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STEM activities in secondary education textbooks in Chile: Skills and levels of integration

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ABSTRACT

This study aims to analyze the levels of integration and the scientific, mathematical, and technological skills present in the science, technology, engineering, and mathematics (STEM) activities included in secondary education textbooks in Chile. The research addresses theoretical elements such as the conceptualization of STEM education, its integration in the curriculum, and STEM-related skills. A qualitative methodology is employed, based on content analysis, to examine the activities proposed in school textbooks. The results reveal that transdisciplinary integration predominates in STEM activities. Regarding STEM skills, communication-oriented activities are most prevalent in mathematics, while analysis skills are more common in science, and teamwork is emphasized in technology. These findings highlight the importance of promoting a STEM approach that integrates key skills for effective learning.

Keywords: textbooks, STEM education, STEM skills, mathematics skills, science skills, technology skills

INTRODUCTION

In recent years, education has undergone a significant transformation driven by the need to prepare students to face the challenges of the 21st century (Goos et al., 2023). In an increasingly interconnected and technology-driven world, educational systems are challenged to go beyond the transmission of specific knowledge and instead foster the development of competencies that enable students to adapt to a constantly evolving environment (Siregar et al., 2020). This shift involves not only acquiring academic knowledge but also strengthening key skills that facilitate complex problem-solving, informed decision-making, and collaborative work in multidisciplinary settings (DeCoito et al., 2024). Consequently, the education system must offer learning experiences that integrate various disciplines and approaches, equipping students with the ability to address global challenges in innovative ways (Halawa et al., 2024; Paul & Elser, 2006).

Within this context, science, technology, engineering, and mathematics (STEM) activities have gained prominence as a pedagogical approach that promotes the integration of these disciplines while fostering essential skills such as critical thinking, creativity, collaboration, and problem-solving (DeCoito et al., 2024; Paul & Elser, 2006; Saavedra & Opfer, 2012; Schwab, 2017). These activities not only facilitate knowledge acquisition in fundamental areas but also prepare students for 21st century challenges by bridging theory with practice, incorporating scientific, technological, and mathematical concepts into real and multidimensional contexts (Kelley & Knowles, 2016; Lee et al., 2023). Thus, STEM methodologies are positioned as a fundamental tool for promoting interdisciplinary learning and equipping students with transversal competencies that will benefit them throughout their academic and professional careers (Toma & García-Carmona, 2021).

In the educational landscape, textbooks play a crucial role as one of the most widely used pedagogical resources in classrooms by both students and in-service teachers (Díaz-Levicoy et al., 2017). In this regard, the inclusion of STEM activities in secondary education textbooks serves as a key mechanism for integrating content and fostering skill development in students (Wang et al., 2023). Furthermore, textbooks provide an essential resource for incorporating STEM activities, as they facilitate the acquisition of scientific, technological, and mathematical skills within the school learning process (Ferrada et al., 2021). Similarly, Aguirre-Navarrete et al. (2024) emphasize that STEM activities included in textbooks should be designed with an interdisciplinary approach, ensuring that the skills and objectives of each discipline extend beyond isolated content areas, ultimately enhancing students' learning outcomes.

Given these considerations, this study aims to analyze the levels of integration and the scientific, mathematical, and technological skills embedded in the STEM activities proposed in secondary education textbooks. While the development of the STEM approach has gained prominence in primary education (Peters-Burton et al., 2022), in the Chilean context, significant attention has been given to secondary education, particularly in the final two years of schooling (Ministerio de Educación [MINEDUC], 2019).

Background

The STEM approach has gained prominence in contemporary education by fostering the development of key competencies in students, such as critical thinking, problem-solving, and creativity (Lee et al., 2023). Various studies have explored STEM activities in textbooks. For instance, Aguirre-Navarrete et al. (2024) analyzed STEM activities in mathematics textbooks for the first and second years of secondary education in Chile. Their findings revealed a predominance of activities related to the numbers strand and a greater representation of the science discipline. Additionally, they identified the contextualized use of images and the promotion of skills such as processing evidence, creating, optimizing resources, and communicating. However, the authors concluded that increasing the number of STEM activities and achieving a better balance between disciplines is necessary to enhance learning experiences.

A study conducted by Ferrada et al. (2021) examined activities in primary education science textbooks from Spain and Chile. Their analysis, based on an integrated curriculum model and an Environmental Education approach, highlighted the importance of connecting various disciplines and linking activities to students' prior knowledge. Similarly, Ferrada et al. (2018) analyzed final unit activities in science textbooks from both Chile and Spain, evaluating their alignment with the STEM approach. They found a low presence of end-of-unit activities that involved knowledge integration and the application of advanced skills, indicating an opportunity to improve the quality and diversity of these tasks.

In a different context, Wang et al. (2023) analyzed how STEM education is presented in Chinese science textbooks. Their findings showed that physics textbooks are closely related to mathematics, while chemistry textbooks are strongly linked to engineering. The STEM integration in these textbooks is primarily structured as a combination involving two subjects, which appears frequently in the text.

Moreover, Janius et al. (2024) explored the effectiveness of implementing STEM programs in early childhood education. They concluded that these programs significantly enhance children's cognitive, problem-solving, and creative skills. The authors emphasized the importance of integrating STEM activities from the early stages of education to establish strong foundations that prepare students for technical and vocational pathways aligned with the demands of the 21st century.

These studies underscore the need to improve and diversify STEM activities in textbooks across different educational levels. In the Chilean context, while progress has been made in primary education, analyzing materials in secondary education is crucial, particularly given their potential to develop scientific, mathematical, and technological skills in students who face increasingly complex challenges in today's society.

THEORETICAL FOUNDATIONS

Conceptualization of STEM

The term STEM has gained significant global relevance and has become a focal point of interest worldwide due to its influence on the transformation of educational curricula (Toma & Retana-Alvarado, 2021). This has led to a significant increase in the attention dedicated to STEM education in international research and innovations (Grimalt-Álvaro & Couso, 2022). Consequently, in recent years, the term STEM has encompassed most didactic research related to science education (Toma & García-Carmona, 2021). Despite its growing popularity, STEM is often perceived as a buzzword lacking a clear conceptualization (Toma & García-Carmona, 2021). In this regard, according to Sanders (2009), integrated STEM education is based on the teaching-learning relationship between two or more STEM areas and/or between a STEM subject and one or more other academic subjects. In this way, integrated STEM education enables students to learn in an interdisciplinary manner. In this approach, students apply concepts from mathematics, science, and other disciplines while actively participating, which contributes to a more rigorous learning process (Johnson et al., 2015).

Complementary to this, a STEM integration framework has emerged, composed of six fundamental principles (Halawa et al., 2024; Margot & Kettler, 2019). These include mathematics and science as core subjects; a student-centered pedagogy; classes developed in a motivating environment; the use of engineering for design and problem-solving; error as a factor that promotes learning; and a teamwork-oriented environment (Moore et al., 2014).

Furthermore, incorporating STEM into the primary and secondary education curriculum is essential to promote literacy in STEM among future workers and to achieve equal opportunities for girls and boys (Margot & Kettler, 2019). Likewise, STEM education at the university level plays a crucial role in providing students with the necessary knowledge to address 21st century challenges and navigate society effectively (Lee et al., 2023).

Integration in STEM Education

Curricular integration is a central aspect of STEM education, as it is essential to make the connection between disciplines and between the context and disciplines sufficiently explicit (Roehrig et al., 2021). This is crucial for students to integrate concepts or content from different disciplines around a real-world problem (Le et al., 2023). Following these precedents, the curricular integration model proposed by Le et al. (2023) can help characterize different degrees or levels of curricular integration in STEM

Table 1. Levels of integration taken from Gresnigt et al. (2014, p. 52)

Level	Description
Connected	Concepts or knowledge from one discipline are developed in another.
Nested	Concepts or knowledge from one subject are developed in another.
Multidisciplinary	Two concepts or thematic areas are part of the same activity or problem, but each subject retains its identity.
Interdisciplinary	There is no reference to individual disciplines, leading to a lack of emphasis on specific disciplines. Concepts or knowledge are highlighted through their integration.
Transdisciplinary	There is no reference to individual disciplines; instead, the focus is on real-world problems.

Table 2. Textbooks considered in the analysis

Code	Authors (Year)	Title	Publisher
T1	Fresno et al. (2020)	Matemática 1° medio. Texto del estudiante	Santillana
T2	Díaz et al. (2020)	Matemática 2° medio. Texto del estudiante	SM
T3	Osorio et al. (2019)	Matemática 3° y 4° medio. Texto del estudiante	SM

education. These levels include fragmented, connected, nested, multidisciplinary, interdisciplinary, and transdisciplinary, which are defined in **Table 1**. This study does not address the fragmented level, which refers to considering subjects or disciplines separately and distinctly (Gresnigt et al., 2014). Instead, it focuses on identifying activities that incorporate disciplinary integration.

STEM Skills

STEM skills encompass a set of abilities related to STEM. The integration of these skills fosters more active learning and enhances the understanding of scientific content (Pantoja et al., 2020). Additionally, STEM education can enrich students' learning experiences, preparing them to succeed in an ever-changing world, offering opportunities to explore various fields and disciplines, and equipping them with the skills they need for the future (Aravena-Díaz et al., 2020). These interconnected skills complement one another, providing a solid foundation for addressing complex problems, developing innovative solutions, and contributing to societal progress in various fields.

Mathematical skills

Regarding mathematical skills, it is essential to focus on what is known as mathematical literacy. According to the Organization for Economic Co-operation and Development ([OECD], 2017), mathematical literacy refers to the ability to analyze, reason, model, argue, and communicate effectively when formulating and solving mathematical problems in different contexts and situations (OECD, 2017). Similarly, MINEDUC (2015) identifies problem-solving, representation, modeling, argumentation, and communication as fundamental mathematical skills, emphasizing that these interconnected abilities play a crucial role in acquiring new concepts and applying them in various contexts.

Scientific skills

Scientific literacy, according to Garzón and Martínez (2017), serves as a mechanism for scientific, technological, economic, civic, and cultural development in nations. In the Chilean curriculum, students are encouraged to understand that science is not only a means to comprehend natural phenomena but also a tool for proposing and finding solutions to everyday problems (MINEDUC, 2015). This approach promotes critical, autonomous, and scientific reasoning regarding topics such as the functioning of instruments developed from scientific discoveries, reproduction and nutrition of living beings, and material changes resulting from various forces (MINEDUC, 2015). Thus, in the Chilean national curriculum, scientific skills are structured into five stages: observing and posing questions, planning and conducting research, processing and analyzing evidence, evaluating, and communicating. It is important to highlight that a scientifically literate person is willing to engage in reasoned discussions about science and technology (OECD, 2017).

Technological skills

Technological skills are integrated into STEM education and closely linked to scientific and mathematical literacy. According to MINEDUC (2015), technology education aims to develop fundamental skills and competencies in students, such as information search and analysis, adaptability and flexibility, creativity, entrepreneurship, material handling, energy resources, tools, techniques, and technologies, teamwork, communication, and critical and responsible reflection. These skills enable students to understand and use objects, processes, and systems critically and responsibly within the framework of contemporary society's technological activities.

METHODOLOGY

To achieve the research objective, a qualitative methodology was adopted with a focus on content analysis (Bernete, 2014). The selected sample is purposive and consists of a complete series of mathematics textbooks used in secondary education in Chile (1st to 4th year). These textbooks are distributed free of charge by MINEDUC (2015) to public and publicly subsidized private schools across the country, ensuring wide national coverage. **Table 2** presents the main data of the textbooks considered in the analysis, including a code for their identification in this study.

In each textbook, STEM activities were identified based on the following units of analysis:

Table 3. Excerpt from the data collection tables

Text	Page	Activity	Thematic strand	Level of integration	Mathematical skills	Scientific skills	Technological skills

1. Thematic strands. Corresponding to those described in the national secondary education curriculum for mathematics (MINEDUC, 2015):
   a. numbers,
   b. algebra and functions,
   c. geometry, and
   d. statistics and probability.
2. Levels of integration. Based on the classification by Gresnigt et al. (2014):
   a. nested,
   b. connected,
   c. interdisciplinary,
   d. multidisciplinary, and
   e. transdisciplinary.
3. Mathematical skills. According to the Chilean secondary education mathematics curriculum (MINEDUC, 2015):
   a. argumentation,
   b. communication,
   c. modeling,
   d. representation, and
   e. problem-solving.
4. Scientific skills. Based on MINEDUC (2015), these include:
   a. analyzing,
   b. arguing,
   c. comparing,
   d. communicating,
   e. concluding,
   f. developing and using models,
   g. evaluating,
   h. formulating hypotheses,
   i. formulating problems, and
   j. identifying variables, among others.
5. Technological skills. According to MINEDUC (2015), these include:
   a. handling materials, energy resources, tools, techniques, and technologies,
   b. communication,
   c. creativity,
   d. information search and analysis,
   e. entrepreneurship,
   f. adaptability and flexibility,
   g. critical and responsible reflection, and
   h. Teamwork

To conduct the analysis, an instrument was designed incorporating the units of analysis described above (**Table 3**). This instrument systematically classified the STEM activities identified in the textbooks. The identification was carried out through a systematic procedure involving the review of all activities proposed in the textbooks. Specifically, an activity was classified as STEM if it integrated at least two STEM disciplines and explicitly promoted skills defined in the Chilean national curriculum.

To ensure the reliability of the data collected, four members of the research team independently coded the textbook activities using the developed instrument. A minimum agreement threshold of 75% was established to validate the categorization of each activity.

Finally, illustrative examples were selected to demonstrate the different levels of integration and the skills addressed. These examples are presented and analyzed in the results section. With regard to engineering skills, this study did not analyze them, as they are not included in the national secondary education curriculum in Chile.

Table 4. Frequency and percentage of STEM Activities by thematic strand

Thematic strand	1°		2°		3°		4°		Total	
	F	%	F	%	F	%	F	%	F	%
Algebra and functions	5	16.7	23	44.2	13	37.1	5	15.2	46	30.7
Statistics and probability	12	40.0	11	21.2	5	14.3	5	15.2	33	22.0
Geometry	7	23.3	8	15.4	6	17.1	2	6.1	23	15.3
Numbers	6	20.0	10	19.2	11	31.4	21	63.6	48	32.0
Total	30	100	52	100	35	100	33	100	150	100

4. Visual arts regarding the concept of vanishing point, which you studied at the beginning of the unit, answer the following:
a. **Explain** in your own words what you understand by "vanishing point." If you find it difficult, ask your visual arts teacher for help.
b. **Construct** a three-dimensional image of a cube in your notebook, starting from a square with 5 cm sides. Can you identify any vanishing points associated with the square? Compare your findings with your classmates.
c. **Investigate** the use of the vanishing point in fields such as photography, painting, and architecture.

Figure 1. Example of connected integration activity (extracted from first-year atudent textbook [Fresno et al., 2020, p. 112])

Biology
3. The relationship between the body surface area (a) of a person in m^2, their mass (m) in kg, and their height (h) in cm is given by the following equation: $log(a) = -2.144 + 0.425log(m) + 0.725log(h)$.
a. What is the approximate body surface area of a person if their mass is 70 kg and their height is 1.75 m?
b. Determine the approximate height of a person if their body surface area is 2 m^2 and their mass is 80 kg.
c. Using logarithmic properties, find an equivalent expression to the given formula. Verify it using the previous results.

Figure 2. Example of nested integration activity (extracted from second-year student textbook [Díaz et al., 2020, p. 35])

Physics
5. Analyze the following information, then complete the activities. Tachyons are theorized to be subatomic particles that could hypothetically move at speeds greater than the speed of light, denoted by the letter c, which in a vacuum corresponds to approximately 300.000 kilometers per second. These particles, still undiscovered, arise as a consequence of the development of Albert Einstein's special theory of relativity. The formula for calculating relativistic kinetic energy is: $E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$, where m is the mass and v the velocity, in which we observe that the expression $\sqrt{1-\frac{v^2}{c^2}}$ under certain conditions, can become an imaginary number. However, for a physical quantity to be measurable, it must be a real number. However, for a physical quantity to be measurable, it must be a real number. One property of a particle with these characteristics is that if its velocity exceeds the speed of light, it will result in an imaginary mass, which would not be directly measurable. Thus, the energy of a tachyon would decrease as its velocity increases, becoming more stable at higher speeds, without having an upper limit. Due to these physical properties, scientists have attempted to find them experimentally, but so far without success.
a. What is the energy value for $v = 0, 200{,}000\ km/s$, and 1.5c?
b. Research what the Cherenkov effect is and explain it briefly.

Figure 3. Example of multidisciplinary integration activity (extracted from third-year student textbook [Osorio et al., 2019, p. 99])

RESULTS ANALYSIS

We present the results of the analysis of 749 activities from four educational levels, of which 257 (34.3%) correspond to first-year secondary education, 284 (37.9%) to second-year, 107 (14.3%) to third-year, and 101 (13.5%) to fourth-year. We identified 150 STEM activities (20%) out of the total 749. In this analysis, we provide examples, descriptions, and interpretations of the most representative STEM activities based on the following categories: thematic strands, levels of integration, and mathematical, scientific, and technological skills.

Thematic Strands

Table 4 presents the distribution of STEM activities by thematic strand. In general, the most frequent strands are numbers, algebra and functions, and statistics and probability. The strand with the lowest frequency is geometry, accounting for 15.3% of STEM activities. There is a 1.3 percent difference between the algebra and functions and numbers of strands.

Levels of Integration

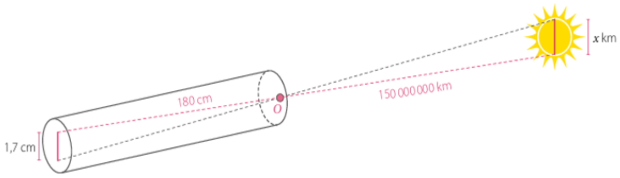
Figure 1 presents an activity where students are asked to explain, construct, and explore the concept of a vanishing point in both mathematical and real-world contexts. This activity is classified as connected integration, as it links mathematics and arts, demonstrating applications in photography, painting, and architecture. The objective is to understand the characteristics of the vanishing point from both mathematical and artistic perspectives. **Figure 2** presents an activity that relates mass (m), height, and body surface area using logarithmic functions. This activity falls under nested integration, as it introduces biological knowledge, such as body surface area, and integrates it into mathematics through logarithmic functions applied to body area calculations.

Figure 3 presents an activity classified as multidisciplinary integration, as it provides information on a specific topic while maintaining distinct disciplinary identities. In this case, tachyons are introduced in physics through the calculation of relativistic kinetic energy, while complex numbers are analyzed in mathematics in relation to this concept.

2. In pairs, complete the following activity. Step 1: Cut a strip of paper or cardboard and insert the ends into a pencil, as shown in the photograph, forming a semicircle. Step 2: Attach each figure to a stick. Step 3: Rotate the stick so that the figures spin around it, as shown in the image, and answer the following questions.	**Materials:** Cardboard, cardstock, paper, stick, and scissors
Questions: a. What 3D shapes did you observe when rotating the stick? Draw them, completing the 2D figure that was used. b. Which of the previous figures corresponds to a sphere? What is the difference between the other 3D shapes?	

Figure 4. Example of interdisciplinary integration activity (extracted from second-year student textbook [Díaz et al., 2020, p. 97])

5. Natural sciences to measure the solar diameter, an instrument can be made using a tube, like the one shown in the image. If the average distance from earth to the sun is 150 million kilometers.



Discuss how you could determine the approximate diameter of the sun using the properties of homothety.

Figure 5. Example of transdisciplinary integration activity (extracted from first-year student textbook [Fresno, 2020, p. 113])

Table 5. Frequency and percentage of STEM activities by level of integration

Level of integration	1°		2°		3°		4°		Total	
	F	%	F	%	F	%	F	%	F	%
Connected	1	3.3	13	25.0	0	0.0	13	39.4	27	18.0
Nested	10	33.3	7	13.5	13	37.1	0	0.0	30	20.0
Multidisciplinary	8	26.7	16	30.8	11	31.4	0	0.0	35	23.3
Interdisciplinary	0	0.0	10	19.2	1	2.9	15	45.5	26	17.3
Transdisciplinary	11	36.7	6	11.5	10	28.6	5	15.2	32	21.3
Total	30	100	52	100	35	100	33	100	150	100

Seismology
4. Apply the model mentioned at the beginning of the unit (page 33) and calculate:
a. The energy released (E) in the Valdivia earthquake (1960) and the 2010 earthquake.
b. The magnitude (M) of the earthquakes in Algarroba and Villena: Algarroba (1985): $3.16 \times 1023\ ergs$ & Vallenar (2013): $9 \times 1022\ ergs$

Figure 6. Example of problem-solving skills (extracted from third-year student textbook [Osorio et al., 2019, p. 50])

Figure 4 illustrates an activity categorized as interdisciplinary integration, as it does not explicitly reference a specific discipline. Instead, students are required to visualize and draw the figure formed by the rotation of a rod, an analysis that can be approached from either mathematics or art. From a mathematical perspective, the activity focuses on solid figures generated by rotation and their connections to real-world objects.

Figure 5 presents an activity classified under transdisciplinary integration, as it involves real-world problem-solving. In this activity, students use various mathematical tools and concepts, including triangle similarity, homothety, calculators, and visualization software, to estimate the approximate diameter of the sun using properties of homothety.

There is no significant variation in the presence of activities categorized under nested, connected, multidisciplinary, interdisciplinary, and transdisciplinary integration (**Table 5**). However, in third- and fourth-year secondary education, activities classified under connected and nested integration, respectively, were absent from the analyzed STEM activities. Notably, transdisciplinary activities were identified at all educational levels, indicating that these tasks cross disciplinary boundaries and foster knowledge acquisition through problem-solving processes.

Mathematical Skills

Figure 6 presents an activity related to problem-solving skills, in which students are encouraged to discover the practical applications of mathematics in real life and its connection with other subjects through a problem that integrates mathematics with seismology. In this activity, students apply a model to calculate the energy released during an earthquake.

Figure 7 illustrates an activity focused on argumentation and communication skills, where students must engage in pair discussions, express clear ideas, and develop a reflective attitude regarding the importance and benefits of cereal consumption in preventing certain diseases. Additionally, this activity integrates mathematics with nutrition in a real-life context.

Figure 8 represents an example of a STEM activity aimed at developing representation skills. This activity allows students to transition between different levels of representation, specifically from a tabular representation to a scatter plot, distinguishing between male and female populations. The objective of this activity is to record distributions and compare populations using double-entry tables and scatter plots.

1. Analyze the following information. Then, answer. Diet is closely linked to health. A diet high in fats, sugars, and sodium increases the risk of developing non-communicable diseases, such as diabetes, cancer, and cardiovascular diseases, among others. However, the opposite is also true: some foods help protect the body. Whole grains are one of them, according to a recent study confirming that their consumption helps reduce the risk of cardiovascular diseases. This meta-analysis reviewed 45 studies that linked a diet rich in whole grains with health improvements and a reduced risk of death from stroke (CVD), diabetes, cancer, respiratory, and infectious diseases. The results showed that consuming 90 grams of whole grains per day reduces the probability of developing coronary diseases by 19% and cardiovascular diseases by 22%. Additionally, mortality related to stroke decreased by 14%, cancer by 15%, respiratory diseases by 22%, infectious diseases by 26%, and diabetes by 51%. The researchers concluded that, up to now, "dietary recommendations for whole grain consumption have often been vague or inconsistent regarding the quantity and types of grains people should eat." However, this thorough scientific review allows for strong support of dietary recommendations aimed at encouraging the consumption of whole grain foods among the general population to reduce the risk of chronic diseases and premature mortality. Nonetheless, the researchers acknowledged that the meta-analysis has certain limitations, particularly related to the heterogeneity of the reviewed studies, as well as differences in lifestyles, dietary habits, and social status of the participants.

a. What information does the news provide? Write it down in your notebook.

b. What is the news trying to convey? Discuss in pairs.

c. Can the following conclusions be considered correct? Analyze and justify.

Figure 7. Example of argumentation and communication skills (extracted from second-year student textbook [Díaz et al., 2020, p. 146])

Health

4. Analyze the following situation, then complete the requested tasks. The protocol in a medical emergency unit includes recording the age and pulse rate of all incoming patients. The data collected during one work shift are as follows:

Men				Women			
Age (years)	Pulse (bpm)	Age (years)	Pulse (bpm)	Age (years)	Pulse (bpm)	Age (years)	Pulse (bpm)
19	64	47	60	37	69	40	72
34	56	49	65	32	76	25	67
55	68	31	58	25	74	45	80
62	62	34	57	39	57	52	75
23	56	19	52	45	70	30	72
52	69	67	70	28	75	47	80
23	53	63	65	19	70	78	77
50	63	62	65	30	75	82	83
40	61	35	53	52	77	61	72
26	55	50	58	20	68	62	75

a. Create a scatter plot for both datasets and use two different colors to differentiate men and women.

b. Draw three straight lines, one for the men and women's scatter plot and one for both groups combined.

c. Describe the scatter plots.

Figure 8. Example of representation skills (extracted from first-year student textbook [Fresno et al., 2020, p. 161])

Application activity–The sound spectrum: What will we do? We will model the vocal registers of artists, musical instruments, or animals using the sine function. Let's plan:

Step 1: Organize into groups of 3 or 4 members and choose a vocalist from a band, a musical instrument, or an animal to investigate. Let's investigate:

Step 2: Research the following:

- What is the vocal range of the artist or the sound frequency of the animal?
- What determines whether a sound is weak or strong? Which parameter of the function does it correspond to?
- What determines whether a sound is high-pitched or low-pitched? Which parameter of the function does it correspond to?

Step 3: As a team, represent the sound spectrum using a function in the form $f(x) = a \cdot sin(b \cdot x)$. Adjust it approximately, considering:

- Is the sound characteristically high-pitched or low-pitched?
- If it is the sound of an animal, can it be detected by the human ear?
- Create a graph of the function that illustrates the amplitude and frequency you determined. Let's present:

Step 4: You may use various media to present your research. Coordinate with your teacher.

- Your presentation should include the following elements:
- What was the reason for your choice?
- How would you describe the sound it produces?
- Which function did you choose to graph it and why? A sample of the determined sound.

Figure 9. Example of modeling skills (extracted from fourth-year student textbook [Osorio et al., 2019, p. 156])

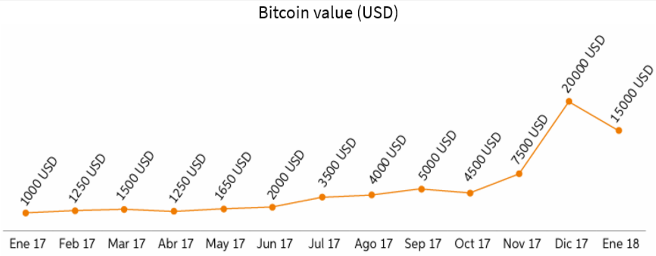
Figure 9 demonstrates modeling skills, as presented in one of the textbooks analyzed. In this activity, students are expected to construct a simplified version of a real-world system, identify key patterns, and express them through mathematical symbols related to the sound spectrum in different contexts using the sine function. This activity requires students to complete a three-stage project focusing on teamwork, research on different vocal registers and their characteristics, modeling the sound spectrum, and presenting the process, guided by structured questions.

Table 6 summarizes the analysis of STEM activities concerning the mathematical skills present in the four textbooks. The findings reveal a high presence of problem-solving (28.8%), argumentation (26.7%), and communication (28.8%). In contrast, representation (9.7%) and modeling (5.9%) are less frequently observed, with modeling being the least represented skill and entirely absent from the first-year textbook activities.

Table 6. Frequency and percentage of STEM activities by mathematical skills

Mathematical skills	1°		2°		3°		4°		Total	
	F	%	F	%	F	%	F	%	F	%
Argumentation	20	28.2	20	21.1	26	27.1	33	30.3	99	26.7
Communication	20	28.2	28	29.5	26	27.1	33	30.3	107	28.8
Modeling	0	0.0	13	13.7	3	3.1	6	5.5	22	5.9
Representation	11	15.5	4	4.2	11	11.5	10	9.2	36	9.7
Problem-solving	20	28.2	30	31.6	30	31.3	27	24.8	107	28.8
Total	71	100	95	100	96	100	109	100	371	100

2. Based on the bitcoin value graph, answer the following questions: | Bitcoin is a type of digital currency.



a. What was the overall return for the entire period?
b. If 1 bitcoin was purchased in January 2017 and sold in December 2017, ignoring fees and commissions, what was the return on investment? How many dollars were gained?
c. Ignoring fees and commissions, how much money was lost if 1 bitcoin was purchased in December 2017 and sold in January 2018? What was the investment return?
d. Demonstrate that the final investment return is equivalent to the multiplication of returns across consecutive months.

Figure 10. Example of analysis skill (extracted from fourth-year student textbook [Osorio et al., 2019, p. 124])

Application activity–Voronoi diagrams in your community. What will we do?
We will trace Voronoi diagrams on maps of your community based on reference points.

Planning

Step 1: In groups of 3 or 4, choose a service in your community or neighborhood (e.g., police stations, pharmacies, schools, supermarkets, banks, etc.). Use online search tools to find all the branches of the selected service around a point of interest.

Step 2: Research what Voronoi diagrams are, what they are used for, and how to construct them for a set of points.

Execution

Step 3: On a digital or physical map of your community or neighborhood, mark the locations of the selected services with points.
Draw the Voronoi diagram by tracing perpendicular bisectors between the points.

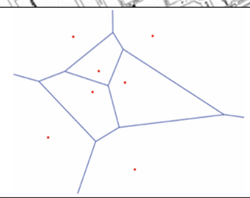
Step 4: Estimate the surface area and population for each region in the diagram. Use digital tools to assist with these calculations.

Presentation

Step 5: Project or display a map with the traced Voronoi diagram, clearly indicating the branches of the selected service. The presentation must answer the following questions:

- Why did you choose this service?
- What elements did you use to create the diagram?
- Which branch serves the most people?
- Which branch serves the fewest people?
- Provide recommendations regarding the placement of future branches.

One of the first applications of Voronoi diagrams was this diagram in England. It was created by John Snow in 1854 to identify the source of cholera cases (marked by black dots).



You can use search tools like Google Maps to find points of interest and mathematically model them by inserting the image into GeoGebra.

Figure 11. Example of research skills (extracted from fourth-year student textbook [Osorio et al., 2019, p. 200])

Scientific Skills

Figure 10 presents an example of a STEM activity focused on analysis skills, as it requires distinguishing different components of a phenomenon to explain the relationships between them. In this activity, students analyze the data presented in a statistical graph that tracks the value of bitcoin (a digital currency) over all months of 2017 and January 2018. The goal is to analyze digital currency trends, considering both time and profitability.

Figure 11 illustrates an activity where students work in teams, gather information, reflect critically, identify areas in their community, determine surface areas and population size, and relate these elements using digital or physical maps. This activity is classified under research skills, as it involves a sequence of tasks to solve a problem, including inquiry, experimentation, and documentation of community data. Specifically, students are required to investigate what Voronoi diagrams are, their purpose, how they function, and how they are used for a given set of points.

Figure 12 presents an example of a STEM activity that fosters multiple scientific skills, including analyzing, arguing, communicating, concluding, evaluating, formulating hypotheses, identifying variables, interpreting, researching, planning, and predicting. This activity is based on battery life, myths, and materials used in battery manufacturing, structured around three key stages: planning, researching, and presenting. Each stage involves processes such as inquiry, data collection and analysis, hypothesis identification, graph creation, and information presentation through an infographic. Also, from a mathematical perspective, students are required to calculate measures of central tendency (mean) and variability (variance) from data.

Application activity–Battery duration. What will we do? We will model battery duration.

Planning

Step 1:

- Organize into groups of 3 or 4 members.
- Determine which electronic device with an internal or external battery you will investigate.

Investigation

Step 2:

- Research the accuracy of common myths regarding batteries and the materials used in their production.

Step 3:

- Define the data collection method, such as researching product specifications on different brand websites or conducting surveys among classmates.

Step 4:

- Classify the collected data.
- Consider a sample size of at least 30.
- Use a spreadsheet to calculate the mean and variance.

Step 5:

- Assuming the population follows a normal distribution, determine at least five intervals, including:
- The duration interval for the top 90% of data.
- The duration interval between the 75% and 90% top percentiles.

Presentation

Step 6:

- Create a graph of the normal distribution associated with battery duration.
- Label the mean (μ) and standard deviation (σ) values.

Step 7:

- Conclude: Which product has the longest battery life?
- To which percentile does it belong?

Step 8:

- Present your findings in a creative infographic.
- Include:
- The research from step 2.

Descriptive statistics summarizing the data collected.

Figure 12. Example of argumentation, comparison, conclusion, evaluation, hypothesis formulation, variable identification, interpretation, research, planning, and prediction skills (extracted from fourth-year student textbook [Osorio et al., 2019, p. 182])

Application activity–Antennas.

Objective: Study and estimate antenna coverage.

What will we do? We will determine the position and coverage of antennas.

Planning

Step 1:

- Organize into groups of 3 or 4 people and select a location or area of interest to analyze telecommunication antennas or other nearby services.

Step 2:

- Investigate the coverage radius and the maximum user capacity that each antenna can handle.
- If the exact data is unavailable, estimate it approximately.

Analysis

Step 3:

- Model the position of the antennas to illustrate an approximate coverage area for each one.
- You may use a digital map such as Google Maps for reference.

Step 4:

- Identify whether any issues exist or could arise due to:
- Maximum user capacity
- Coverage limitations
- Other related factors

Presentation

Step 5:

- Prepare a summary presentation of your research, including:
- The selected location.
- The number of identified antennas.
- Your conclusions, estimations, and predictions.

Figure 13. Example of developing and using models, evaluating, identifying variables, interpreting, predicting, and using ICT skills (extracted from fourth-year student textbook [Osorio et al., 2019, p. 214])

Figure 13 presents an activity aimed at studying and estimating antenna coverage. This activity promotes scientific skills such as developing and using models, evaluating, identifying variables, interpreting, predicting, and utilizing ICT. It encourages teamwork, research, and modeling of radio antenna coverage and capacity. Additionally, it requires the use of Google Maps as a visualization tool to determine an object's position in space.

The distribution of scientific skills in the analyzed STEM activities shows that textbooks place greater emphasis on formulating analysis-oriented questions (16%) and communication (13.5%). In contrast, problem formulation, observation, questioning, and evidence recording appear less than 1% of the time. Notably, measurement and instrument use skills are entirely absent, both registering a 0% presence in the activities analyzed (**Table 7**).

Table 7. Frequency and percentage of STEM activities by scientific skills

Scientific skills	1°		2°		3°		3°		Total	
	F	%	F	%	F	%	F	%	F	%
Analysis	26	23.0	43	25.1	8	7.8	33	11.0	110	16.0
Argumentation	15	13.3	22	12.9	16	15.5	33	11.0	86	12.5
Compare	4	3.5	11	6.4	8	7.8	32	10.7	55	8.0
Communication	15	13.3	33	19.3	12	11.7	33	11.0	93	13.5
Conclude	9	8.0	2	1.2	5	4.9	33	11.0	49	7.1
Develop and use models	4	3.5	10	5.8	17	16.5	8	2.7	39	5.7
Evaluate	1	0.9	4	2.3	0	0.0	9	3.0	14	2.0
Formulate hypotheses	2	1.8	0	0.0	0	0.0	6	2.0	8	1.2
Formulate problems	1	0.9	0	0.0	0	0.0	0	0.0	1	0.1
Identify variables	6	5.3	7	4.1	2	1.9	33	11	48	7.0
Interpret	3	2.7	19	11.1	0	0.0	33	11	55	8.0
Investigate	10	8.8	2	1.2	8	7.8	14	4.7	34	4.9
Measure	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Observe	1	0.9	0	0.0	5	4.9	0	0.0	6	0.9
Plan	2	1.8	0	0.0	4	3.9	9	3.0	15	2.2
Predict	2	1.8	7	4.1	4	3.9	16	5.3	29	4.2
questioning	2	1.8	0	0.0	0	0.0	0	0.0	2	0.3
Process evidence	2	1.8	6	3.5	1	1.0	0	0.0	9	1.3
Record evidence	5	4.4	0	0.0	1	1.0	0	0.0	6	0.9
Use instruments	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Use ICT	3	2.7	5	2.9	12	11.7	8	2.7	28	4.1
Total	113	100	171	100	103	100	300	100	687	100

Table 8. Frequency and percentage of technological skills in Chilean textbooks

Technological skills	1°		2°		3°		4°		Total	
	F	%	F	%	F	%	F	%	F	%
Handling of materials, energy resources, tools, techniques, and technologies	4	6.6	1	1.5	15	20.8	7	11.9	27	10.4
Communication	13	21.3	40	58.8	6	8.3	7	11.9	66	25.4
Creation	4	6.6	0	0.0	5	6.9	0	0.0	9	3.5
Information search and analysis	20	32.8	2	2.9	31	43.1	33	55.9	86	33.1
Entrepreneurship	0	0.0	1	1.5	0	0.0	0	0.0	1	0.4
Adaptability & flexibility	0	0.0	2	2.9	0	0.0	0	0.0	2	0.8
Critical and responsible reflection	8	13.1	15	22.1	3	4.2	0	0.0	26	10.0
Teamwork	12	19.7	7	10.3	12	16.7	12	20.3	43	16.5
Total	61	100	68	100	72	100	59	100	260	100

Technological Skills

Figure 12 illustrates how investigating battery usage and the myths associated with their production fosters information search and analysis, communication, and critical reflection. This activity requires students to gather information, interpret it, and represent it in different formats to evaluate the battery life of various devices. Regarding the technological skills identified in the analysis of STEM tasks in textbooks, **Table 8** presents the frequency and percentage of these skills in the analyzed textbooks. The results indicate that the most frequently observed skills are information search and analysis (33.1%) and communication (25.4%).

CONCLUSIONS

There has been a growing interest in the implementation of educational approaches that not only integrate content but also promote essential 21st century skills. Through this rigorous and systematic analysis, both the levels of STEM discipline integration and the specific skills these activities foster in students have been identified. The study analyzed a total of 749 activities from textbooks, of which 150 were classified as STEM activities, representing 20% of the total. While this figure is significant, it suggests considerable room for increasing the inclusion of STEM activities in the curriculum. The distribution of these activities was influenced by the thematic strands, where Algebra and Functions, and Numbers were the most frequent topics. However, Geometry was the least represented strand, indicating a potential area for improvement in content integration.

Regarding the levels of integration observed in the STEM activities, they were categorized according to a model proposed in the literature. The activities were identified as nested, connected, interdisciplinary, multidisciplinary, and transdisciplinary. The majority of the activities were classified as transdisciplinary integration, suggesting a trend toward real-world problem-solving that transcends disciplinary boundaries (Ferrada et al., 2021). This finding aligns with the research of Aguirre-Navarrete et al. (2024), who highlight that STEM activities proposed in textbooks tend to integrate only one of the STEM areas along with mathematics, treating activities similarly to contextualized problems, usually placing them within a specific area to relate them to mathematics.

The skills emerging from STEM activities were categorized into mathematical, scientific, and technological skills. In this regard, the most common mathematical skills were problem-solving, argumentation, and communication. This indicates that textbooks prioritize the practical application of mathematics in real-life contexts, which is essential for developing competent students. Similarly, in terms of scientific skills, there was a significant emphasis on analyzing, arguing, and communicating, reflecting a focus on developing critical thinking and students' ability to engage in informed discussions on scientific topics (Le et al., 2023). For the technological skills, their representation was lower compared to mathematical and scientific skills. This suggests that more effort is needed to fully integrate technological literacy into STEM activities (Aravena-Díaz et al., 2020).

However, the limited presence of skills such as modeling or mathematical representation could hinder the development of fundamental competencies in applied contexts. Since modeling helps to strengthen mathematics learning by enhancing comprehension, meaning, and retention, in addition to motivating its study (Niss & Blum, 2020), its absence in the early stages of secondary education points to a curricular opportunity that has not yet been fully leveraged to reinforce scientific and mathematical literacy.

Finally, it is important to highlight that the analysis of STEM activities in Chilean secondary education textbooks reveals both achievements and challenges in the integration of these critical disciplines. While strengths have been identified in the inclusion of activities that foster key skills, there remains a need for greater diversity and quantity of activities, as well as a stronger focus on technological literacy. The research underscores the importance of preparing students for a future where integrating knowledge and skills from various disciplines will be essential to addressing the complex challenges of the 21st century (Gresnigt et al., 2014).

Implications

Regarding the implications derived from this research, first, the results highlight the need to strengthen the presence of skills such as modeling, computational thinking, and open-ended problem-solving, which are key to the development of STEM education (Halawa et al., 2024). To this end, it is recommended that curriculum designers include more explicit guidance on how these skills can be articulated within the activities proposed in textbooks.

Second, the importance is raised of developing initiatives aimed at both initial and ongoing teacher training that promote tasks based on integrated approaches, such as design-based learning or project-based learning, which have proven effective in developing 21st century skills such as collaboration, creativity, and critical thinking (DeCoito et al., 2024).

Finally, textbook editorial teams could benefit from reference frameworks that guide the explicit incorporation of STEM skills. This would not only increase the number of interdisciplinary activities, but also ensure a more balanced distribution among science, mathematics, technology, and engineering, appropriate to the educational level and learning objectives.

In addition to the previous considerations, it is important to acknowledge that increasing the inclusion of STEM activities in school textbooks should not only focus on quantity but also on the diversity of contexts and pedagogical approaches that connect learning to real-world situations (Wang et al., 2023). This diversification would enhance students' preparation for contemporary challenges and strengthen the social relevance of the curriculum, aligning with the Sustainable Development Goals.

From a practical perspective, the findings of this study can be leveraged by educators to intentionally identify and use the STEM activities already present in textbooks. This strategy would not only contribute to the development of essential competencies but also foster greater interdisciplinary connection in the classroom. Moreover, teacher training programs could incorporate reflective spaces on these activities, guiding future teachers in their pedagogical planning and implementation. As Goos et al. (2023) point out, the design of integrated tasks requires not only disciplinary knowledge but also a deep understanding of their formative value.

Limitations and Future Directions

Regarding the limitations and future research, this study focused exclusively on textbooks distributed by MINEDUC (2015) for secondary education. In this sense, one limitation is that textbooks from private publishers and other complementary pedagogical resources–which may also influence students' learning experiences–were not included. Likewise, the analysis was restricted to scientific, mathematical, and technological skills, without considering those related to engineering, as they are not formally incorporated into the national secondary education curriculum (e.g., MINEDUC, 2015, 2019). This omission stems from a methodological decision consistent with the current curriculum framework, but it leaves open the possibility for future research to explore how such skills could be incorporated or developed at school levels.

Another limitation is that the study focused on the analysis of textbooks, without examining the actual implementation of these activities in the classroom. Teaching practices, pedagogical decisions, and the perceptions of teachers or students regarding the use and value of the STEM activities present in textbooks were not addressed. Although beyond the scope of this study, these dimensions are relevant to understanding the gap between the proposed curriculum and the implemented curriculum.

From these limitations, several future research directions emerge. On the one hand, it would be pertinent to develop qualitative or mixed-method studies that explore how teachers interpret and adapt the STEM activities proposed in textbooks, as well as the degree of ownership and the difficulties they face in implementing them. Furthermore, the use of technologies in the context of textbook STEM activities should be evaluated–not only for their curricular presence but also for their pedagogical applicability and connection to the development of digital competencies.

Finally, longitudinal studies based on the evolution of textbook learning activities over the years would make it possible to observe whether there have been changes in learning and in the development of STEM skills, while comparative studies with other countries could help identify best practices and reference frameworks useful for enriching the curricular design of STEM activities.

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