Design and Technology Education: An International Journal

29.2

Empowering learning through integration: Enhancing understanding of variables and functions in the context of STEM education

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Abstract
This paper explores the integration of STEM activities in teaching and learning, emphasizing the importance of innovative pedagogical approaches in effectively introducing theoretical concepts, such as variables and functions, and merging them with practical applications. Drawing on existing literature, this study investigates the integration of STEM activities with real-world applications to enhance mathematics learning, highlighting intrinsic motivation, self-efficacy beliefs, and goal orientation as key factors in fostering student engagement. This case study explores the integration of a STEM activity to introduce students to variables and functions through a pendulum experiment. The aim is to demonstrate the impact of this approach on students' understanding of abstract mathematical concepts, as well as their problem-solving skills. By combining cognitive and social constructivism with technological modes (virtual labs), the study showcases the transformative potential of innovative techniques in STEM education. The outcomes of the study highlight, to some extent, the positive effects of STEM activities on students' engagement, motivation, understanding of theoretical concepts, and problem-solving skills. The focus on hands-on activities supports practical learning experiences and fosters critical thinking. Additionally, virtual labs enrich students' exploration of complex mathematical phenomena, enhancing their ability to apply prior knowledge to new contexts and transcend the boundaries of traditional lab settings. Overall, the findings underscore the transformative potential of innovative pedagogical approaches and technological modes in creating engaging learning environments within STEM disciplines.

Keywords
STEM activities, variables and functions, motivation, pendulum motion.

Introduction
In today's educational landscape, the integration of STEM (Science, Technology, Engineering, and Mathematics) has become paramount in shaping effective teaching and learning practices, especially in mathematics and science classrooms. This study explores the critical role of STEM in helping students not only understand variables and functions in mathematics, but also prepare them for the challenges of a rapidly evolving world. Building on the foundational work of scholars such as Bybee (2011) and Rocard et al. (2007), this article goes even deeper into the integration of STEM in mathematical context in a rapidly evolving world. Moreover, we further explore how inquiry-based learning methods can enhance critical thinking skills and enable primary students to make interdisciplinary connections crucial for real-world problem-solving (Hmelo-Silver, 2004). By examining key principles and strategies in these domains, we uncover

the transformative impact they have on enhancing student engagement, promoting critical thinking, and nurturing a future-ready mindset.

Literature Review

Teaching Variables and Functions

Teaching variables and functions is crucial for developing students' mathematical proficiency and problem-solving skills. By understanding the benefits and challenges associated with these concepts, teachers can enhance the learning experience and support students' mathematical growth. Why are teaching variables and functions is so important? According to Smith & Thompson (2018), introducing variables and functions helps students develop a deep conceptual understanding of mathematical concepts. They learn to connect abstract ideas with real-world applications, enhancing their problem-solving abilities.

Moreover, working with variables and functions encourages students to think critically and analytically. They learn to analyze relationships, make connections, and apply mathematical reasoning to solve complex problems (Boaler, 2016). Beside that, mastering variables and functions prepare student for advanced mathematics such as algebra, calculus, and statistics. Students who master these concepts are better prepared for higher-level math courses (Schoenfeld, 2016). Additionally, Stacey & Turner (2014) highlight that variables and functions are extensively used in various fields, including science, engineering, and computer science. Teaching these concepts equips students with skills applicable in real-world scenarios and professional domains.

However, teaching variables and functions can be too abstract for some students, posing initial challenges in comprehension. To address this, educators should use concrete examples and visual representations to make these concepts more accessible (Burns & Hattie, 2019). Similarly, the interplay between variables and functions can be complex for students, especially when it comes to understanding domain and range, function transformations, and inverse functions (Cai & Leikin, 2020). Many other scholars highlight that students may develop misconceptions or incorrect interpretations of variables and functions. Addressing these misconceptions requires targeted instruction, formative assessment, and opportunities for corrective feedback (Hiebert & Grouws, 2007). Under these circumstances, teachers should commit wholeheartedly to the success of all students by adapting their teaching methods to accommodate diverse learning needs. Meeting these needs, especially for students requiring additional support, can be challenging. However, employing differentiated instruction strategies, such as traditional labs and virtual labs, can help address this challenge effectively (Tomlinson, 2017).

Comprehensive Concerns in STEM Education

In our analysis of educational literature, we explored various justifications put forth by scholars advocating for the integration of STEM education into secondary schools. The review revealed a diverse range of reasons supporting the adoption of STEM initiatives. In light of this review, we noticed that scholars categorize their justifications into five distinct groups that significantly influence pedagogical strategies and impact student learning outcomes. These concerns extend across epistemological, curricular, procedural, motivational, and technological dimensions, highlighting their shared significance and influence in these educational domains.

Epistemological Concern

In the context of STEM education, epistemology refers to the study of how knowledge is acquired, constructed, and applied within the fields of STEM (Duschl et al., 2007). It emphasizes the effectiveness of STEM epistemic practices, which can help students acquire new knowledge through activities such as investigating processes, sense-making, and critiquing (Bevan et al., 2019; Fortus et al., 2004). These practices are essential for students to develop a deep understanding of the nature of science and the processes involved in STEM disciplines. Among the investigative processes, inquiry-based learning and the Technological Design Process (TDP) deserve special attention as they play a significant role in facilitating students' acquisition and application of new knowledge across diverse fields for problem-solving in the science and engineering context (Rocard et al., 2007). By engaging in these processes, students actively inquire, leading to a deeper understanding of mathematical, scientific, and engineering concepts, and facilitating the transfer of knowledge.

The work of Bybee (2011) and Rocard et al. (2007) discuss how investigative processes enable students to explore scientific phenomena, design artifacts, conduct experiments, analyze data, and draw conclusions. Through these processes, students actively construct knowledge, demonstrating the central focus of epistemology. Additionally, Hmelo-Silver (2004) supports this notion by affirming that inquiry-based learning and TDP enhance critical thinking skills, enabling students to evaluate evidence and make interdisciplinary connections crucial for real-world problem-solving. By transcending rote learning, these investigating processes promote a profound understanding of scientific, mathematical, and engineering concepts, aligning with the core principles of epistemology. They encourage students to actively engage in learning experiences, fostering a passion for knowledge acquisition.

Curricular Concern

Our study aligns with the principles outlined in various studies and curricula around the world. It suggests that the integration of STEM education can effectively enhance traditional subject areas, requiring a clear distinction between STEM skills and disciplinary knowledge. By embracing the interdisciplinary nature of STEM, educators can foster a deeper understanding of core concepts while promoting critical thinking, problem-solving, and collaboration among students (National Research Council, 2012; Ontario curriculum, 2022). The integration of STEM education in schools has significant implications for the curriculum, necessitating a thoughtful consideration of its interactions with other disciplines. Tytler (2020) highlights the importance of differentiating STEM skills from disciplinary knowledge, recognizing the unique contributions and challenges that STEM education brings. Moreover, STEM education plays a critical role in cultivating essential skills needed for the twenty-first century and preparing students for a job market that increasingly demands STEM expertise (Tipmontiane & Williams, 2022).

In addition to the broader context of STEM education, Technology Education (TE), the subject used in the Quebec context to teach STEM, faces specific learning challenges that require attention within the curriculum. These challenges include effectively integrating practical activities with theoretical concepts from various disciplines and adapting to the ever-evolving landscape of technological advancements (Dugger, 2009, El Fadil et al., 2018). Since the publication of the Standards for Technological Literacy (ITEA, 2007), the introduction of STEM education has further disrupted traditional subject areas, necessitating not only a clear distinction between STEM skills and disciplinary knowledge but also potential interactions between these disciplines. These interactions are crucial in preparing students for STEM-focused careers and ensuring that they possess the necessary skills and competencies to thrive in a rapidly changing world (National Research Council, 2011).

By addressing these curricular aspects, educators can navigate the disruptions caused by the integration of STEM education and leverage its potential to enhance student learning experiences. It requires a deliberate and intentional approach to curriculum design that incorporates STEM skills, while also providing a solid foundation in disciplinary knowledge. Through this balanced integration, schools can prepare students to excel in the interdisciplinary nature of STEM fields and equip them with the skills and knowledge they need to succeed in the twenty-first century.

Procedural Concern

As emphasized by Herschbach (2011), teachers encounter significant challenges when integrating hands-on activities with engaging cognitive processes during instruction. This challenge is compounded by the lack of consensus and clarity in instructional approaches, as well as inadequate training among teachers in integrated STEM education, leading to confusion and inconsistency (Breiner et al., 2012). Furthermore, many teachers feel ill-equipped to effectively utilize STEM activities in the classroom, underscoring the critical need for comprehensive training and support (Bybee, 2010; El Fadil et al., 2018).

According to Desimone (2009), improving teacher training and professional development programs is essential to address the challenges faced in STEM education. Offering comprehensive training that focuses on integrating hands-on activities, cognitive processes, and effective instructional strategies can equip teachers with the necessary skills and confidence to navigate the complexities of STEM education. It is important to move away from biases towards specific evaluation methods and instead focus on a balanced approach that incorporates observation, interviews, surveys, and other research-backed measures.

Motivational Concern

Motivation plays a crucial role in shaping students' engagement and achievements in STEM education. Various key factors, such as intrinsic motivation, extrinsic motivation, self-efficacy beliefs, goal orientation, perceived competence, task values, and social and cultural contexts, significantly influence learning outcomes (Eccles & Wigfield, 2002).

Briefly speaking, intrinsic motivation refers to the internal desire to engage in an activity for its own sake, driven by interest and enjoyment. In STEM education, this can be fostered through real-world problem-solving by incorporating the TDP or inquiry-based learning, enabling students to find joy in the learning processes themselves (National Research Council, 2012). Extrinsic motivation, on the other hand, involves engaging in an activity to achieve external rewards or meet teachers' requirements to avoid punishment. In the context of STEM, extrinsic motivators might include grades, competition, or recognition. While often seen as less ideal than intrinsic motivation, extrinsic motivation can still be utilized to encourage participation and effort (Deci & Ryan, 2000).

According to Wigfield and Eccles (2000), expectancy-value theory suggests that students' motivation is shaped by their expectations of success and the value they attribute to a task. In the context of STEM education, this implies that students are more motivated when they have confidence in their ability to succeed in STEM tasks, such as integrating knowledge from various school subjects and using technological tools. Additionally, they are motivated when they perceive the relevance and significance of STEM skills for their future careers.

By recognizing the multifaceted nature of motivation and its impact on student outcomes, educators can design instructional strategies and learning environments that cultivate and sustain motivation in STEM education. This includes providing opportunities for hands-on experiences (Hidi & Renninger, 2006), promoting a sense of competence and mastery (Bandura, 1997), and fostering collaborative and supportive learning environments (Johnson & Johnson, 2009). To enhance motivation in STEM education, educators can go beyond the boundaries of traditional teaching methods and incorporate innovative approaches. This can involve using project-based learning (Thomas, 2000), the Technology Design Process (El Fadil & Najar, 2023), integrating technology and digital tools (Kay, 2006), and embracing active learning strategies (Freeman et al., 2014). By highlighting the relevance of STEM subjects to real-world contexts, educators can help students see the practical application of their learning (Eccles & Wigfield, 2002).

Technological Modes Concern

Technological modes in education encompass a variety of tools and methods that leverage technology to enhance teaching and learning. These include virtual labs, simulations, online resources, and other digital tools. One significant advancement in science and engineering is the emergence of virtual labs, which offer unique opportunities to enhance practical learning experiences. These digital environments provide interactive and immersive experiences, fostering curiosity, critical thinking, and problem-solving skills among students (Johnson et al., 2014).

According to Johnson et al. (2014), virtual labs have proven effective in promoting engagement and a deep understanding of scientific concepts. They allow students to explore and experiment in a controlled and safe environment, enabling them to make connections between theory and practice. Additionally, virtual labs provide access to knowledge when the phenomenon being studied is inaccessible or uncertain using traditional methods, such as when it is too fast, too slow, too far, or infinitely small (Honey et al., 2014).

For example, students can use virtual labs to observe and manipulate objects at the atomic or molecular level, study fast motions such as oscillations, explore astronomical phenomena that occur over vast distances, or conduct experiments in extreme environments that are impractical or unsafe in a physical laboratory. By integrating both virtual and real-life modes of learning, educators can create a more comprehensive and dynamic learning environment. Virtual labs can simulate complex experiments and scenarios, providing students with interactive and immersive experiences that foster curiosity, critical thinking, and problem-solving skills (Johnson et al., 2014). On the other hand, real-life modes offer tactile and experiential learning opportunities, allowing students to engage with physical materials and environments.

In this paper, we define a STEM activity as a teaching and learning scenario in which students collaborate in small teams, integrating knowledge from diverse disciplines such as science, engineering, and mathematics. These activities involve the use of technological tools to tackle problems and engage in hands-on problem-solving experiences.

To address the challenges and inconsistencies in the implementation of STEM activities, the proposed project aims to introduce seventh-grade students to the concepts of variables and functions (*mathematics*). This will be achieved through an activity centred around pendulums (*science*). As well, the project will incorporate elements by challenging students to design and make their own pendulum (*engineering*). The use of virtual labs will be integrated to further enhance the learning experience (*technology*).

By combining these elements, students will have an opportunity to apply their knowledge of variables and functions in a real-world context. They will explore the principles of pendulums, investigate how different variables (independent and dependent) affect their behaviour. The use of virtual labs will allow students to simulate and observe the behaviour of pendulums under different conditions that are almost impossible in a traditional lab setting (very short, very long, very heavy, very light), providing a dynamic and interactive learning environment.

Research Questions: the proposed project aims to address the following research questions:

- To what degree do STEM activities, including the integration of virtual labs, contribute to students' comprehension of variables and functions?
- In what ways do STEM activities influence students' motivation to grasp abstract concepts and actively engage in investigative processes?

By exploring these research questions and considering the role of motivation in STEM education, we can gain valuable insights into the effectiveness of STEM activities, including the use of virtual labs, in enhancing students' understanding and motivation in both mathematics and the TE.

Conceptual Framework

This study encompasses various pedagogical approaches and underlying philosophical concepts influencing observed teaching practices. The framework examines pedagogy from a practical perspective, incorporating three modes of transfer: cognitive constructivism, social constructivism, and the technological mode.

Cognitive constructivism centres on individual learning, emphasizing internal rigor and knowledge construction through effective teaching strategies (Williams, 2016). According to this perspective, learners actively construct their understanding by integrating new information with their existing knowledge (Piaget, 1972). Moreover, Bruner's works have significantly influenced cognitive constructivism (Bruner, 1960), emphasizing learner-centred activities, problem-solving, and critical thinking to foster meaningful learning experiences.

Social constructivism stresses knowledge construction through social interactions, including engagements with teachers and peers. Vygotsky's sociocultural theory posits learning as a collaborative process occurring through social interactions and meaningful activities (Vygotsky, 1978). Through dialogue, scaffolding, and cooperative learning, learners actively construct knowledge, negotiate meaning, and develop cognitive and social skills (Johnson & Johnson, 1999).

Embed a focus on equity and inclusion within the project involves acknowledging diverse learners' needs, ensuring equitable access to educational resources and opportunities, and promoting inclusive teaching practices. Scholars such as Ladson-Billings have extensively written about the importance of equity and culturally responsive teaching (Ladson-Billings, 1995). By emphasizing equity and inclusion, the framework can guide educators in creating learning environments that accommodate the diverse strengths, interests, and backgrounds of all students, fostering a supportive and inclusive STEM education ecosystem.

The technological mode underscores teaching facilitated and supported by digital tools and methods. Technology has become integral to modern education, offering avenues to enrich teaching and learning experiences (Koehler & Mishra, 2009). The integration of technology can create interactive and engaging learning environments, enhance information access, and facilitate communication and collaboration (Liu & Reed, 1994). Digital tools and resources also support inquiry-based learning, problem-solving, and creativity (Means et al., 2010).

The integration of these pedagogical approaches forms a comprehensive framework for understanding teaching practices and their impact on student learning outcomes. By incorporating cognitive constructivism, social constructivism, and the technological mode, educators can design learning environments promoting knowledge construction, social interaction, and effective digital tool utilization. This holistic pedagogical approach aligns with contemporary educational theories and practices.

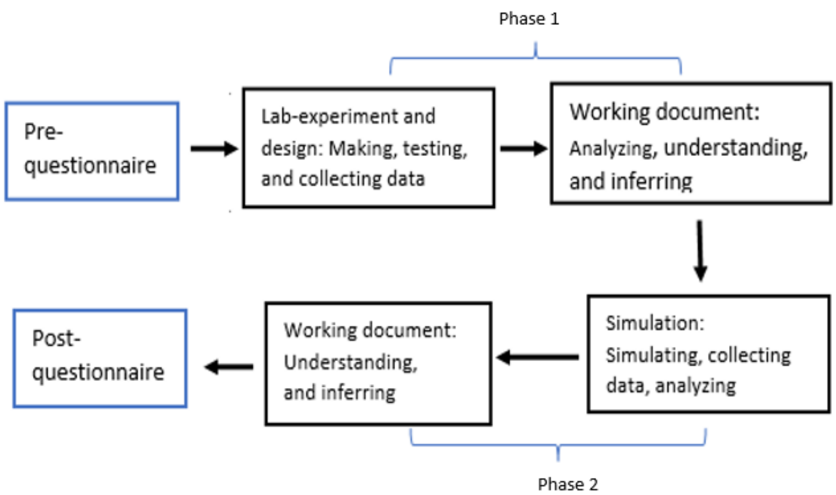

Figure 1. Project implementation phases (Source: El Fadil & Najar, 2022)

Method

In the Quebec Curriculum, where STEM is not explicitly included, we often promote transdisciplinary learning through Technology Education and its associated processes. In this study, we initiated our study with a physics activity centred on pendulums. This choice is justified by the natural connections between physics, engineering, and technology, as well as physics' ability to foster interdisciplinary dialogues and methodologies that transcend traditional disciplinary boundaries (Sinatra et al., 2015).

The project involved designing, making, and analysing a pendulum, using two teaching phases outlined in Figure 1.

The aim was to gain insight into the interrelationships among the variables of the pendulum. Data was collected from a seventh-grade classroom with 20 students. We understand that the number of participants in our study is insufficient to achieve representativeness or support in-depth statistical analysis. This limitation stems from the restricted access to schools due to COVID-19 pandemic.

To ensure the credibility of our findings, we followed a case study design and used multiple data sources (Yin, 2003). These sources included pre- and post-questionnaires, hands-on observation during the TDP, as well as a working document that captured students' understanding.

The first phase focused on designing, making and testing of a simple pendulum to explore its function and the variables involved. It began by assessing students' prior knowledge through a pre-questionnaire designed around three fundamental principles: (1) Mitcham's typology of technology, which encompasses objects, activities, knowledge, and volution (De Vries, 2021; Mitcham, 1994); (2) STEM epistemic practices, including investigating, sense-making, and critiquing (Bevan et al., 2019); and (3) content derived from the Mathematics, Science, and Technology subject area in the Quebec Education Program (Government of Quebec, 2006). Students then designed, made, and tested the pendulum using lab-tools to measure its variables. They worked in small teams and generated ideas for designing a simple pendulum, considering the key factors that influence its swings. During a group discussion, students identified mass, length, period, and deviation (angle) as important factors to consider in analysing the pendulum's behaviour. We then prompted them to think deeply about how to effectively operationalize the variables.

After a second round of discussion, they identified mass (m), length (l), angle (θ) as independent variables, while the period of oscillation is identified as the dependent variable, T=f(m,l, θ), which cannot be controlled.

To explore the relationship between these variables, students were assigned the task of investigating the impact of an independent variable (m, l or θ) on the period of the pendulum (T=f(m), T=f(l) or T=f(θ)). Collaborating in teams, students engaged in designing, creating, and testing simple pendulums, utilizing a variety of technological and lab tools.

To gather data on the effect of length ($T = f(l)$), students designed pendulums with various lengths of wire (l = 30 cm; 40 cm; 50 cm; 60 cm; and 70 cm). For each length l, they conducted three measurements and calculated the average. Subsequently, they changed the wire (l) and repeated the measurement process. Figure 2 provides further details on the experimental setup.

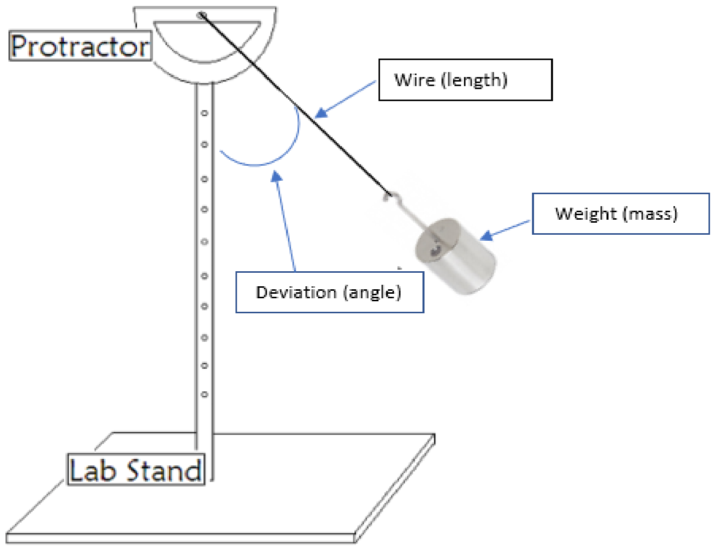

Figure 2. An Example of Designed Pendulum

To gather data on the impact of the mass as an independent variable, the group designed a pendulum with a fixed wire and varied the weights suspended to its free end. They used weights of mass *m = 20 g*, *50 g*, *100 g*, and *200 g*. Regarding the angle as a variable, students encountered issues with the stability of the setup, which resulted in the cancellation of its experimentation. After completing the design activities, the students answered questions related to graphical analysis and extrapolation.

In the second phase, students used a simulation tool (virtual lab) available on the platform phet.colorado.edu/ to simulate pendulum motions and gather data, replicating the physical experiments conducted in phase 1. The students were prompted to think critically about the accuracy of their results and the ability to draw valid inferences about the relationship between independent and dependent variables. To evaluate the impact of the design activities on the students' understanding of variables, functions, and the TDP, a post-questionnaire was administered.

Results and Discussion

The first category of questions in the pre- and post-questionnaires addresses pupils' prior knowledge about pendulums and how they work. Here is a sample of questions provided in the first category:

- Do you know what a pendulum is?
- Can you explain how a pendulum works?
- What type of energy do you think causes pendulums to move?

Data collected from the pre-questionnaire indicates that out of the 20 respondents, only one student did not know what a pendulum is. However, the remaining 19 students confirmed their familiarity with the concept of a pendulum, although many of them struggled to identify its components. Also, only 6 out of 20 respondents were able to accurately identify the parts of a simple pendulum and correctly associate its function with the swinging motion.

Regarding the variables and the type of energy involved in a pendulum motion, only one out of 20 students showed a limited recognition that the mass of the suspended weight and the length of the wire are variables. Similarly, only one student made a connection between energy and the gravitational force.

The second category of questions focuses on scientific and mathematical concepts that are essential to understanding the physics of pendulums. Here are some questions from the second category:

- Explain in your own words what the term "variable quantity" means.
- What method or technique can you use to describe or represent a situation involving two variable quantities?
- Can you determine which variable is considered the independent variable and which one is the dependent variable in a situation where two variables are involved?

In contrast to the first category, the second category of questions display varying levels of understanding. Regarding the meaning of "variable quantity," eight students mentioned that it refers to a quantity that can change. One student stated that it signifies an unknown quantity, another mentioned that it is an expression used in algebra, while the remaining students had no idea about its meaning.

With reference to the method that can be used to represent a situation involving two variables, two students mentioned charts and graphs, while another student mentioned algebraic equations.

Regarding the ability to distinguish between variables, only 3 students claimed that they can correctly identify which variable is independent and which one is dependent.

Table 1. Length-Period Collected Data

L: Pendulum length (cm)	30	40	50	60	70
T: Period (s)	1,1	1,3	1,4	1,6	1,7

The working document provided to the students contains a series of questions that specifically relate to both the process of collecting data from a designed experiment, and how to effectively organize this data into table of values and graphs to make a successful analysis. After designing and making their pendulums, students collected data on length-period variables (T=$f(l)$), (Table 1 and Figure 1). Therefore, they plotted correspondent graphs.

To gain insight into the students' analytical abilities, we instructed them to use their tables and graphs as references to examine the relationship between the two variables (Length & Period). This task aims to assess not only their proficiency in interpreting and analysing data based on the visual representations created, but also their ability to think outside the box, by using extrapolation and inference.

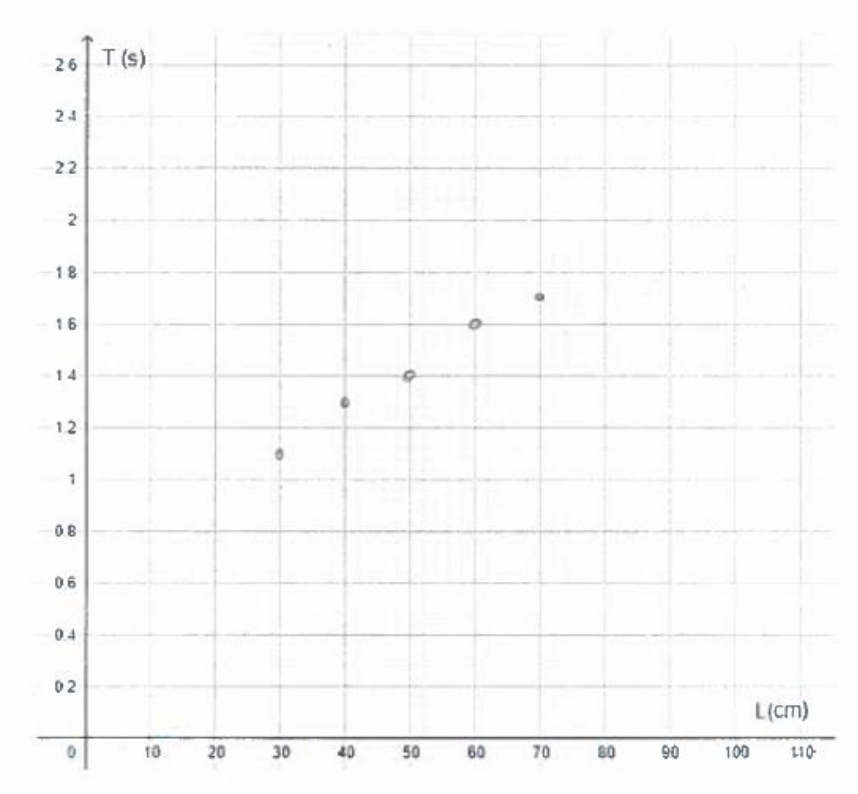

Figure 3. Length-Period Graph

The pre-questionnaire's responses indicate that 14 out of 20 students demonstrated the ability to extrapolate their graphs to predict periods for some hypothetical pendulums. For instance, we asked them to determine the periods of the 20-cm-pendulum, 55-cm-pendulum, and 90-cm-pendulum. After analysis, it became evident that the 14 students were able to formulate acceptable answers, as depicted in excerpt 2 (Figure 2).

Table 2. Period Extrapolation Question and Student Responses

Question: can you determine, from the graph 1, the oscillation period T of	
	Students' answers
a 20-cm pendulum?	T= 1 second
a 55-cm pendulum?	T = 1,5 second
a 90-cm pendulum?	T = 1,9 second

To investigate the relationship between mass and period (T=$f(m)$), students conducted a second experiment. They made another simple pendulum with a fixed length and suspended successively various weights at its free end. The responses indicate a similar level of understanding among the students as in the previous experiment, with the exception that the period varies only slightly as a function of the mass.

The incorporation of digital tools as virtual laboratories has proven to be beneficial for students in enhancing their comprehension of abstract concepts.

In the second phase, students replicated the same experiments conducted in phase 1, but in a virtual environment. This activity provided students with an opportunity to reflect on the advantages and limitations of physical laboratory experiments, simulations, as well as modelling. Through this second phase, students learned how the virtual environment empowers them to surpass the limitations imposed by the physical constraints of the lab-equipment. It allowed them to explore and push the boundaries of their knowledge in ways that may not have been possible in the traditional lab setting. The responses indicate that 14 out of 20 students successfully collected data from the simulation platform, generated graphs, extrapolated data, and provided answers to related questions.

After completing the second phase, we proceeded to assess their understanding by administering a post-questionnaire. The analysis of the data collected from the questionnaire revealed that all students had acquired a solid comprehension of the steps involved in the TDP and demonstrated a clear understanding of both the concept of a simple pendulum and how it operates. Additionally, it was observed that 16 respondents displayed an understanding of the connection between the function of a pendulum and the period of its swings, which is primarily influenced by the length of the wire.

However, the analysis of both the post-questionnaire and the working document indicates that only two out of the 20 students were able to make a correlation between the force of gravity and the potential energy involved in the oscillating motion of the pendulum. To gain a deeper understanding of the impact of this project on mathematics learning, we included a question about the inverse function in the working document. We asked the students how they could design a pendulum to achieve a specific period of oscillation. For instance, we inquired whether they could calculate the length (l) of pendulums that oscillate respectively with periods of T = 1.00 s, 1.40 s, and 2.00 s.

The responses show that 11 out of 20 students have used their graphs by starting their lines from the y-axis, which corresponds to the period (T), to find the lengths (l), on the x-axis, of the three hypothetical pendulums, as shown in excerpt 3 (Table 3).

Table 3. Inverse function questions and students' answers

Question: can you determine, by using graph 1, the length l of pendulums that have the following period of oscillation?	
	Students' answers
a 1,0-second pendulum?	l = 20 cm
a 1,4-second pendulum?	l = 50 cm
a 2,0-second pendulum?	l = 70 cm

Conclusion and recommendations

This study provides valuable insights into students' prior knowledge of pendulums and their comprehension of the scientific and mathematical concepts related to pendulum motion. While many students were familiar with the concept of a pendulum, they faced challenges in identifying its components and understanding the variables and energy involved in its motion.

Data collected from both traditional laboratory settings and virtual environments showcased students' ability to gather and analyze data, create graphs, and make extrapolations using visual representations. The hands-on, inquiry-based learning approach employed in this study slightly improved students' understanding of abstract concepts like variables and functions.

Collaboration among students during the project had a positive impact on peer learning and social constructivism, particularly when negotiating pendulum variables. Students engaged in exchanging ideas, discussing observations, and working together to solve problems using various approaches, including traditional labs, virtual labs, and working documents. This collaborative learning environment fostered the development of communication skills, teamwork abilities, and the capacity to consider multiple perspectives, reflecting the social nature of knowledge construction.

However, it is important to acknowledge the limitations of this study. The sample size was relatively small, with only 20 students participating amidst COVID-19 restrictions, which may limit the generalizability of the findings. In addition, the study focused exclusively on pendulum motion and variables, without exploring other areas of science and engineering. To provide a more comprehensive understanding of the topic, further research is needed, building upon the findings of this study. Such research endeavors will enable educators and researchers to enhance teaching strategies and promote meaningful learning experiences for students in STEM education.

Future studies should aim to encompass larger sample sizes and a broader range of topics to gain a comprehensive understanding of the impact of STEM learning experiences on students' understanding of variables and functions. Implementing longitudinal designs could assess the long-term effects of such learning experiences. Furthermore, incorporating qualitative methods like interviews or observations may provide deeper insights into students' thought processes and learning experiences. Exploring the effectiveness of different instructional strategies and interventions could contribute to the development of more effective pedagogical approaches in teaching variables and functions.

In order to foster inclusivity, diversity, and a comprehensive understanding of STEM concepts across diverse cultural backgrounds, we believe that it is so important to incorporate cultural considerations into the investigation. This can be achieved by integrating Indigenous perspectives, traditional practices, and community-based approaches into the design and implementation of problem-solving activities.

Ultimately, assessment strategies are the cornerstone of teaching and learning. Educators and researchers must develop appropriate assessment strategies that align with the goals and objectives of STEM activities, covering knowledge, processes, skills, collaboration, and the use of digital tools. Performance-based assessments, rubrics, and self-reflection exercises can be valuable tools to evaluate students' understanding, problem-solving abilities, and collaboration skills. By implementing these strategies, educators can gauge the effectiveness of their teaching methods and provide students with meaningful feedback to enhance their learning experience in STEM education.

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