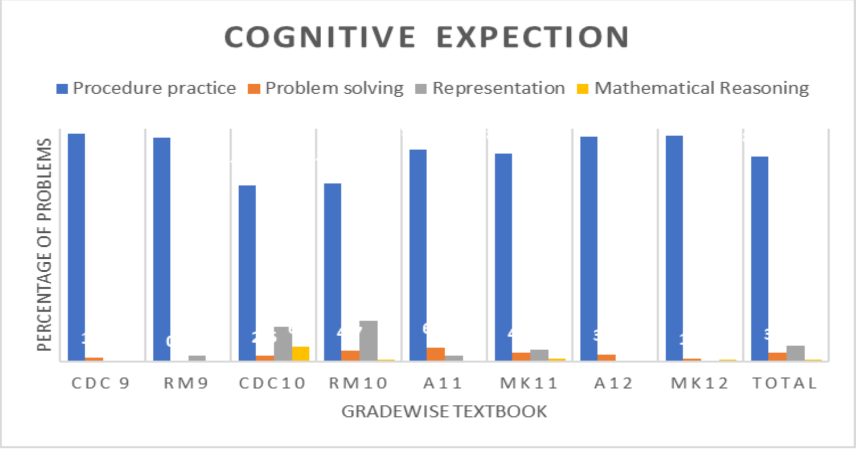


Cognitive Expectation

Students use various approaches when solving mathematical problems, with cognitive demand being a key measure of cognitive expectation—what is required during problem-solving (Son & Senk, 2010). Table 7 presents the problem analysis results by cognitive expectation, revealing that only 6.7% of the total problems (n=3,342) fall into the representation category, which aims to enhance skills in algebraic, graphical, and numerical representations. Additionally, only 32 problems (1.1%) were classified as Mathematical Reasoning, and 3.8% as Problem Solving. In contrast, the majority (88.4%) were categorized as Procedure Practice, indicating a reliance on procedural tasks. While both textbooks show similar distributions, the CDC-issued textbook for grade 10 has a higher percentage (6.4%) of problems classified as Mathematical Reasoning compared to just 1% in the Readmore textbook (RM10), highlighting a significant imbalance in addressing different cognitive expectations.

Table 7. Distribution of the problems based on cognitive expectation
Bar graph below represents the data of table 7.
Figure 2.

Grade	Procedure practice	Problem solving	Representation	Mathematical Reasoning	Total
CDC9	160 (98.2%)	3 (1.8%)	0 (0%)	0 (0%)	163
RM9	308 (96.2%)	2 ((0.6%)	10 (2.6%)	2 (0.6%)	322
CDC10	154 (75.9%)	5 (2.5%)	31 (15.3%)	13 (6.4%)	203
RM10	491 (76.8%)	30 (4.7%)	112 (17.5%)	6 (1%)	639
AP11	756 (94%)	34 (4.2%)	14 (1.8%)	0 (0%)	804
MK11	640 (89.5%)	29 (4.1%)	37 (5.2%)	9 (1.3%)	715
AP12	327 (97.6%)	8 (2.4%)	0 (0%)	0 (0%)	335
MK12	181 (97.3%)	3 (1.6%)	0 (0%)	2 (1.1%)	186
Total	3017(88.4%)	114(3.8%)	204 (6.7%)	32 (1.1%)	3367



Response Type
The problem analysis results regarding response types are summarized in Table 8. Approximately 95% of the problems do not require graphing skills, with only about 5% prompting students to draw graphs or apply their graphing knowledge. In grades 10 and 11, both grade 10 textbooks include around 15% of problems related to graphing functions, but this drops to 2% in the Asmita textbook (AP11, n=804) and 5% in the MK textbook (MK11, n=715) for grade 11. Notably, grade 12 textbooks contain no problems requiring graphical responses, despite the importance of graphical understanding in calculus and differential equations. Overall, the number of problems that develop essential graphing skills is significantly lower than those that do not, contrasting with the recognized need for understanding various function

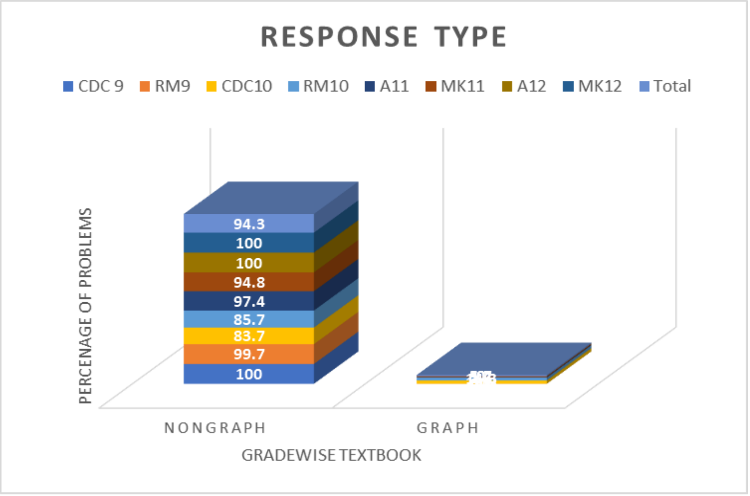
representations to enhance problem-solving abilities (Even, 1990; Hartter, 2009).

Table 8. Distribution of response type of the problems

Book	Graph	Nongraphical	Total
CDC9	0 (0%)	163 (100%)	163
RM9	1(~0%)	313 (100%)	314
CDC10	31 (15.3%)	172 (84.7%)	203
RM10	100 (16%)	522 (84%)	622
AP11	14 (1.74%)	790 (98.26%)	804
MK11	37 (5.2%)	678 (94.8%)	715
AP12	0 (0%)	335 (100%)	335
MK12	0 (0%)	186 (100%)	186
Total	185 (5.5%)	3157 (94.5%)	3342

The graph below represents the data of the table 8.

Figure 3.



Type of Functions

The concept of functions and their graphs is fundamental to secondary school mathematics (M. K.J, 1922), necessitating a balanced distribution of problems across various learning dimensions. However, the problem analysis in Table 9 raises concerns about the types and quantities of functions included in exercises for developing graphing skills. In Nepal, graphing functions is introduced in grade 10, focusing on linear, quadratic, cubic, and basic trigonometric functions, but transformations are not covered. In grade 11, students learn to graph exponential, logarithmic, and rational functions alongside those from grade 10.

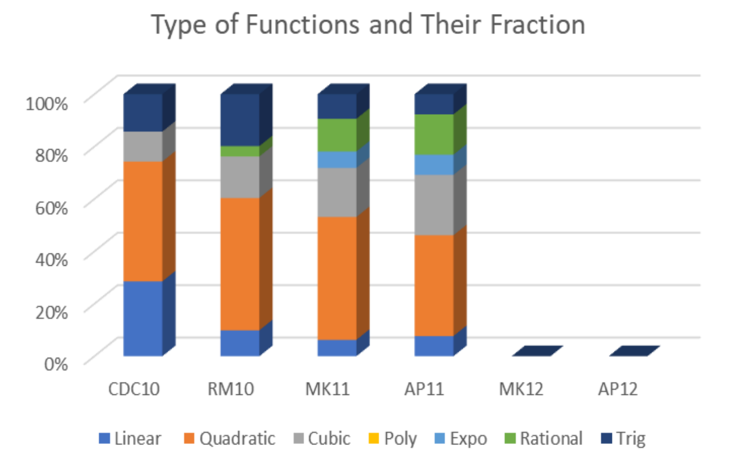
Despite this, only 185 out of 3,342 analyzed questions (5.5%) pertain to graphing functions, primarily involving linear, quadratic, and cubic functions, with about 9% covering exponential, logarithmic, and rational functions. Alarmingly, the grade 12 textbook lacks problems that require students to use function graphs, limiting their understanding of the connection between graphing and problem-solving.

Book	Linear	Quadratic	Cubic	Poly (n>3)	Exponential	Logarithm	Rational	Trig
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CDC10	10	16	4	0	N/A	N/A	N/A	5
RM10	8+2*	51	16	0	0		4**	20
MK11	2	15	6	0	3	2	4	3
AP11	1	5	3	0	1	1	2	1
MK12	0	0	0	0	0	0	0	0
AP12	0	0	0	0	0	0	0	0
Total	23	87	29	0	4	3	10	29
Percent	12.4%	`47%	15.7%	0	2.2%	1.6%	5.4%	15.7%

Table 9. Type and number of functions requiring graphical response.

N/A. The syllabus does not include the graphing of the function as part of the learning objective.
* Graphing of piecewise function which is not part of the learning outcomes stated in the syllabus.
** Graphing of rational function which is not part of the learning outcomes stated in the syllabus.
Poly: Polynomial
Trig: Trigonometric

Below is the bar graph which represents the data of the table 9.
Figure 4.



Summary and Discussion

This study examines how secondary school mathematics textbooks in Nepal address functions and their graphs through a problem analysis of context, response type, and cognitive demand across two textbooks per grade from 9 to 12. A major finding is the imbalanced distribution of problems across learning dimensions. While functions are crucial in mathematics and require cognitive engagement, literature shows students often hesitate to utilize different representations (Dyke & White, 2004) and struggle to connect algebraic and graphical forms (Knuth, 2000). Our analysis reveals a significant discrepancy in problem allocation essential for understanding functions and their graphs, with an emphasis on purely mathematical contexts, non-graphical responses, and procedural practices. Many problems involve finding the domain and range or computing limits and derivatives, lacking graphical interpretations and connections to mathematical reasoning.

Despite research indicating that students struggle to understand various symbolic representations of functions (Hitt, 1998), the limited representation in textbooks hampers comprehension. Another key finding is the narrow variety of function types for graphing in exercises. Although algebraic, trigonometric, rational, exponential, and logarithmic functions are included in the curriculum, significantly fewer problems focus on graphing these functions. Most graphing-related problems are limited to linear and quadratic functions, lacking prompts for transformational skills to connect functions with their graphs.

Additionally, this study uncovers a disconnection between the curriculum's learning goals and the structure of exercises in the selected textbooks. The absence of clear guidelines for textbook authors leads to inconsistent interpretations across grade levels. For example, the grade 11 curriculum mandates that students learn to graph various functions but does not specify the need to include transformations. While textbooks should provide graph interpretations for simple cases, they often lack clarity on what constitutes "simple." This disconnect is evident in calculus topics for grades 11 and 12 and in chapters on differential equations and hyperbolic functions, where graphical aspects are frequently absent from problem formulations.

Implication

The limited number of textbooks analyzed in this study may limit the generalizability of its findings. However, it provides important insights for curriculum developers, teachers, and textbook authors in Nepal. A gap was found between the intended curricula and how textbook authors interpreted them. This suggests that curriculum developers should revisit learning objectives and offer clearer guidelines. Textbook authors should include a wider variety of problems, featuring diverse contexts, response types, and cognitive demands. More emphasis should be placed on problems that encourage graphical knowledge, problem-solving, and mathematical reasoning to promote creative rather than imitative reasoning (Lithner, 2007).

This study's implications align with those of Son and Hu (2015) and are important for future research. Comparative studies of functions in secondary school mathematics textbooks across different countries could reveal alternative instructional designs (Ferrini & Graham, 1994). Four essential characteristics of effective textbooks include: (a) systematic opportunities to learn concepts and procedures; (b) illustrative examples of various computational strategies; (c) engagement with diverse problem types; and (d) problems requiring a range of cognitive demands, such as procedural practice and mathematical reasoning.

The Curriculum Development Center should address the current treatment of functions and their graphs in Nepal's textbooks. Ambiguous curriculum guidelines have led to the neglect of important aspects of learning functions and their graphical representations (Ministry of Education, 2009, 2012, 2014).

In conclusion, Nepalese secondary school mathematics textbooks disproportionately focus on procedural practice, neglecting graphical problems, which leads to an incomplete understanding of functions. Collaboration between curriculum developers, policymakers, teachers, and textbook authors is key to achieving more balanced and globally competitive learning outcomes.

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Declaration of Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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