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An introduction to functions and variables in technology education in a STEM-centred context at the elementary level

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Abstract

STEM education is gaining popularity in primary and high school curricula worldwide, emphasizing effective instructional methods. This article discusses a case study using the Technology Design Process (TDP) to create teaching materials to introduce variables and functions in a mathematical context at the elementary level. The TDP's iterative stages were used in the development, and data was collected from different sources: pre- and post-questionnaires, as well as a working document dealing with pupils' understanding based on designing, making, testing, and simulating. Nineteen students from a fourth-grade classroom (9–10 years old) participated in the study. The results indicate that STEM activities enhance classroom engagement and math learning while fostering problem-solving skills in a transdisciplinary context. This research encourages elementary teachers to incorporate more STEM activities and emphasizes the importance of the design process for critical thinking and practical skills. It also suggests that technology teachers include these design process steps in their teaching to develop engineering design skills and spark student interest in STEM subjects.

Keywords

STEM; technology design process; variables and functions; motivation; pendulum motion

Introduction

In classroom activities, science is rarely used to solve real-life problems (Nisa et al., 2021). The lack of real-world representation in teaching activities causes students not to bring their knowledge to solve science and mathematics problems.

Moreover, many scholars have noted that problems in life can be resolved through thought activities centred on the experimental process. Indeed, these kinds of activities provide opportunities for students to reactivate and transfer their prior knowledge from different disciplines to new learning activities that model real-life problem-solving. However, as argued in the scientific literature, many teachers fail to associate hands-on activities with mind-on activity during teaching and learning (Engström, 2022; Nisa, 2021). Innovative techniques are therefore needed to connect teaching and learning activities, especially in science and mathematics, to various problems in life. Besides, the addition of engineering concepts to elementary and secondary education (ITEA, 2007; National Research Council, 2012) has expanded consideration of integration beyond the disciplines of science and mathematics.

This paper aims to define the scope of STEM education centred on the TDP and its impact on enhancing elementary students' learning in the context of introducing variables and functions in mathematics.

Literature review

Technology education in many curricula is characterised by the technological design process (Dym, 1999). This process is by nature, hands-on, integrative, creative, and encourages critical thinking. It involves drawing up plans first and implementing and testing them afterwards (De Vries, 2005; Mitcham, 2022). By integrative, we mean integrative learning that transcends academic boundaries and encourages students to address real-world problems, synthesise multiple areas of knowledge, and consider issues from a variety of perspectives. Based on this line of reasoning, improving teaching to promote integrative learning strategies is crucial in positively impacting students' ability to harness their knowledge and transform it into useful strategies for acquiring new concepts and content (Wells, 2019). To legitimise the integration and enhance students' engagement in the learning process, it is essential to educate them on the principles of engineering and technology (Martinand, 1985) and how they integrate with other subjects, such as mathematics and science. By approaching their projects as if they were engineers, students will develop positive attitudes towards STEM fields and a thorough understanding of the problem-solving nature of engineering (Webster et al., 2006). Furthermore, engaging in design and making activities holds immense potential for students to gain hands-on experience with new materials, tools, and technologies. Also, these activities can transform young students' personal and social abilities by providing opportunities to come up with creative solutions and express their ideas through sketching and model-making (Yrjönsuuri, 2019).

According to Kelley and Knowles (2016), the TDP is an ideal integrator of STEM content. The implementation of teaching and learning activities based on the TDP has been shown to have a positive impact on students' motivation to study science, technology, engineering, and mathematics (van Deventer & Steyn, 2022). It is no accident that scientists and educators include technology education in the STEM reform movement. Some believe that technology education through the TDP can not only be the ideal integrator platform of science, engineering, and mathematics, but it can also provide the principles for developing solutions to real-world problems (Bybee, 2013; Dökme et al., 2022; Wells, 2019). Based on this line of reasoning, technology-learning activities oriented on the TDP should be useful for implementing STEM education. The learning activities STEM-centred often bring learners to connect abstract concepts and create new artifacts to represent thoughts through various forms of representation, not just through verbal statements. This helps learners to develop a deeper understanding of the material to use and apply their knowledge in new and creative ways. By using a variety of representations, such as visual diagrams, prototypes, and written explanations, learners can better understand complex ideas and communicate their understanding to others (Lin et al., 2021). As a result, STEM education has become a primary focus of many curricula around the world because it is crucial not only for economic development, but also for acquiring STEM literacy and for facing complex problems in real life (Guan et al., 2020). This focus was prompted by the new challenges of the 21st century, an era characterised by advanced technology and vast amounts of information that are having a significant impact on modernisation, globalisation, scientific advancement, and technological development (Suwarma & Kumano, 2019).

According to Bybee (2013), STEM education can be integrated in multiple ways, including combining two or three STEM subjects, or integrating all four STEM disciplines in a transdisciplinary manner. That means the elements or concepts of science, technology, engineering, and mathematics are integrated to produce a new course or unit where learning is applied to real-world problems and projects.

In Quebec, the current Education Program (2000) integrates science and technology in a single discipline but keeps mathematics as a separate one. It’s worth noting that in the Quebec Education Program, the term “technology” refers to technology education. Focusing on integrating STEM content in technology education is a relatively new or uncommon practice in the Quebec context. It is only offered in a few schools through elective programmes like robotics or science and engineering.

Nevertheless, as Liu (2020) highlights, the fundamental aspect of STEM education is its integrated and transdisciplinary nature; instruction in its component disciplines is conducted taking them as a whole rather than as separate, isolated subjects. The term “transdisciplinary” refers to a process that goes beyond merely combining two or more disciplines. It involves a synergistic and reflective relationship attained through dialogues among individuals, practices, and concepts from multiple fields (Tan, 2019). On a different note, numerous scholars have expressed concerns about the integration of STEM education. Koh and Tan (2021) have highlighted that the understanding of STEM education does not align with the potential promised in the literature and is often inadequately comprehended by school administrators and teachers.

Indeed, STEM integration is supposed to emphasise the need for design-process decisions to be based on scientific knowledge. However, many researchers pointed out that design knowledge in teaching practice tends to be technical (El Fadil et al., 2018). This could be due either to curriculum instructions and teachers’ training, or to few or no standardised measures of integrated learning in other contexts (Honey et al., 2014).

Besides, as Liu (2020) stated, integrated STEM education is based on the combination of conceptual understanding and procedural knowledge. In addition to this, Laksmiwati et al. (2020) argued that in the implementation of STEM, the TDP becomes very significant in the development of students’ thinking and problem-solving in STEM activities. In accordance with the above, many initiatives have been taken to analyse the implementation of STEM activities in classrooms, and the results of those studies showed that most of the activities were connected to the TDP (Knowles et al., 2017; McFadden & Roehrig, 2019).

To get more insight into how the TDP is understood by science and technology teachers in the Quebec context, El Fadil et al. (2018) investigated teaching practices and found that teachers’ understanding of this process varies; this could be seen in the variety of ways in which the TDP was implemented in their classroom practices. Most teachers present the TDP as a linear process to their students. Without a common understanding of STEM concepts, particularly the TDP, inconsistencies will arise in interpreting and implementing STEM education in the classroom (Honey et al., 2014). Instructively speaking to design and conduct meaningful lessons, teachers use the current curriculum, syllabus outlines, and sometimes the literature. In the absence of a sound collective understanding of the characteristics of STEM education, teachers and administrators can misunderstand STEM education policies and outcomes (Tan et al., 2019).

To gain a comprehensive understanding of STEM education, it is crucial to examine the perspectives of both students and teachers regarding classroom practices (Liu, 2020). From a student's point of view, a successful STEM career pathway requires a strong understanding of individual STEM disciplines. The study carried out by Katehi et al. (2009) supports this idea by noting that integrating ideas across all STEM disciplines is challenging when students have little understanding of the relevant concepts in the individual disciplines. As a result, teaching STEM subjects as isolated disciplines can make it challenging for students to establish connections and utilise their knowledge in an integrated context. From a teacher's point of view, the consensus is that strong content preparation in individual disciplines is necessary for successful integrated STEM education. For instance, elementary school teachers may make common mistakes in mathematics, which could be attributed to their separate training in different disciplines (Liu, 2011, 2017). These findings suggest that effective STEM integration requires both students and teachers to possess adequate disciplinary knowledge.

Additionally, a curriculum analysis in terms of the number of hours allocated to different subjects has revealed that certain subjects are prioritised due to their practical benefits and integration with other subjects. Mathematics, for example, is considered a crucial subject in STEM education, as highlighted by Milaturrahmah et al. (2017).

Several studies have addressed STEM integration, and the ways of doing so vary from perceiving STEM as a single discipline to taking a transdisciplinary approach that regard STEM as a multi-component discipline (Bybee, 2013; English, 2016). As emphasised by Haupt (2018), the evolving perspectives in technology education, which include the emphasis on knowledge, process, and products, highlight the crucial role of teachers in keeping the TDP central in the curriculum. This is essential in bridging the gap between opposing viewpoints.

Moreover, Sireger et al. (2020) conducted a literature review and reported that the integration of STEM activities has a positive impact on the academic achievement of students in elementary, middle, and high school (Han et al., 2016; Hansen & Gonzalez, 2014). For instance, in his study with fourth-grade pupils, McCaslin (2015) showed the effects of STEM education on pupils' achievement with respect to numbers and operations, data measurement, analysis, geometry, and algebra.

In the context of transdisciplinary integration, when it comes to mathematics learning, two trends have emerged in the literature. Firstly, although STEM education promotes mathematical skills, few studies have explored the reciprocal relationship between mathematics and the other STEM disciplines. Secondly, some studies have nuanced the contribution of STEM education to mathematics learning (Fitzallen, 2015). Following this path, Liu (2020) argues that despite the importance of mathematics in all other STEM disciplines, students who struggle with mathematics tend to avoid it due to its perceived difficulty. Kelley and Knowles (2016) suggest that incorporating STEM practices into teaching and learning environments can facilitate integration, including mathematics. However, Honey et al. (2014) have noted that the implicit use of mathematics as a tool in science and now in STEM has limited impacts on students' mathematical knowledge despite being in practice for decades.

Without adhering to any particular school of thought, it is worth considering that the subject of learning mathematics is not a singular entity. Devlin (2000) points out that it has four characteristic aspects: computation, formal reasoning, problem-solving skills, as well as being a way of knowing, a creative medium, and featuring practical applications. Therefore, further research is needed to determine how to distribute learning across disciplines more evenly. This would prevent student achievement in one area, especially mathematics, from overshadowing their proficiency in other areas (English, 2016).

Purpose and research questions

The proposed project aims to introduce elementary-level students to the mathematical concepts of variables and functions through a physics activity centred on the TDP. The primary goal is to help students develop a better understanding of these concepts and their relationships through STEM activities. The rationale for focusing on these concepts is two-fold, one being historical and the other curricular. The historical reason is that the concept of function is considered one of the most important in mathematics due to its historical significance. It was first introduced in science by Galileo (1564–1642) when he proposed an activity to study the motion of a pendulum. Galileo identified variables in a situation and sought to investigate how they may be quantitatively related. Subsequently, a preliminary definition of a function emerged as being an algebraic expression representing the relation between two variables (da Ponte & Henriques, 2013). The curricular reason is that fourth-grade students have not yet learned the concept of variables, which makes this an ideal time to introduce them to STEM activities related to variables and functions. By doing so, the measurements obtained from the study would not be influenced by prior knowledge.

Research questions

- To what extent do science, engineering, and technology activities affect students' understanding of mathematics in the context of Northern Quebec?
- What is the impact of STEM activities on students' motivation to learn abstract concepts?

Conceptual framework

The framework chosen for this study is based on the Haupt (2018) model, developed to cover the various pedagogic approaches and underlying philosophical conceptions of designing that were observed in teaching practice. From that point of view, pedagogy is considered from a practical perspective, regarding three modes of transfer: cognitive constructivism, social constructivism, and the technological mode.

Cognitive constructivism focuses on individual performance, internal rigour, and knowledge construction with the aid of teaching strategies (Williams, 2016). Social constructivism focuses on knowledge that is constructed using external and social elements through interactions with the teacher and peers (Danermark, 2006). The technological mode focuses on teaching that is facilitated and supported by digital and other technological learning support materials and methods.

The philosophical conceptions include the four subcategories of epistemology, ontology, methodology, and values (Franssen et al., 2009). Epistemology is related to knowledge types and their sources that are needed for designing. Ontology refers to the nature of the mental processes, types of thinking, and psychological characteristics involved in the activities of designing. Methodology refers to themes focusing on the TDP that suggest the structuring of design procedures and strategies. Values refer to soft skills; attitudes; efficacy judgements; ethics; the effects of technology and artifacts; social awareness; cultural, environmental, technical, and economic values; and environmental sustainability (Haupt, 2018).

Methodology

We conducted a case study to facilitate our understanding of the impact of integrated STEM activities, TDP-centred, on mathematics learning, in a rural context (a northern region of the Quebec Province). Consistent with Li & Schoenfeld (2019), we were guided by the proposition that learning by doing has the potential to increase students' motivation on learning new mathematics concepts through designing, making, developing ideas, and connecting science, technology, and mathematics.

This paper presents the research tools used to explore the interventions over time. This approach was appropriate for the study because it is robust enough to adjust for uncertainties, which might arise when implementing designed STEM activities; it also has a feedback loop via pre- and post-questionnaire that support critical reflection, evaluation, and learning to provide a broader understanding of how STEM activities, TDP-centred, could benefit technology education and mathematics learning.

To promote transdisciplinary learning through STEM integration, we began our project with a physics activity focused on the motion of pendulums. Physics was chosen due to its natural connections with engineering and technology, as supported by previous research (Bunyamin et al., 2020). Additionally, the literature highlights the significance of physics in facilitating dialogue between various disciplines, driven by methodologies that transcend traditional boundaries (Sinatra et al., 2015). More specifically, the project activity consists of designing, making, and analysing a pendulum, using two teaching sequences, as shown in Figure 1, to get insight into the interdependence between the pendulum's variables. Data was collected from a fourth-grade classroom of 19 pupils (9–10 years old). Consistent with the case study design, we used multiple data sources to enhance data credibility (Lune & Berg, 2017. These included pre- and post-questionnaires and a working document dealing with pupils' understanding based on lab experiments and simulations.

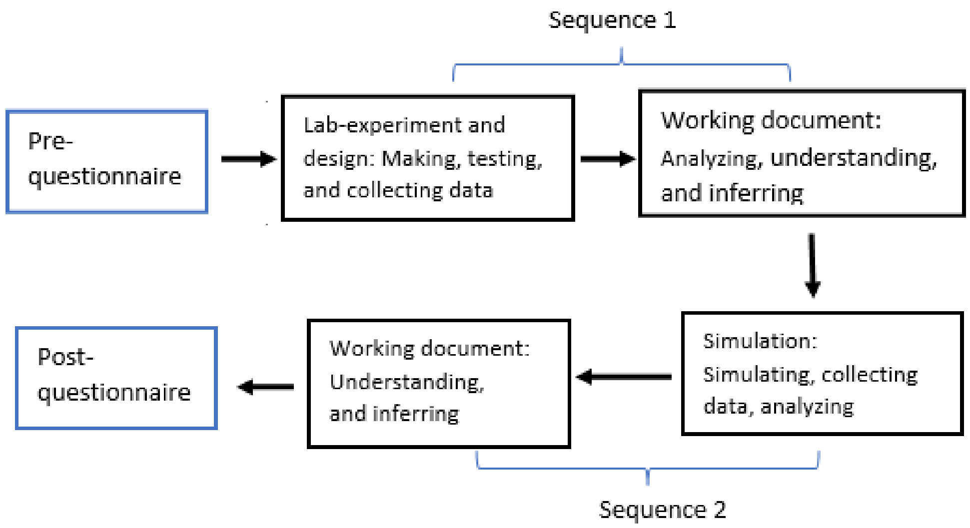

Figure 1. Project stages of implementation.

The first sequence was about making and testing a pendulum to understand not only how it works, but also the variables involved. This sequence began with the exploration of pupils' previous knowledge of pendulums and interests, and data was collected by using a pre-questionnaire. This was followed by designing, making, and testing a pendulum, using lab tools, and making measurements about the pendulum's variables. Students then worked in small teams on designing and making. During the brainstorming, two types of pendulums emerged: a simple pendulum and a physical pendulum. When it was time to discuss the experimental setup, pupils realised that it is extremely difficult, if not impossible, to control only two variables in the physical pendulum, in the classroom context. So, as a team, they decided to design and make the simple pendulum only. Thereafter, students worked in a small group to come up with some ideas about how to design a simple pendulum, and what the major factors were influencing its swings.

Then we showed the students two videos about pendulums and asked them to pay attention to the different measurements that can be made on a pendulum's motion. Afterward, we had a full group discussion, where the students identified the following variables: mass, length, time (period of one swing), and deviation (angle).

Moreover, we asked them to discuss in small groups which of the four variables identified could be controlled and which ones could not be. The discussion led to an understanding that mass, length, and deviation could be controlled, while pupils had no idea about how to control time (period of the oscillation). Subsequently, we introduced the concepts of independent and dependent variables to them. With that introduction in mind, the group identified mass, length, and deviation as independent variables, and period as a dependent variable. To gain a better understanding of the relationship between these variables, we instructed the students to test the effect of only one independent variable on the period of oscillation, as it would have been impossible to determine which variable had a significant impact on the pendulum's motion if two independent variables were changed simultaneously. Students then designed, constructed, and tested a pendulum, using lab tools, and measured its variables. The students worked in teams to complete the project.

In order to collect data on the length as an independent variable, the group designed a simple pendulum with different wires (40 cm, 50 cm, and 60 cm). They used a wire (of a specific length) and completed the sequence of three measurements of the same length, then calculated the average of the three collected data. They then changed the wire to another length and redid the measurement (see Figure 2).

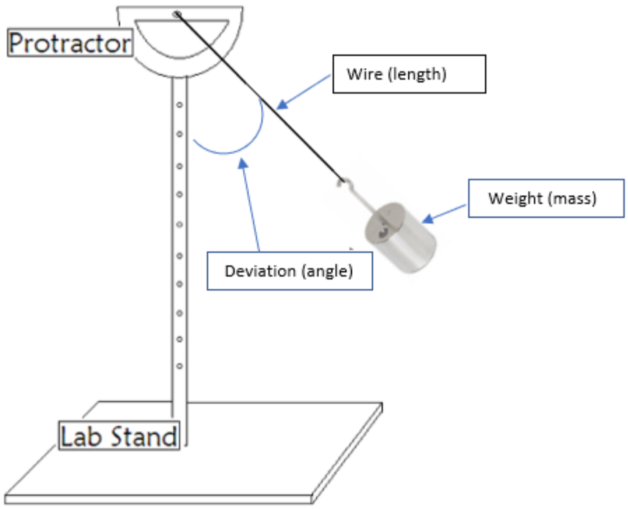

Figure 2. An example of a simple pendulum design.

To collect data on the effect of mass as an independent variable, the group designed a simple pendulum with a fixed wire, on which they could hang different weights at its free end. They used weights of 20 g, 50 g, 100 g, and 200 g and completed the sequence of three measurements for each weight, then calculated the average. To collect data on the angle as an independent variable, the group faced challenges with the stability of the setup. After discussing these challenges as a group, they decided to eliminate the angle from the experiment. Once the design activity was completed, the students conducted tests then answered questions about graphical analysis and interpretation provided in the working document.

The second sequence aimed at using a technology tool (simulation). This sequence refers to the teaching that is supported by digital tools (Haupt, 2018), where pupils used an interactive platform (at https://phet.colorado.edu/) to simulate pendulum motions and to collect data as they did in the lab experiment. Later, we asked pupils to think about the limits and the extrapolation (inference) of their lab experiment and the technological tools they used. We encouraged them to think critically about the accuracy of their results, and whether they could make valid inferences about the relationship between the independent and the dependent variables beyond the specific values they tested. At the end of the second sequence, we administered a post-questionnaire to assess the impact of the STEM activity on the students' understanding of variables and functions.

Results

In order to answer the questions, "To what extent do science and technology activities affect pupils' understanding in mathematics, in the Northern Quebec context?", and "What impact do STEM activities have on students' motivation to learn abstract concepts?", data was collected from both pre- and post-questionnaires, as well as from observations of students' engagement and enthusiasm while working on the project.

The first category of questions in the pre- and post-questionnaires addresses pupils' basic 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 name the different parts that make up a pendulum?
- Can you explain how a pendulum works?
- What type of energy do you think causes pendulums to move?

Data collected from the pre-questionnaire shows that 11 respondents do not know what a pendulum is, while the others confirm that they know what a pendulum is, but they could not identify its components.

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

- How can you measure the length of a pendulum?
- How can you measure the period of a pendulum?
- How can you calculate the average of a set of measurements?
- Can you draw a graph from a table of values?

In contrast to the first category, the answers of respondents in the second category show different levels of understanding. In terms of measuring lengths, eight respondents mentioned using a metre stick or a ruler, three mentioned the unit of length (cm) instead of the instrument, and others admitted not knowing how to measure length.

In the question related to how to measure a period of time, only seven pupils answered that they could use a stopwatch or a clock to measure time, while the others either said they did not know how to do it or provided incorrect answers. The responses derive from confusion between the concept of time, the measuring tool, and the actual process of measuring time.

With reference to plotting a graph, we provided pupils with the table of values shown in Table 1 and asked them to plot those values in the provided coordinate plane (Figure 3).

Table 1: ***Values to Plot***

e 1 (x)			
e 2 (y)			

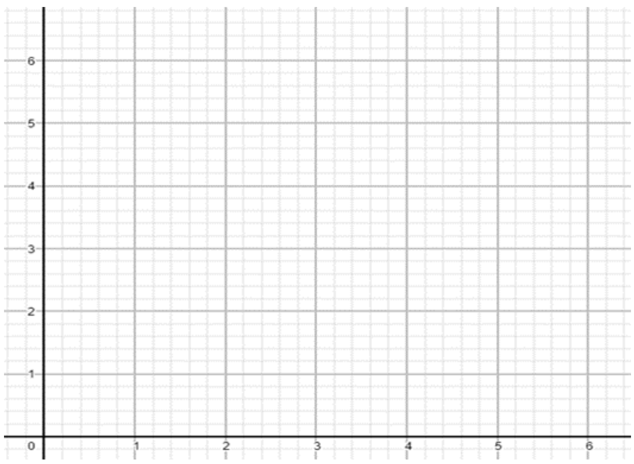

Figure 3. Coordinate plane.

The graphic representations showed that the students were not familiar with this kind of task. All participants successfully plotted only the first point (1, 2), which contains whole numbers. We concluded that their inability to plot the remaining points, (2, 3.5) and (2.75, 1), was due to the use of decimal numbers. Children in fourth grade may not be familiar with plotting this kind of number.

In order to assess the impact of using technological tools on motivation and engagement in learning, we asked the students two questions. The first question was whether they had used any technological device to learn science and/or mathematics. The second question asked was if the technological devices made scientific and/or mathematics learning easier or harder. The results revealed that as students worked in collaborative groups on STEM projects, they experienced high levels of motivation that facilitated meaningful learning. All respondents except one reported using computers in learning mathematics. Eight of them acknowledged that computers might make science and mathematics learning easier, while five said that computers might make learning harder. The remaining respondents stated that using computers had no effect on their learning experience.

The post-questionnaire data revealed that all students had acquired an understanding of what a simple pendulum is and could give a brief description of it as a weight when suspended by a string and oscillating back and forth. Moreover, 15 respondents demonstrated an understanding of the relationship between the function of a pendulum and the period of its motion, which is dependent on the length of its string. However, four pupils still did not understand the mechanism behind the pendulum's motion.

Regarding plotting values in a coordinate plane, the responses indicate that despite the activity, students still faced challenges when dealing with decimal numbers. Only five students were able to plot the values correctly. As for the impact of using technological tools, surprisingly, eight respondents claimed that simulations had no impact on their learning.

Analysing the data from the working document, which focused on pupils' understanding through designing and testing a pendulum, most of the answers were impressive. Sheet 1 contained experimental data about the period of the pendulum as a function of the length of the string. An example of the collected data is shown in Table 2 (Excerpt 1).

Table 2: ***Collected date about the period as a function of length***

Length (cm)		40	50	60
Period (s)		1.14	1.33	1.45

The question in relation to this table of values is "Based on your data, can you say if the period of the oscillation changes when the length of the string charges?" All pupils confirmed that the period changes when the length of the string charges. As an example, here is an answer provided by a respondent: "Yes, it changes because when the wire is 41 cm long, it takes 1.14 s, and when the wire is 51 cm long, it takes 1.33 s."

After collecting the data on the periods of oscillation for various string lengths, we asked the respondents to plot their values on a coordinate plane. The purpose of this exercise was to enable them to visualise the relationship between the period and the length of the string, and to use the resulting graph to predict the periods for some pendulums whose lengths were not included in the collected data.

For instance, we asked them to find:

1. the period of a 20-cm-pendulum: T =
2. the period of a 75-cm-pendulum: T =

By plotting the data on a coordinate plane, 12 students were able to observe a kind of linear relationship between the two variables. This activity enabled them to draw a line of best fit through the plotted points, which they then used to estimate the period for pendulums with string lengths not included in the original data set.

Regarding the simulation activity, the data shows that all pupils have learned from designing and making activity. All of them succeed in collecting data from the simulation platform, plotting the graphs, and using extrapolation to predict periods of different pendulums.

Discussion and conclusion

The purpose of this study is to investigate the impact of STEM activities designed for the fourth-grade level on attitudes and learning STEM concepts, in a rural area.

The consideration of the TDP criteria consists of defining a problem, coming up with ideas and plans, making, testing, and analysing.

Despite being a well-known concept in classical physics, the simple pendulum may be unfamiliar to primary school students. However, by including activities related to pendulum motion in the TDP, we can enhance the students' learning experience by promoting collaboration and hands-on exploration. The activities included in the TDP will give students opportunities to observe, operate, and experiment, allowing them to develop their problem-solving skills and improve their ability to create and learn new concepts, such as variables and functions. Through hands-on exploration, students can gain a deeper understanding of the underlying principles of simple harmonic motion, such as the relationship between the period and length of the pendulum. Moreover, collaboration among students during the activities will promote peer learning and provide opportunities for the students to share ideas and discuss their observations.

During the pre-questionnaire administration, pupils used their initial knowledge of pendulums and their initial learning about graphic representation acquired in mathematics. In the post-questionnaire, students used the knowledge that had been acquired through this project.

Throughout the project, we emphasised that analysis is a key skill that students must master through the TDP, especially in making prototypes in connection with the concept of variables. By engaging in hands-on experimentation and data analysis, pupils can develop their analytical skills and learn how to use variables to manipulate and control the behaviour of the system they are studying. The TDP encourages pupils to think creatively and to take risks, which are important elements of the design process. By embracing the TDP, students can develop a growth mindset and a willingness to learn from failures, which are essential qualities for success in any field.

Based on the findings, it is evident that the STEM activities had a positive impact on learning abstract mathematical concepts and on students' attitudes towards STEM. The students demonstrated improvement not only in their knowledge of pendulums but also in their ability to analyse the variables involved in a pendulum motion.

The analysis of pre- and post-questionnaire data revealed a noteworthy improvement in students' understanding of the concept of pendulum motion and the notions of independent and dependent variables. Before the project, 11 out of 19 students had little or sometimes no understanding of pendulum motion and had limited analytical skills. After participating in the project, almost all students demonstrated either good or very good understanding of pendulum motion. This improvement is a clear indication of the effectiveness of the project in enhancing students' learning outcomes and developing their critical thinking and problem-solving skills.

The results of the post-questionnaire also revealed that students were highly engaged and motivated by the STEM activities, with the majority reporting that they enjoyed the project and learned a lot from it. In addition, many students expressed a desire to continue learning about STEM subjects in the future, demonstrating the lasting impact of the project on their attitudes towards these subjects.

The results of this study, along with previous research in the literature, support the potential of TDP-based STEM education to enhance students' motivation and facilitate their acquisition of new knowledge. A considerable body of evidence indicates that STEM education can improve students' learning outcomes in mathematics and science (Weber et al., 2013).

To conclude, this case study provides promising results that demonstrate the positive and significant impact of STEM activities on students' learning. The integrated activities effectively help students understand how STEM concepts relate to real-world problems.

As Zhan et al. (2021) note, the most effective method for providing STEM education is through transdisciplinary projects. However, developing appropriate projects for students at different levels of education and selecting the right methodology for solving complex problems is a critical challenge for educators.

The findings of this study can provide valuable insights for teachers, policymakers, and other educators to enhance students' learning in STEM education. Specifically, teachers can use these outcomes to incorporate TDP into their teaching practices; and policymakers and curriculum editors can use them to reform instructional approaches and develop pedagogical materials that foster students' learning across all levels.

Furthermore, the results suggest that there is a need for further refinement of the meaning of STEM-integrated learning, development of pedagogical materials to guide pupils' learning, and training of teachers in delivering transdisciplinary knowledge from STEM. This would help enhance our understanding of the complexities involved in teaching and learning STEM, and better equip students with the skills necessary for the 21st century.

The results of this study demonstrate that the simple pendulum is an effective tool for introducing abstract concepts, such as variables and functions in a STEM context, making it a valuable project for primary and high school instructors.

In the future, further research could explore the relationship between pendulum variables through an experimental study or surveys of a larger and more diverse sample of students, including those from digital environments, indigenous communities, and high schools. Such research could lead to a deeper understanding of STEM learning and help to refine instructional approaches and pedagogical materials that support the development of 21st-century skills among pupils.

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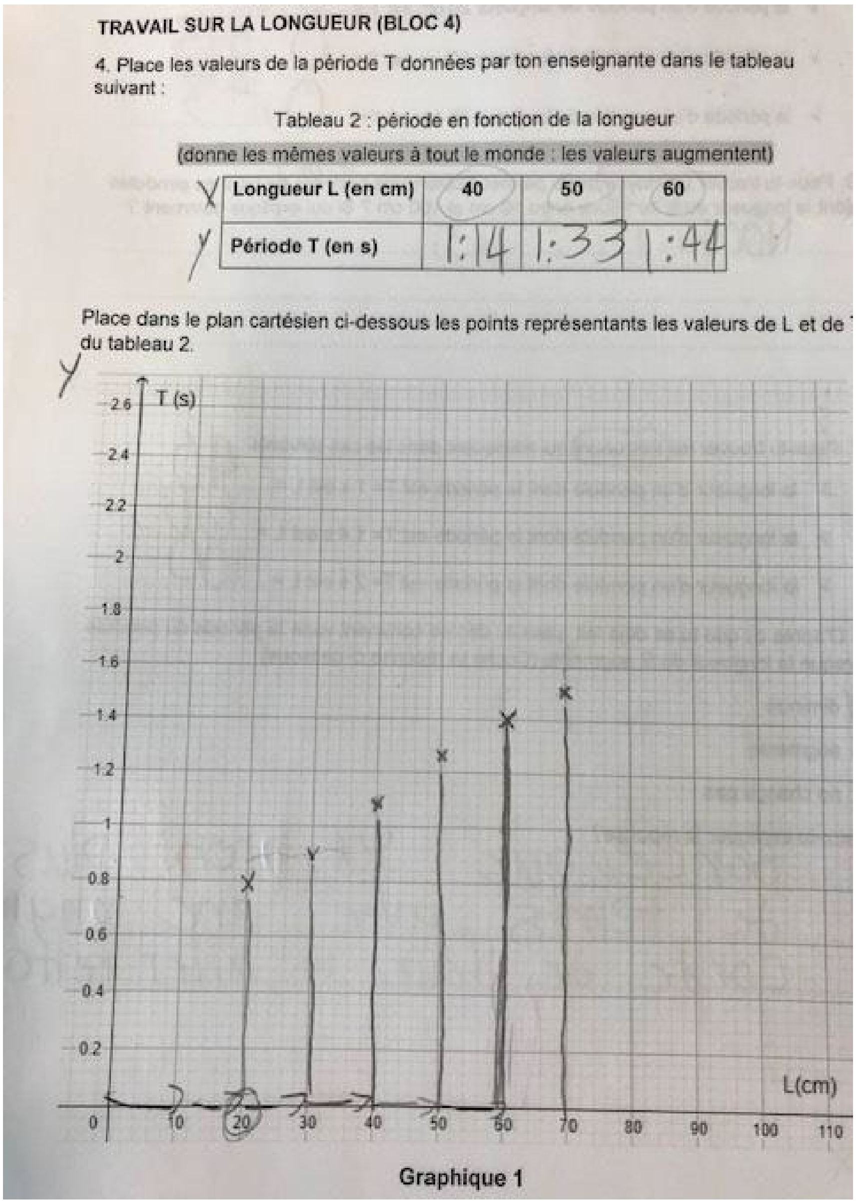
Excerpt

An example of questions provided in working document.


TRAVAIL SUR LA LONGUEUR (BLOC 4)

4. Place les valeurs de la période T données par ton enseignante dans le tableau suivant :

Tableau 2 : période en fonction de la longueur

(donne les mêmes valeurs à tout le monde : les valeurs augmentent)

Longueur L (en cm)	40	50	60
Période T (en s)	1:14	1:33	1:44

Place dans le plan cartésien ci-dessous les points représentants les valeurs de L et de T du tableau 2.

Graphique 1