Teaching Variables and Functions at the Secondary Level in a STEM Context

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Outline

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The problem

- **Technology education is characterized by the eTchnology Design Process (TDP).**
- This process is by nature, hands-on, integrative, creative, and encourages critical thinking.

Why TDP is so important for Education?

- It holds immense potential for students to gain hands-on experience with new tools (digital, sensors, simulations, machine tools …).
- It can transform young students' personal and social abilities to come up with creative solutions (Yrjönsuuri, 2019).
- It is an ideal integrator of STEM content (Kelley and Knowles, 2016).
- It has a positive impact on students' motivation to study S. T. E. & M. (van Deventer & Steyn, 2022).
- It offers the opportunity to combine conceptual understanding with procedural knowledge (Liu, 2020).

Provincial Context

The Quebec Education Program (QEP, 2006) integrates science and technology in a single discipline but keeps mathematics as a separate one. It’s worth noting that in the QEP, 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 programs like robotics or science and engineering.

The Problem

- It is through the TDP that this study joins technology education as prescribed in the QEP (2006).
- **STEM discipline is challenging when students have little understanding of the relevant concepts in the individual disciplines**.
- In these circumstances, it is **difficult for students to make connections and transfer their knowledge**.
- Also, curriculum analysis **clearly shows** that some **subjects are considered more important than others. For instance,** one such important subject is Mathematics.

The problem

- The aim of this project is to investigate how STEM activities, with a focus on TDP, can assist secondary students in gaining a deep understanding of challenging mathematical concepts, such as **variables and functions**.

- ***Research questions***

1. To what extent do STEM activities enhance students' understanding of both mathematics and TDP?
2. How do STEM activities impact students' motivation to grasp abstract concepts and actively engage in technological problem-solving processes?

Conceptual Framework

- Various **pedagogic approaches** and underlying **philosophical conceptions** of designing that were observed in teaching practice (Haupt, 2018).

- **Pedagogic approaches** ➔ three modes of transfer:

  1. **cognitive constructivism** (individual performance, internal rigour …) (William, 2016)
  2. **social constructivism** (knowledge constructed using external and social elements through interactions with the teacher and peers (Danermark, 2006; Vygotski, 1978).
  3. **technological modes** (focuses on teaching that is facilitated and supported by digital and other technological learning support materials and methods).

Conceptual Framework

Philosophical conceptions ➔ four subcategories:

1. **Epistemology** (knowledge types and their sources that are needed for designing).
2. **Ontology** (nature of the mental processes, types of thinking …).
3. **Methodology** (design procedures and strategies).
4. **Values** (soft skills; attitudes; efficacy judgements; ethics; the effects of technology and artifacts; social awareness; cultural, environmental, technical, and economic values; and environmental sustainability).

Method

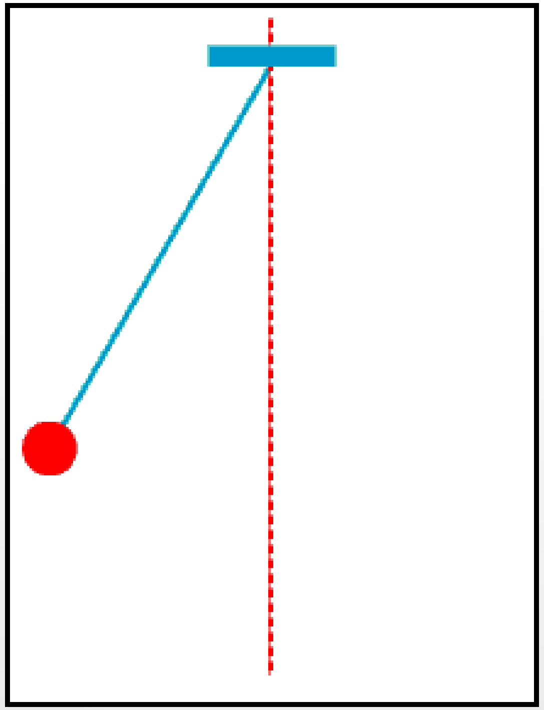
- This project is a continuation of the project that we have implemented in a primary school and presented at PATT39
- Sample: COVID-19 restrictions ➔ 1 grade 7 classroom in Northern Quebec (rural area).

- Data were collected from:
  - Pre- and post-questionnaires;
  - Observations (technology workshop & simulation);
  - Working documents;

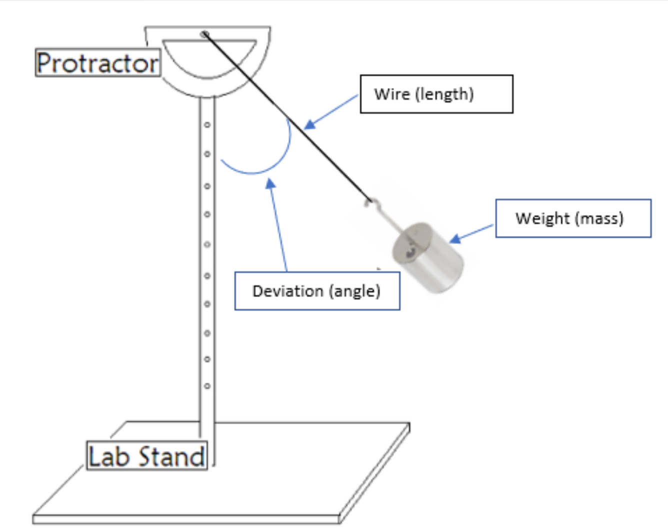
Method: Design of the project

Designed activity

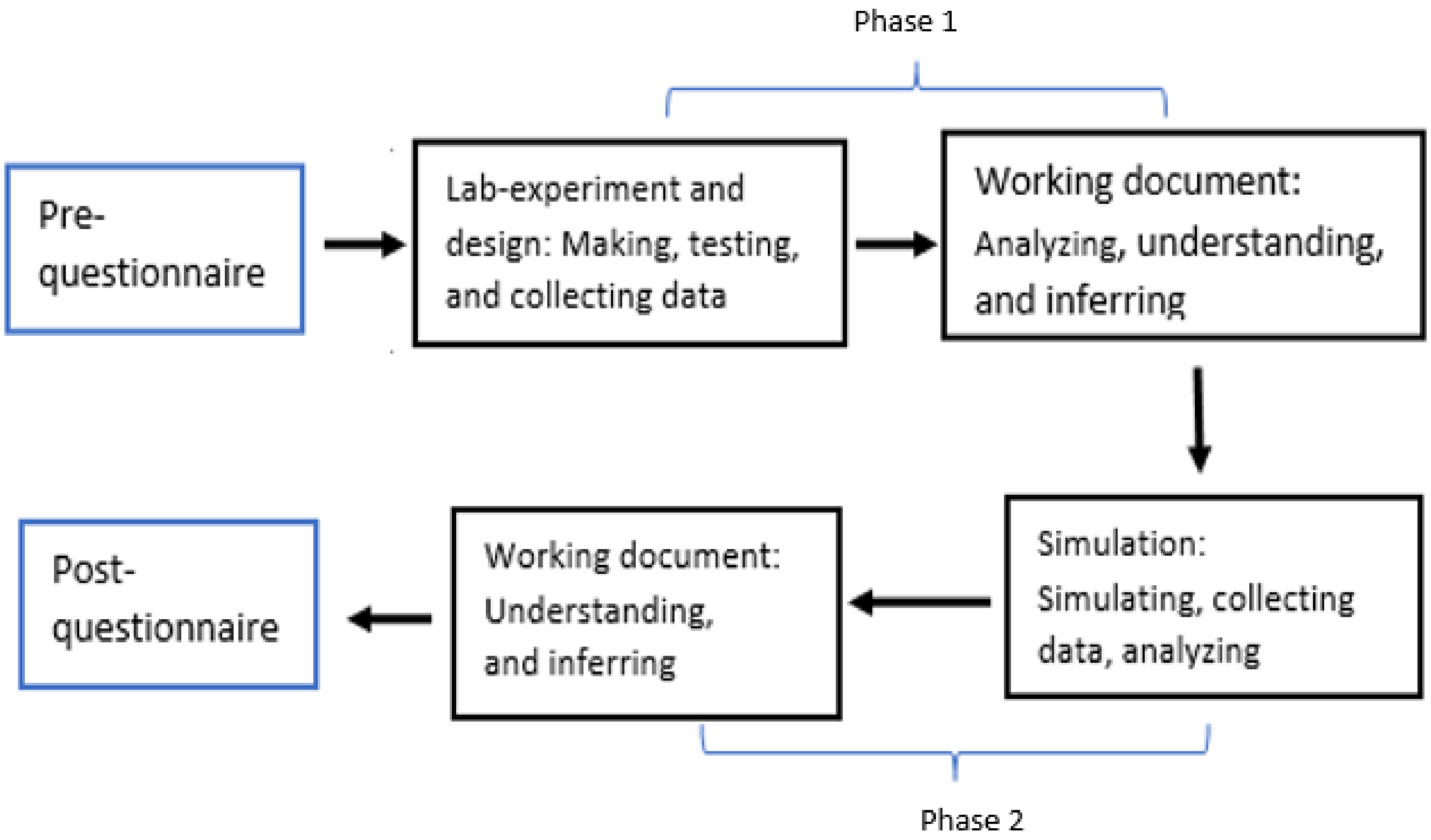
- To promote transdisciplinary learning through the TDP, our initiative started with a physics activity centred on pendulums.
- Designing, Making and Analyzing a pendulum to get insight into the interdependence between the pendulum's variables (***length, mass, angle*** *and* ***period***).
- **Justification**: physics has natural connections with engineering and technology, has the capacity to initiate interdisciplinary dialogues and methodologies that transcend traditional disciplinary boundaries (Sinatra et al., 2015).



Variables



Implementing steps



Method: Project implementation

- **The first phase ➔** begins by assessing students' prior knowledge through a pre-questionnaire designed around three fundamental principles:

  (1) Mitcham's typology of technology (objects, activities, knowledge, and volition.

  (2) STEM epistemic practices (investigating, sense-making, and critiquing (Bevan et al., 2019);

  (3) content derived from the Mathematics, Science, and Technology subject area in the Quebec Education Program (2006).

- Then, Designing (generating ideas) ➔ students identified mass, length, period, and deviation (angle) as important factors to consider in analyzing the pendulum's behavior.

- Furthermore, they identified mass, length, and angle as variables that can be controlled (independent variables), while the period of oscillation is identified as the dependent variable, which cannot be controlled.

Method: Project implementation

- To explore the relationship between these variables, students investigated the impact of an independent variable on the period of the pendulum.
- Collaborating in teams, students were engaged in making, and testing the pendulum in lab setting.
- To collect data on the impact of the mass ➔ students **designed a pendulum** with a fixed wire and varied the weights suspended to its free end.
- To collect data on the impact of the angle as a variable, students encountered a stability issue → this experiment was canceled.
- After completing the design activities, the students answered questions related to graphical analysis and extrapolation.

Method: Project implementation

- **The second phase: (virtual lab or simulation)**

- Students used a simulation tool available on the platform phet.colorado.edu/ to simulate pendulum's motions and gather data, replicating the physical experiments conducted in phase 1.

- 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

- **Pre- and post-questionnaire**

The first category of questions addresses pupils' prior knowledge about pendulums and how they work.

- **Sample of questions**:

  - 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?

Results

- Data indicates that out of the 20 respondents, **only one student did not know what a pendulum is**. The remaining 19 confirmed their familiarity with the concept of a pendulum, although many of them struggled to identify its components.

- Also, **only 6 out of 20 were able to accurately identify the parts of a simple pendulum** and correctly associate its function with the swinging motion.

- Regarding the type of energy involved in a pendulum motion, **only one student made a connection between energy and gravitational force**.

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

Sample of questions:

- 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?

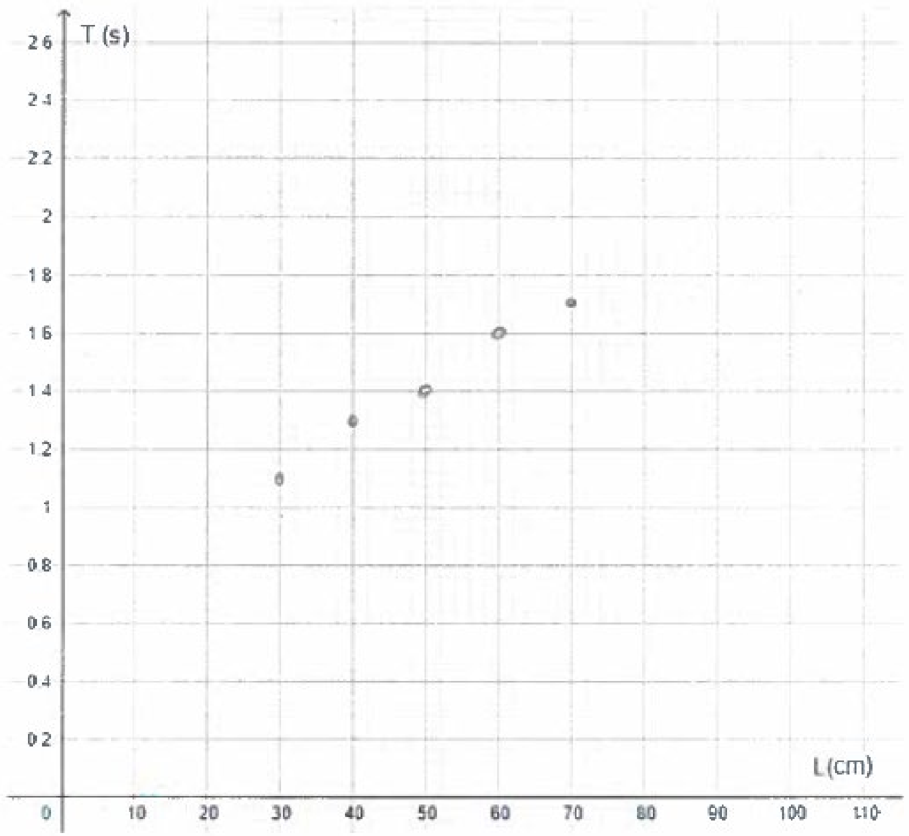
Regarding the meaning of **"variable quantity**," 8 students mentioned that it refers to a quantity that can change.

- One student stated that it signifies an unknown quantity,
- Another one 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**.

- **Working document** ➔ questions related to collecting data and sketching graphs to make a successful analysis.
- **Excerpt 1**
- *Table*

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

- *Figure 3. Length-Period graph*



- Students used their tables and graphs as references to examine the relationship between the two variables (Length & Period). In terms of their ability to interpret and analyze data through visual representations, students demonstrated creative thinking by using extrapolation and inference.

- The responses from the pre-questionnaire indicated that 14 out of 20 students demonstrated the ability to extrapolate their graphs to predict periods for hypothetical pendulums.

- For instance,

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

Phase 2 - simulation

- **Virtual laboratories** have proven to be beneficial for students in enhancing their comprehension of abstract concepts. At this stage, our goal is to encourage students to reflect on the advantages, limitations, and constraints of both physical laboratory experiments and simulations.

- Through simulations, students have learned how the virtual environment empowers them to overcome the limitations imposed by physical constraints of lab equipment. This allowed them to explore and expand the boundaries of their knowledge in ways that may not have been possible in a traditional lab setting, such as dealing with small values, friction, stability, and quick data collection.

- 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.

- **Post-questionnaire**

- The post-questionnaire analysis reveals that all students had acquired an understanding of the steps involved in the TDP and a clear comprehension of a simple pendulum and how it works.

- Sixteen students demonstrated 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, only two out of the 20 students were able to establish a correlation between the force of gravity and the potential energy involved in the pendulum's oscillating motion.

- To explore this topic further, we included a question about the inverse function in the working document. We prompted the students to consider how to design a pendulum to achieve a specific oscillation period.

- For example, the responses indicate that 11 out of 20 students used their graphs to identify the hypothetical pendulums.

Can you determine, by using graph 1, the length L of pendulums that have different periods 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

- By engaging in STEM and hands-on activities, students have the opportunity to:
    - Develop their technological literacy.
    - Enhance their understanding of TDP and the principles governing simple harmonic motion.
    - Experience a smoother transition to variables and functions.
- Active involvement in TDP-centered activities empowers students to generate innovative solutions, analyze data, identify models, and establish connections between variables. This fosters their ability for critical thinking, questioning, reasoning, meaningful exploration of concepts, and increases their motivation. Additionally, collaboration among students during these activities offers opportunities for peer learning.

Thanks for your attention!