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When Research Meets Reality

Lessons from STEM Education for Addressing Canadian K-12 Teaching Crisis

How diverse research methodologies inform teaching, teacher education, and policy

Prof. Marina Milner-Bolotin

MathEd Forum Research Day, January 31, 2026

Acknowledgement

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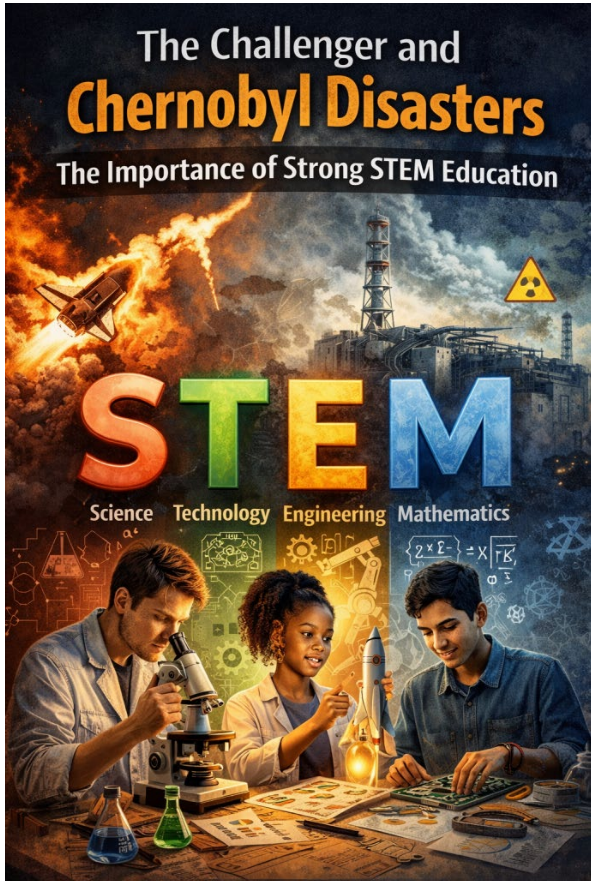
40 years after Challenger and Chernobyl: What have we learned?

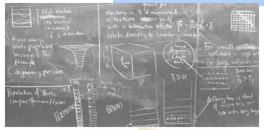


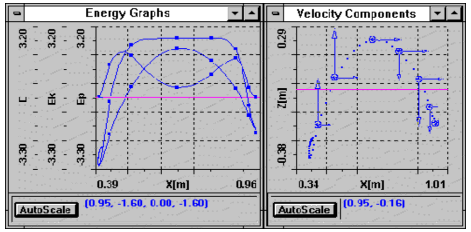
The Post-Disaster Paradox in STEM Education

One might expect that such events would strengthen science education, deepen respect for expertise, and reinforce the value of rigorous thinking. Instead, the decades that followed saw a **gradual erosion of deep STEM engagement**. Enrolment in advanced physics, chemistry, and mathematics declined. Students disengaged just as ideas became conceptually demanding. STEM became louder in policy documents but thinner in classrooms. We added activities, tools, slogans, and technologies—but often weakened the intellectual core. This is not coincidence. When STEM education drifts away from **foundational understanding**, it produces graduates who can follow procedures but struggle to evaluate evidence, question assumptions, or recognize when systems are being pushed beyond safe limits. That is precisely the failure mode exposed by both CHALLENGER and Chernobyl.

https://blogs.ubc.ca/mmilner/2026/01/20/forty-years-later-challenger-chernobyl-and-the-cost-of-weak-stem-foundation/

Dr. Marina Milner-Bolotin: Education Journey





V-scope

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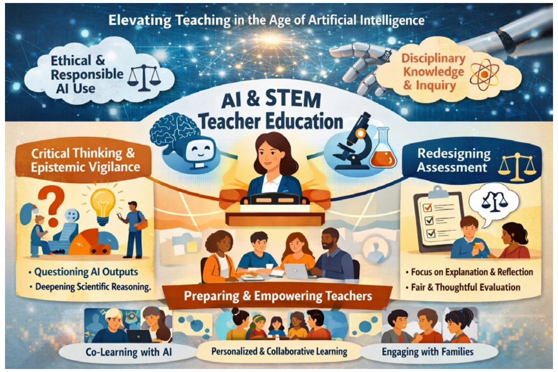
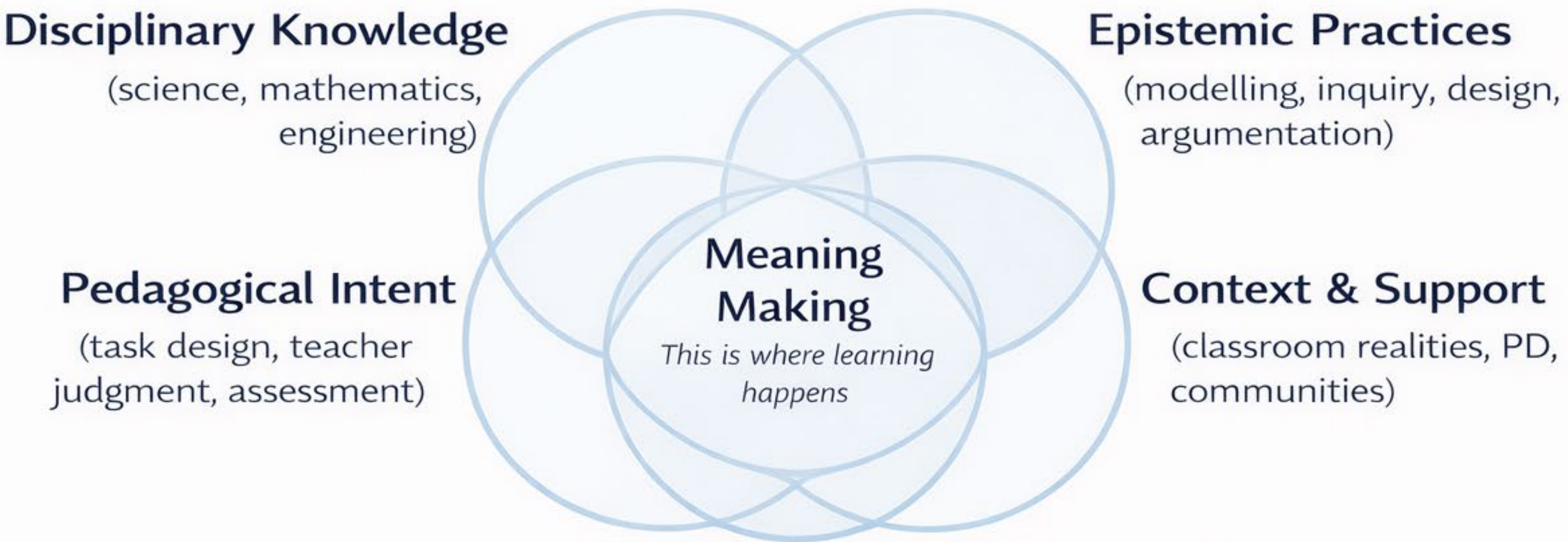


What STEM Education Is: A research-informed view

STEM education is **not** a subject, a program, or a slogan.

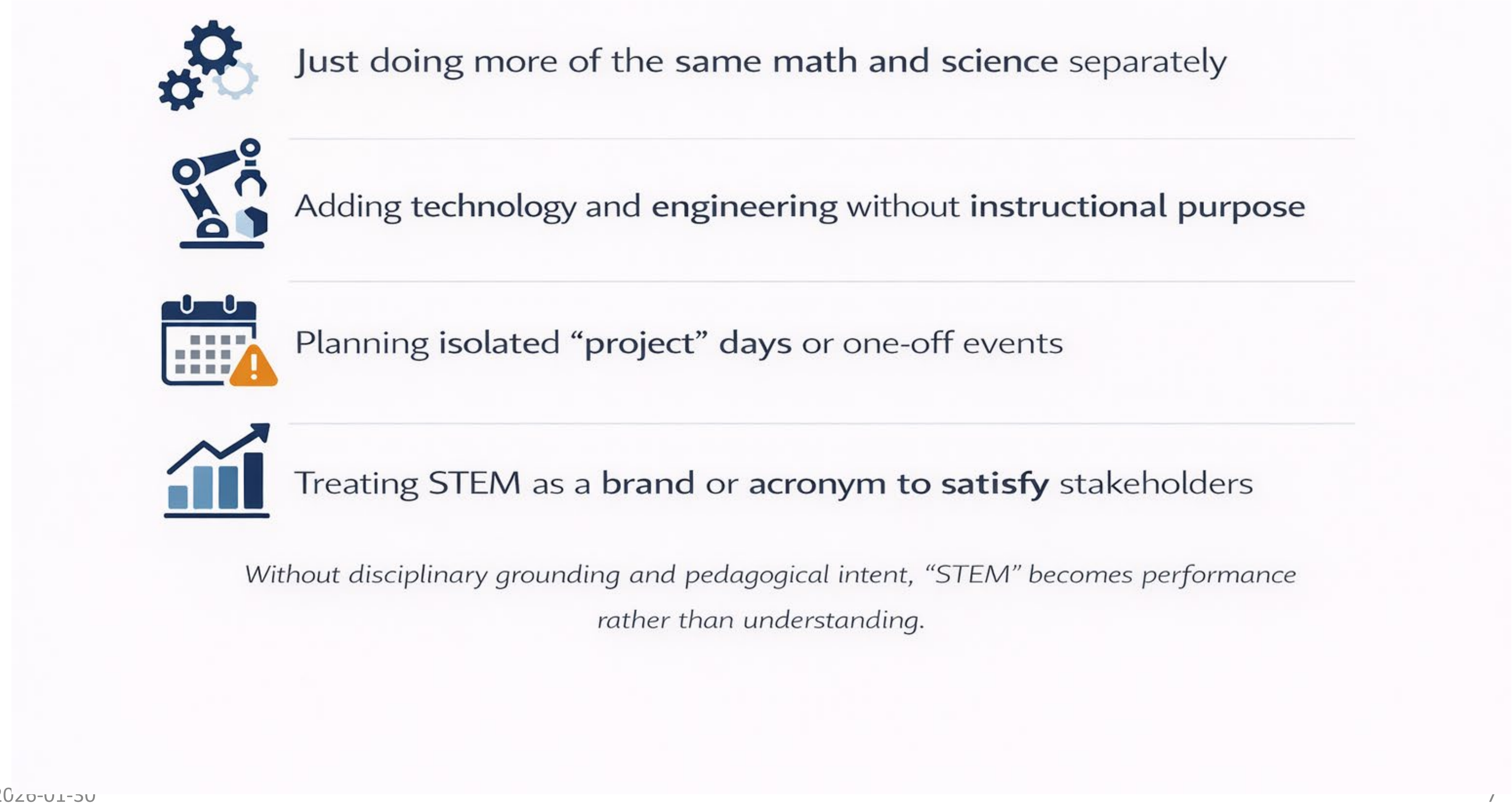
It is **a research-informed approach** to teaching and learning.



Without disciplinary grounding and pedagogical intent, “STEM” becomes performance **rather than understanding.**

STEM education intentionally integrates disciplinary knowledge and practices from science, mathematics, technology, and engineering to support **meaningful inquiry, modelling,** and problem solving— **guided by pedagogical purpose and sustained teacher learning.**

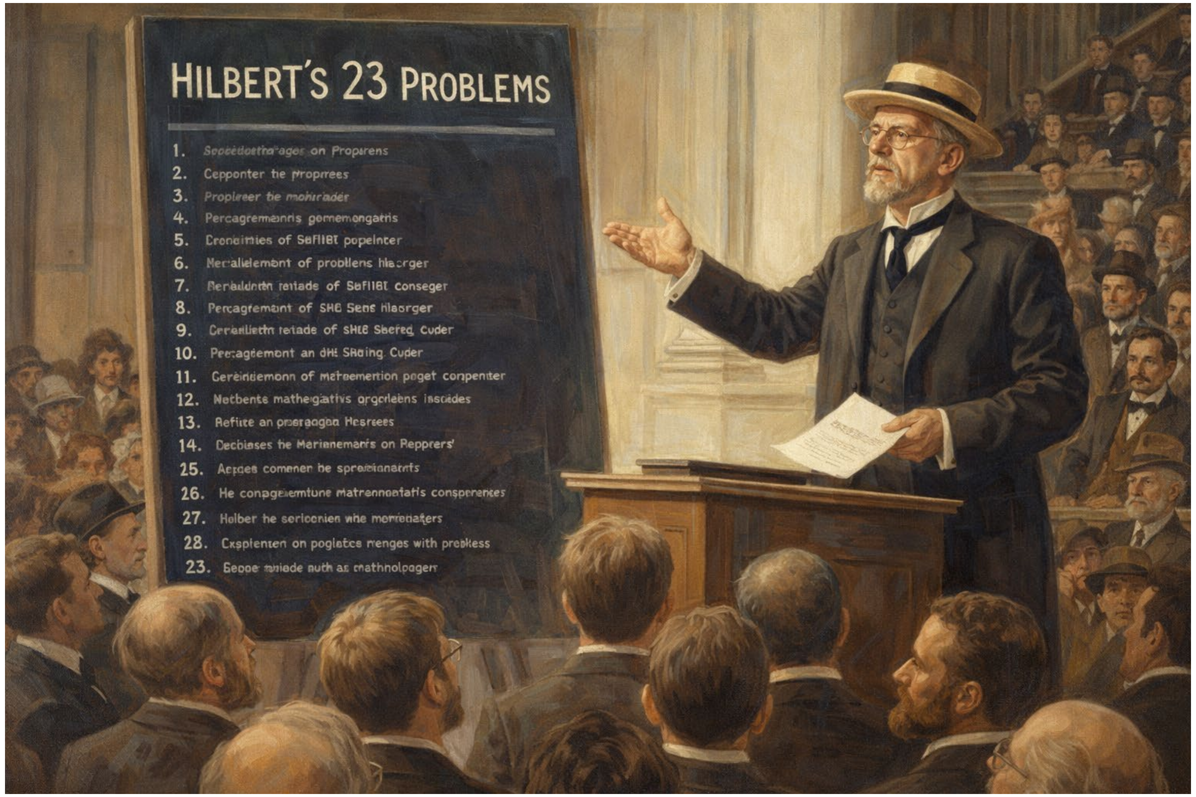
What STEM Education is NOT: A research-informed view



How Do We Know What Works in STEM Education?

1. Technology has **the potential** to improve education
2. We need knowledgeable teachers who will ***use technology to improve learning***
3. We need research evidence:
    - Ask hard research questions
    - Produce meaningful answers
    - Apply answers to practice
4. Research-practice-policy connection

STEM Education Lessons from David Hilbert

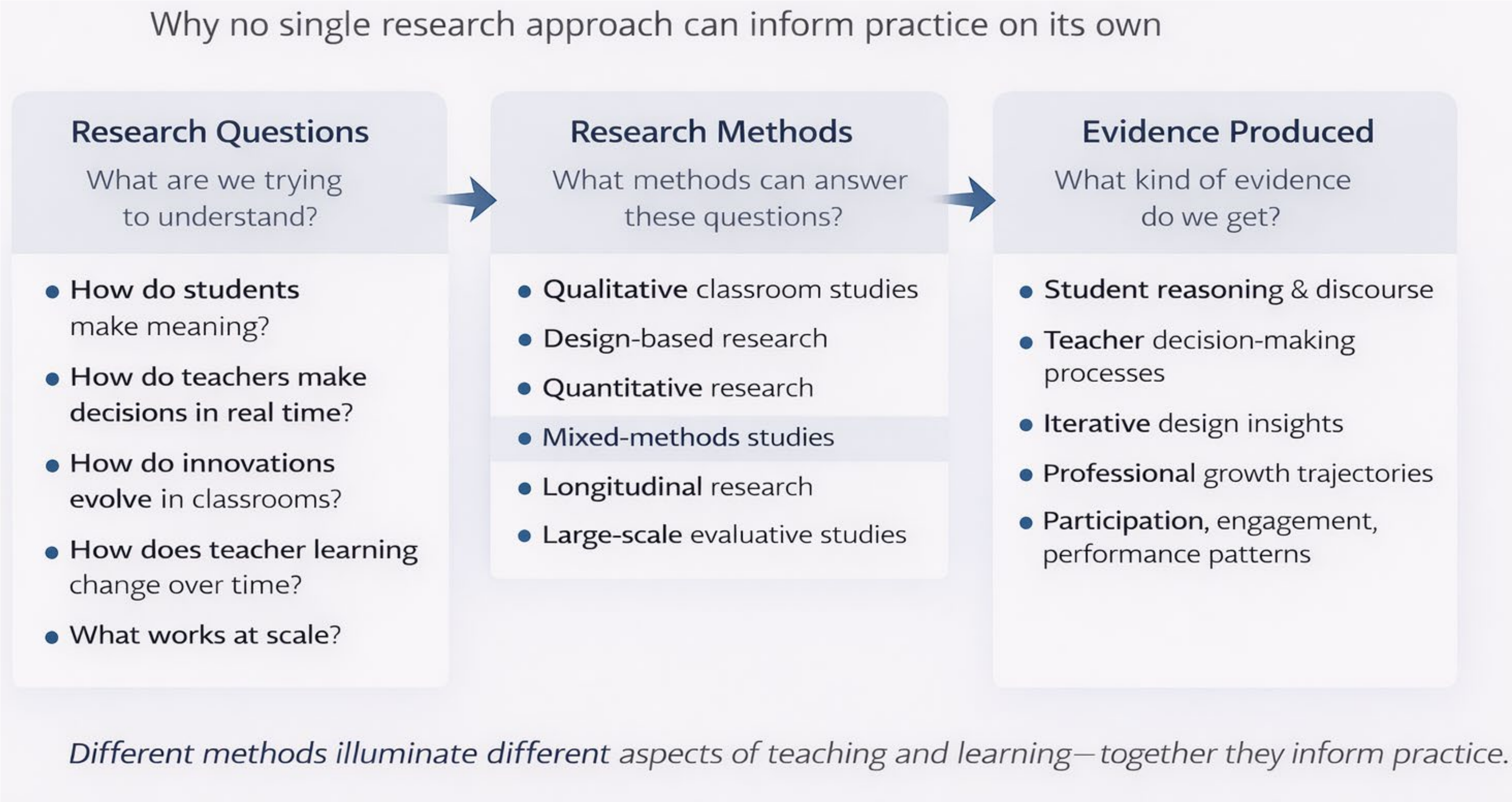


David Hilbert proposed 23 problems at the Congress of Mathematics in Paris, 1900

Hilbert's vision as a model for inquiry in education:

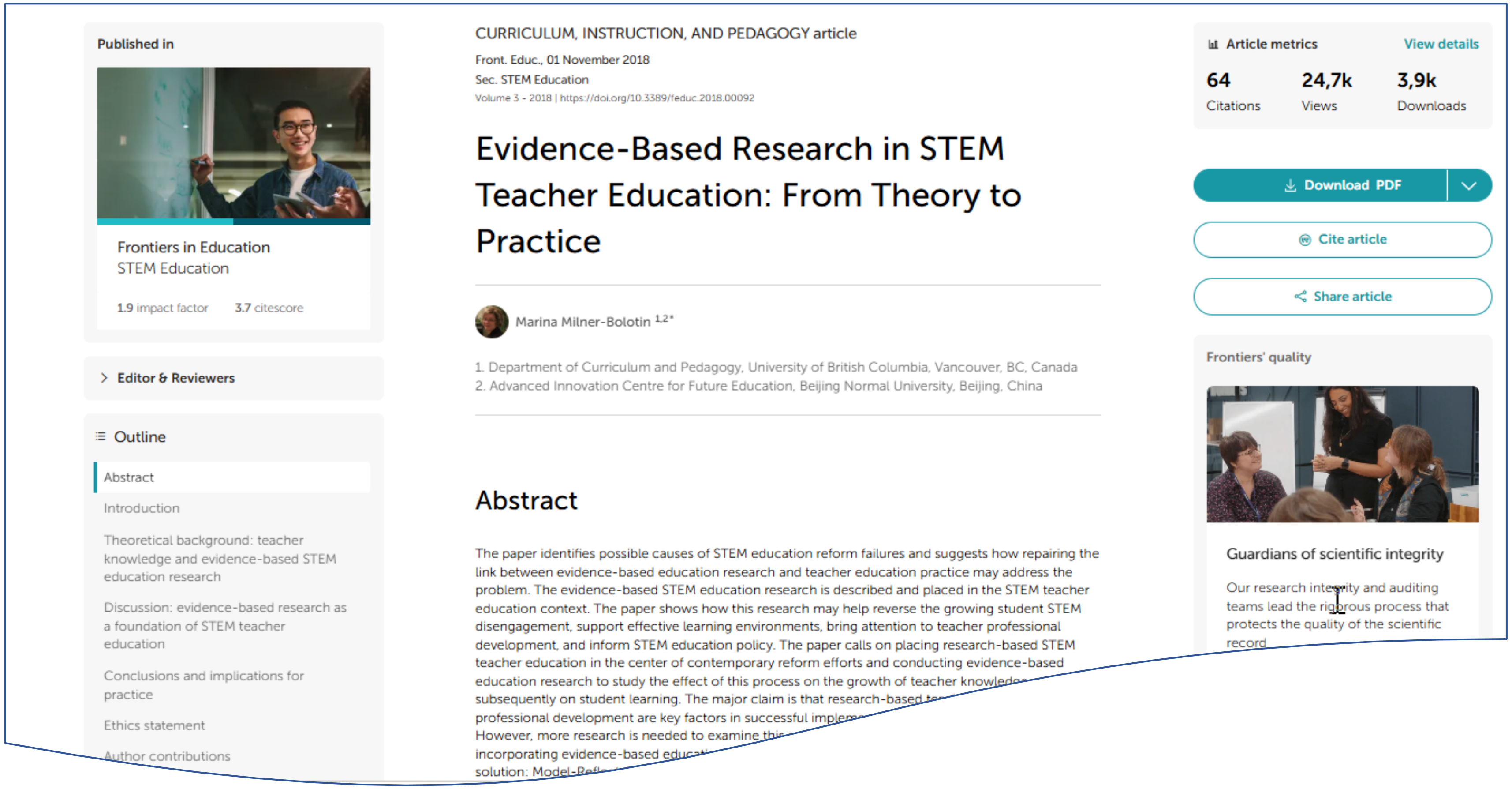
- Research (evidence)-driven inquiry
- Authentic inquiry begins with uncertainty
- Epistemic humility and collective progress
- Research practice and policy

Different Questions – Different Methods – Different Evidence



Paper 1: Evidence-Based Research in STEM Education, 2018 (theoretical, conceptual, epistemological)

frontiers



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Outline

Abstract
Introduction
Theoretical background: teacher knowledge and evidence-based STEM education research
Discussion: evidence-based research as a foundation of STEM teacher education
Conclusions and implications for practice
Ethics statement
Author contributions

CURRICULUM, INSTRUCTION, AND PEDAGOGY article

Front. Educ., 01 November 2018
Sec. STEM Education
Volume 3 - 2018 | https://doi.org/10.3389/feduc.2018.00092

Evidence-Based Research in STEM Teacher Education: From Theory to Practice

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Abstract

The paper identifies possible causes of STEM education reform failures and suggests how repairing the link between evidence-based education research and teacher education practice may address the problem. The evidence-based STEM education research is described and placed in the STEM teacher education context. The paper shows how this research may help reverse the growing student STEM disengagement, support effective learning environments, bring attention to teacher professional development, and inform STEM education policy. The paper calls on placing research-based STEM teacher education in the center of contemporary reform efforts and conducting evidence-based education research to study the effect of this process on the growth of teacher knowledge subsequently on student learning. The major claim is that research-based te... professional development are key factors in successful implem... However, more research is needed to examine this... incorporating evidence-based educa... solution: Model-Refl...

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[Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education: STEM Education*, *02*(November), 14. https://www.frontiersin.org/journals/education/articles/10.3389/feduc.2018.00092/full]

Cargo-Cult Science: When Research Looks Right but Isn't

"The first principle is that you must not fool yourself—and you are the easiest person to fool." — Richard Feynman

In **cargo cult science**, researchers follow the ***rituals of science***—experiments, statistics, graphs, technical language—but miss its core commitments:

1. **Intellectual honesty**
2. **Careful control of variables**
3. **Transparent reporting of negative or null results**
4. **Critical self-scrutiny and openness to being wrong**

[Feynman, R. P. (1974). *Cargo Cult Science*. Caltech Commencement Address. Reprinted in *Surely You're Joking, Mr. Feynman!* (1985).]

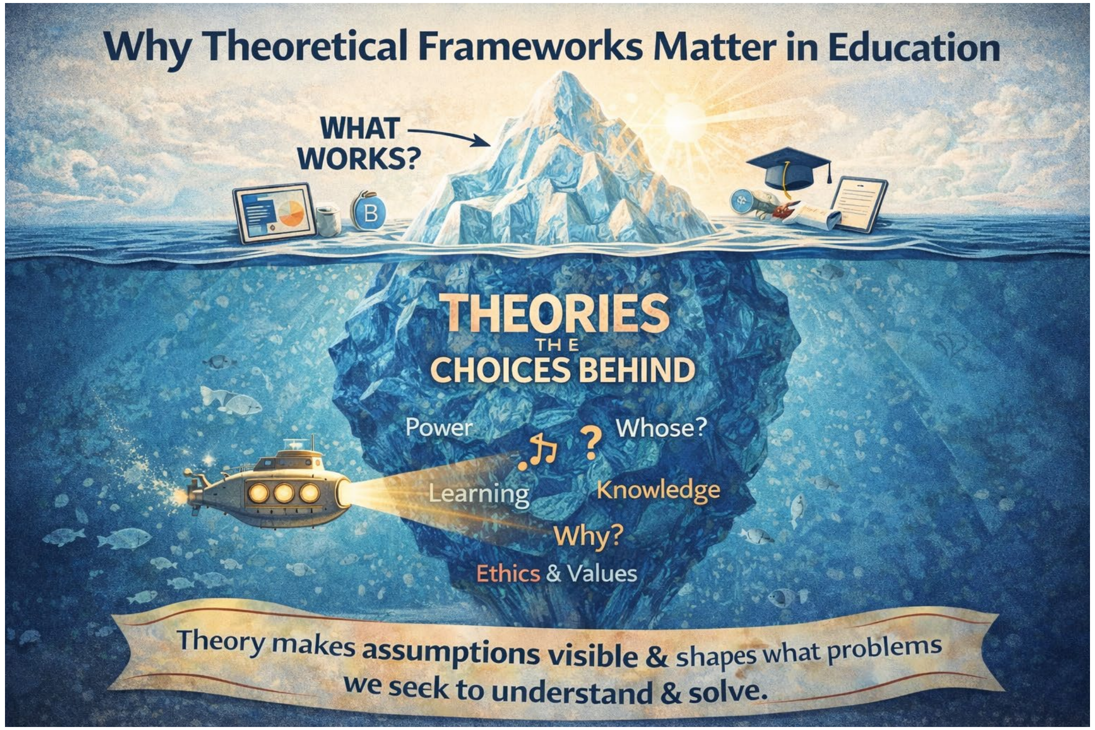
Why This Matters to STEM Education

Cargo-cult science in STEM education emerges when we **value the performance of innovation over deep disciplinary understanding and pedagogical content knowledge:** leaving teachers to enact reforms without the intellectual resources needed to make them work.

Cargo-cult STEM education thrives because form is easy to copy and evaluate, while genuine understanding, the core of STEM, is slow to earn and harder to discern.

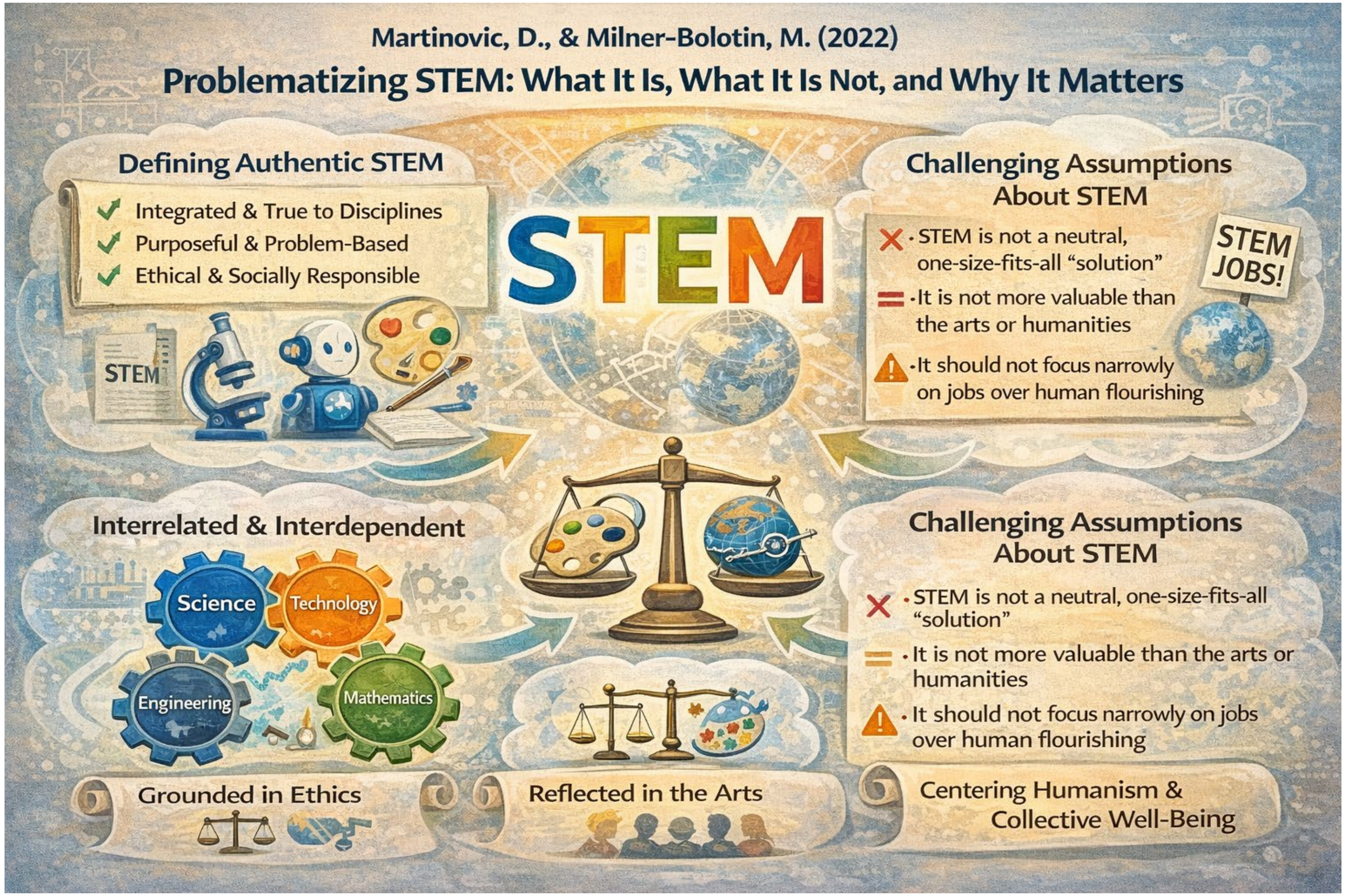
Theoretical Frameworks in Education Research

1. They make assumptions visible
2. They guide *what* questions we ask
3. They prevent “cargo-cult” research
4. They connect research, practice, and policy
5. They support ethical and professional judgment



Theoretical frameworks in education are not decorative—they allow us to ask better questions, interpret evidence responsibly, and act with professional and ethical judgment.

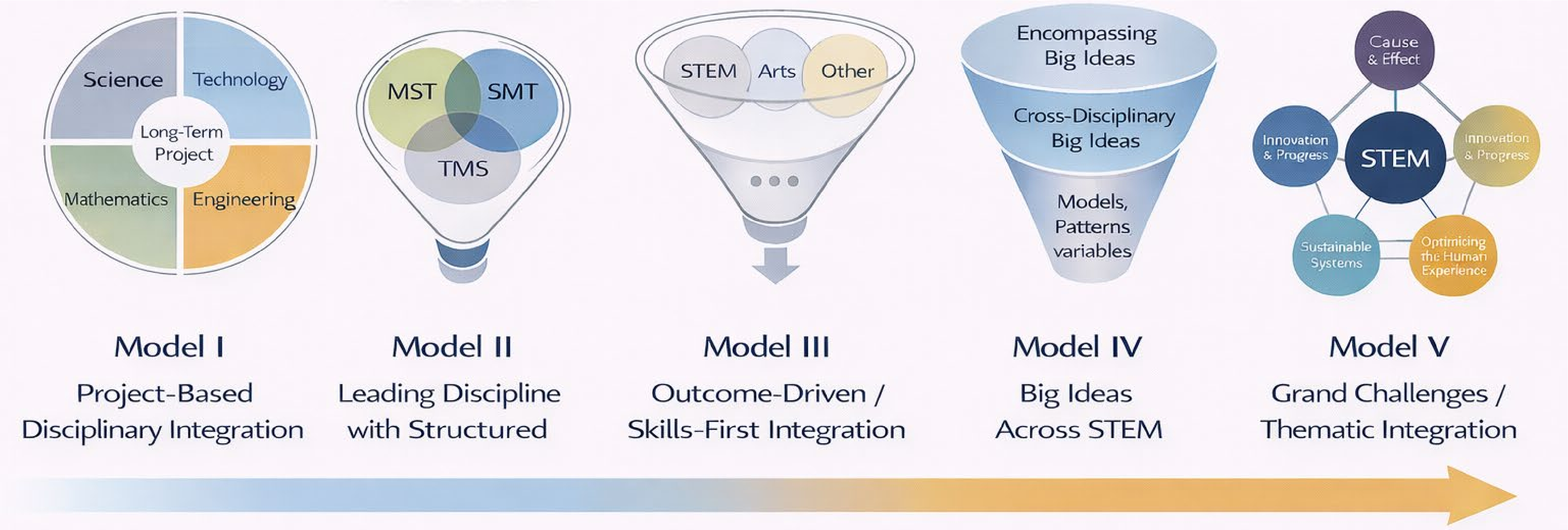
Paper 2: Nature of STEM Education (analysis, raising new questions, implications for policy)



Problematizing STEM: What it is, what it is not, and why it matters

[Martinovic, D., & Milner-Bolotin, M. (2022). Problematizing STEM: What it is, what it is not, and why it matters. In C. Michelsen, A. Beckmann, V. Freiman, U. Thomas Jankvist, & A. Savard (Eds.), *15 Years of MACAS (Mathematics and its Connections to the Arts and Sciences)* (pp. 135-162). Springer Nature. https://doi.org/https://link.springer.com/chapter/10.1007/978-3-031-10518-0_8]

Paper 2: 5 STEM Education Models: From fragmentation to purpose-driven integration



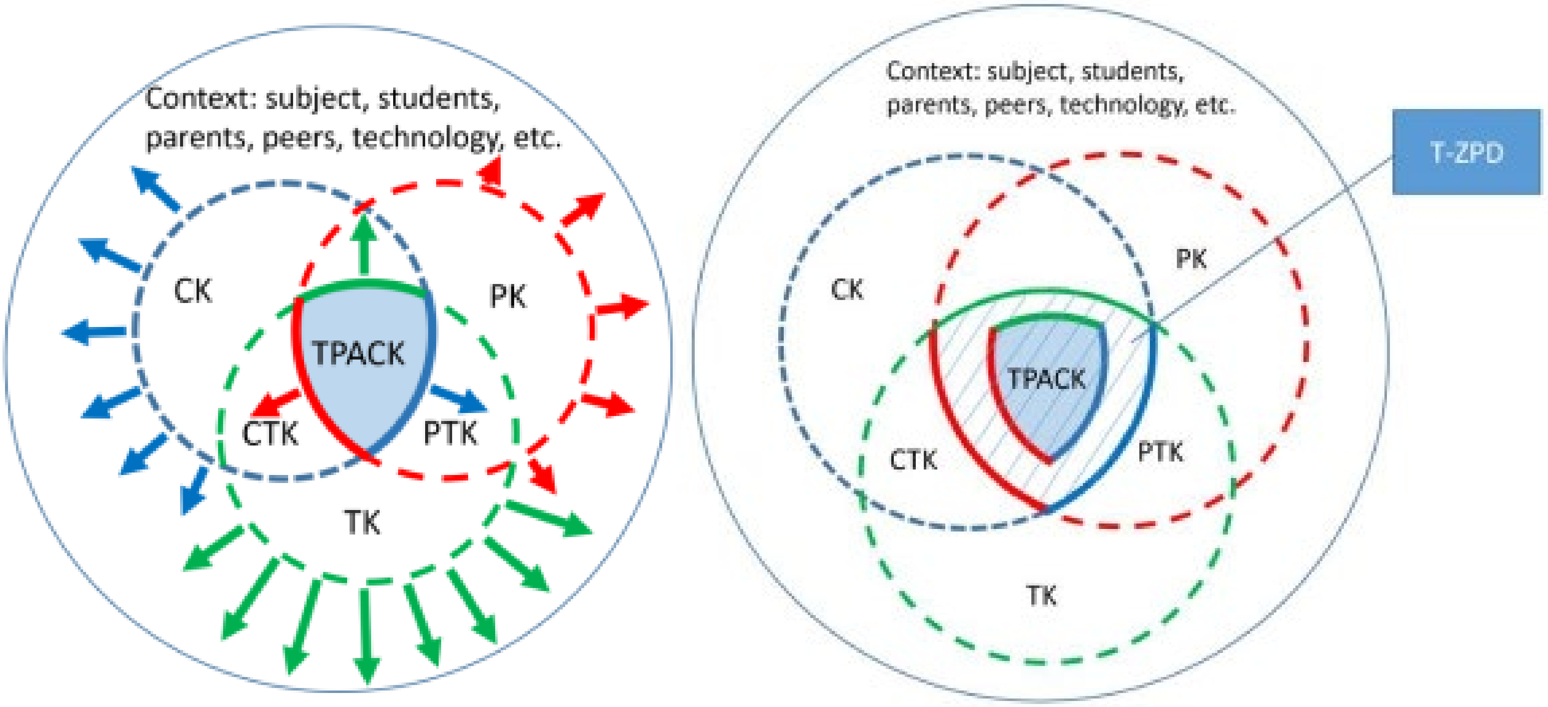
How do we create purposeful epistemologically sound models for STEM education?

Papers 3-4: Deliberate Pedagogical Thinking with Technology Framework (theoretical & practical implications)

1. What makes technology "useful" in STEM teaching?
2. What does it mean DELIBERATE use of technology?
3. How do existing frameworks (e.g., TPACK) fall short in explaining teachers' learning with technology?

[Milner-Bolotin, M., & Milner, V. (2023). Smartphone applications as a catalyst for active learning in chemistry: Investigating the Ideal Gas Law. In Y. J. Dori, C. Ngai, & G. Szteinberg (Eds.), *Digital Learning and Teaching in Chemistry* (pp. 266-280). Royal Society of Chemistry.]

Papers 3-4: Deliberate Pedagogical Thinking with Technology Framework (theoretical & implications)



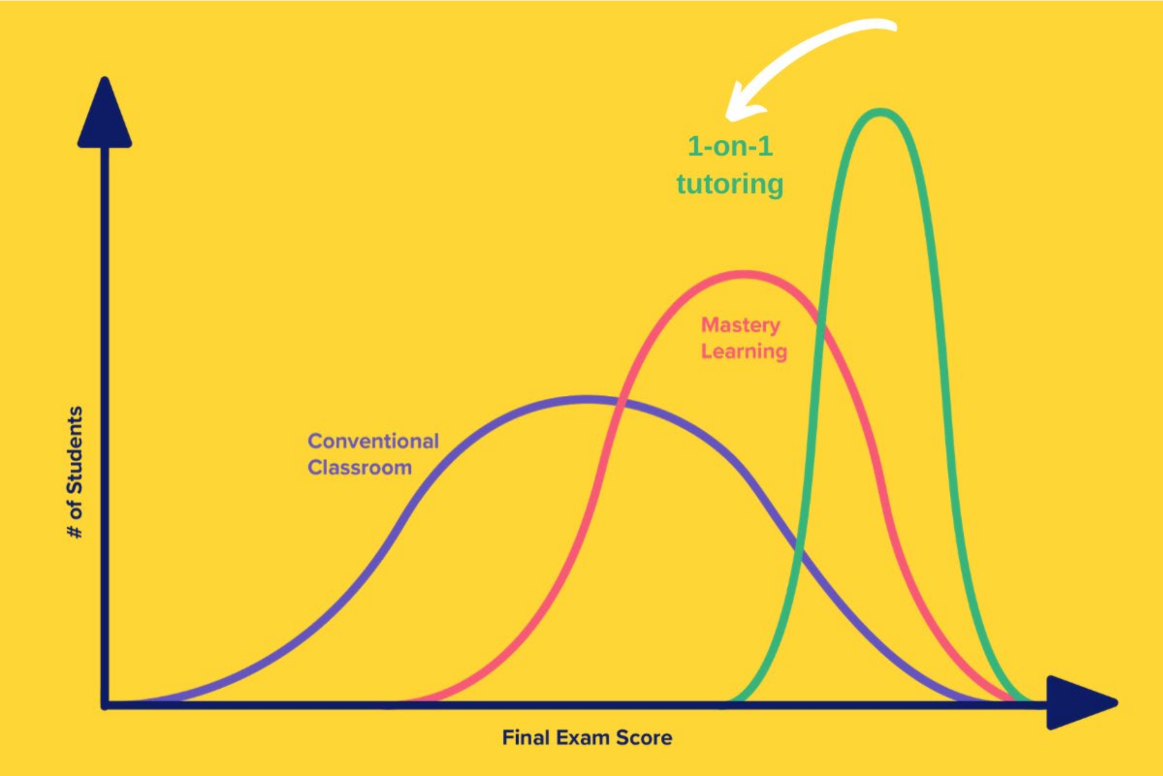
(a) (b)

3. How can existing frameworks be extended to better capture **teachers' professional growth, agency, and pedagogical judgment when using technology?**

[Martinovic, D., Ben-David Kolikant, Y., & Milner-Bolotin, M. (2019). The usefulness of technology in teacher profess. development: Extending the frameworks. *Journal of the International Society for Teacher Education*, *23*(2), 21-36.]

Paper 5: Bloom's 2-Sigma Problem, 1984 (quantitative study, vision for future research)

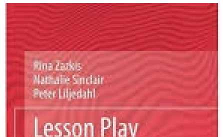
Research question: What instructional methods, feedback systems, and learning designs can approximate the effectiveness of tutoring within scalable group settings?



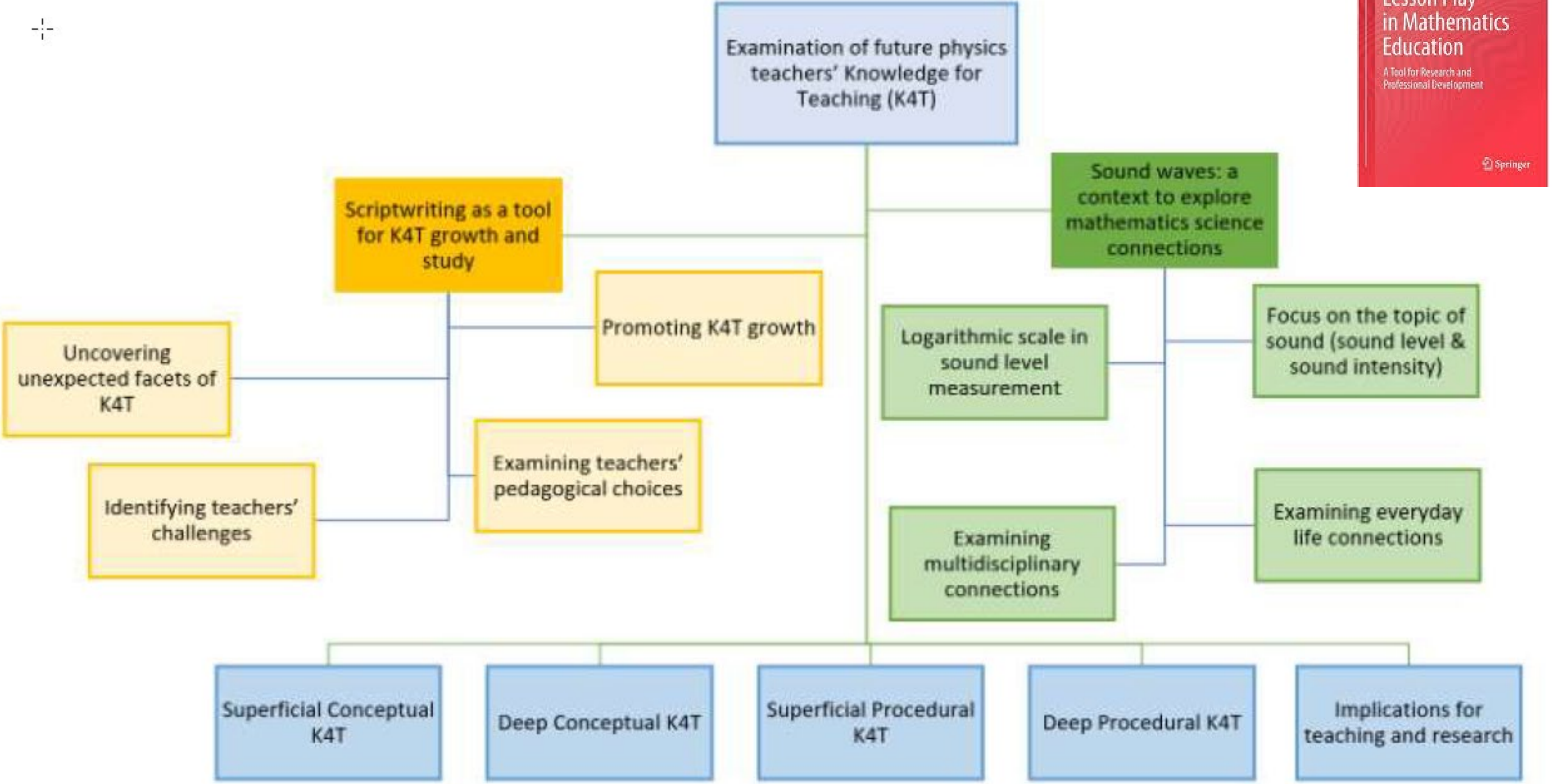
Can researchers and teachers devise feasible learning environments that will enable the majority of class to attain levels of achievement that can at present be reached only under good tutoring conditions?

[**Benjamin Bloom, 1984,** The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring, *Educational Researcher* in June–July 1984, Volume 13, Issue 6, pages 4–16.]

Paper 6: A study of knowledge for teaching (case study, action research)

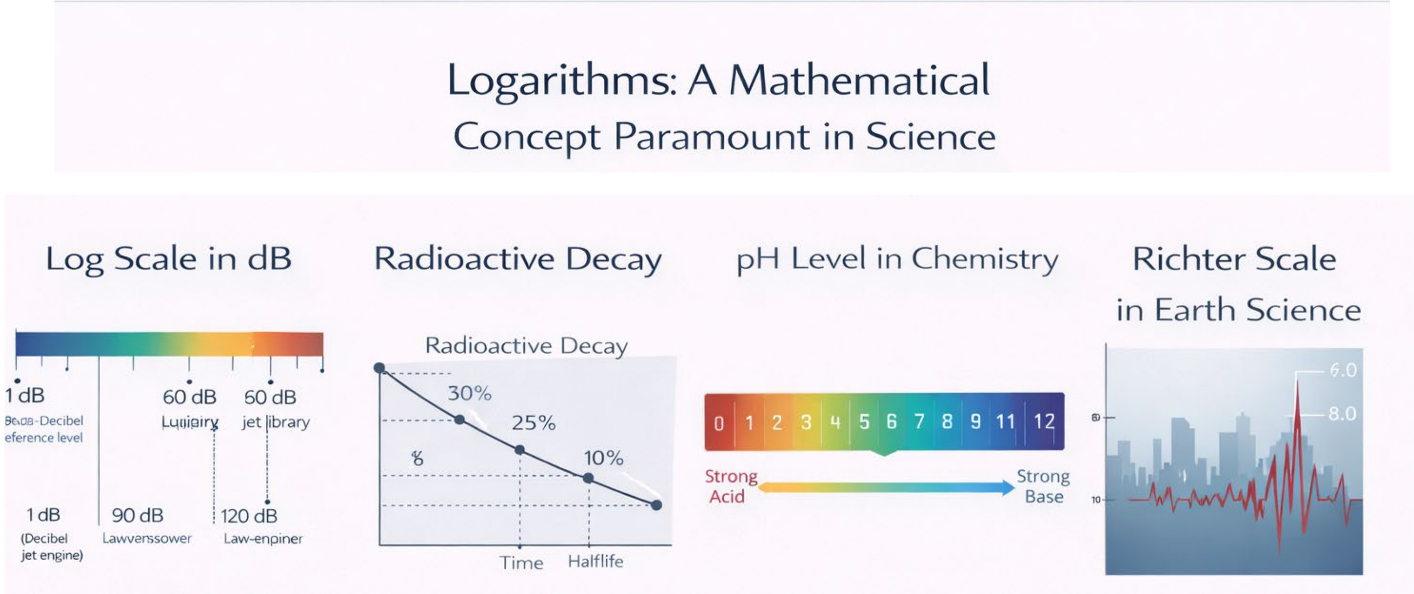


1. What background knowledge do future physics teachers need to teach the dB sound level scale?
2. What challenges do they experience when connecting dB math structure to its physical meaning?



[Milner-Bolotin, M., & Zazkis, R. (2021). A study of future physics teachers' knowledge for teaching: A case of a decibel sound level scale. *LUMAT: International Journal on Math, Science and Technology Education*, *9*(1), 336-365. https://doi.org/10.31129/LUMAT.9.1.1519]

Paper 6: A study of knowledge for teaching (case study, Lesson play as a tool to probe teachers' K4T, action research)



Probing future physics teachers' Knowledge for Teaching (K4T)

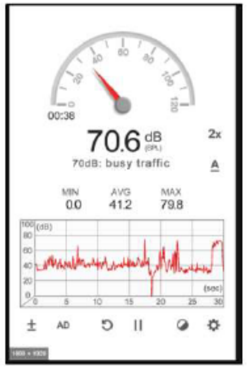
Physics 11: Exploration of sound and its properties

https://curriculum.gov.bc.ca/curriculum/science/11/physics

https://www.healthlinkbc.ca/health-topics/tf4173

Play Setting: *The play is set in a Physics 11 classroom. The students have just finished the intro unit on waves and already had two introductory lessons on sound. They discussed the properties and behaviour of waves, sound characteristics, the phenomenon of resonance, how waves are generated and how they propagate. When the teacher entered the classroom the following week, she noticed a group of students arguing excitedly in the corner about the sound level at the concert they just attended over the weekend:*

Student 1: I had a huge headache after the last Saturday's concert. I had my smartphone app and it measured the sound level there to be 91 dB. This was hurting my ears and my head for the entire Sunday. I still feel it.



Student 2: I have read that sound levels that are above 85 dB are harmful to humans, so this is understandable, but that harmful? 91 dB is less than 10% higher than the threshold. So 91 dB should not be such a big deal.

Student 3: It doesn't make sense! I am very confused with this dB thing. What is it? I have a Sound level app on my smartphone. But what do these measurements mean? This is so confusing.

Teacher: This is an interesting conversation. This is a great opportunity to discuss the concept of sound level and what it means…

Roles:

Teacher: A very thoughtful and inspiring new physics teacher

Student 1: ______________________

Student 2: ______________________

Student 3: ______________________

Additional characters: ______________________

Figure 1. A scripting task on the topic of sound implemented in the study

Paper 6: Study Findings and Implications (case study, action research)

Table 3. Description of four categories of teachers' K4T that guided this study

Category of teacher's K4T	Description of the category
Superficial conceptual	Declaring connections between concepts without elaboration
Deep conceptual	Explaining underlying relationships between concepts
Superficial procedural	Focusing on the use of procedures without elaborating on the underlying principles
Deep procedural	Connecting procedures to underlying principles

Teacher: ... I know that all of you are very comfortable with linear scales. If I double a certain quantity, then the number with its associated unit is doubled as well. This does not work when talking about decibels. If I speak at 50 dB, then double the sound intensity, I do not speak at 100 dB. I will now give you a short introduction to logarithms, and in pre-calculus 12 next year, you will go more in depth learning about them.

Teacher writes the following equation on the board: $\beta = 10 \log \frac{I}{I_0}$.

This is equation we use when we talk about sound intensity measured in decibels. The *log(x)* says to take the logarithm of the quantity in the parentheses, using base 10. This can be done by using the log function on your calculator. As an example, I want you all to calculate what the logarithm of 10 is in base 10.

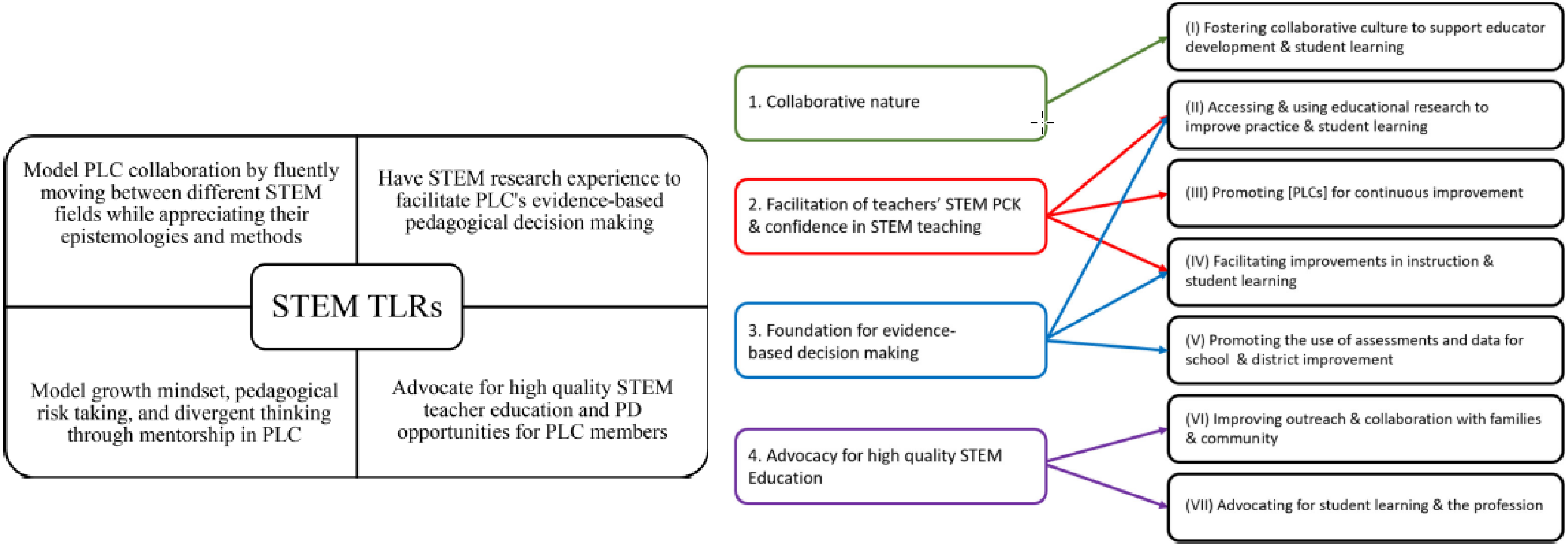
Example of a Superficial Procedural Knowledge for Teaching

Paper 7: Teacher Leadership in STEM (analysis, implications for practice)

1. What differentiates the knowledge, dispositions, and skill sets of STEM teacher leaders (TLRs) from leaders in individual STEM disciplines?
2. What mechanisms and supports, especially within professional learning communities (PLCs), can help STEM teacher leaders empower and sustain their peers?

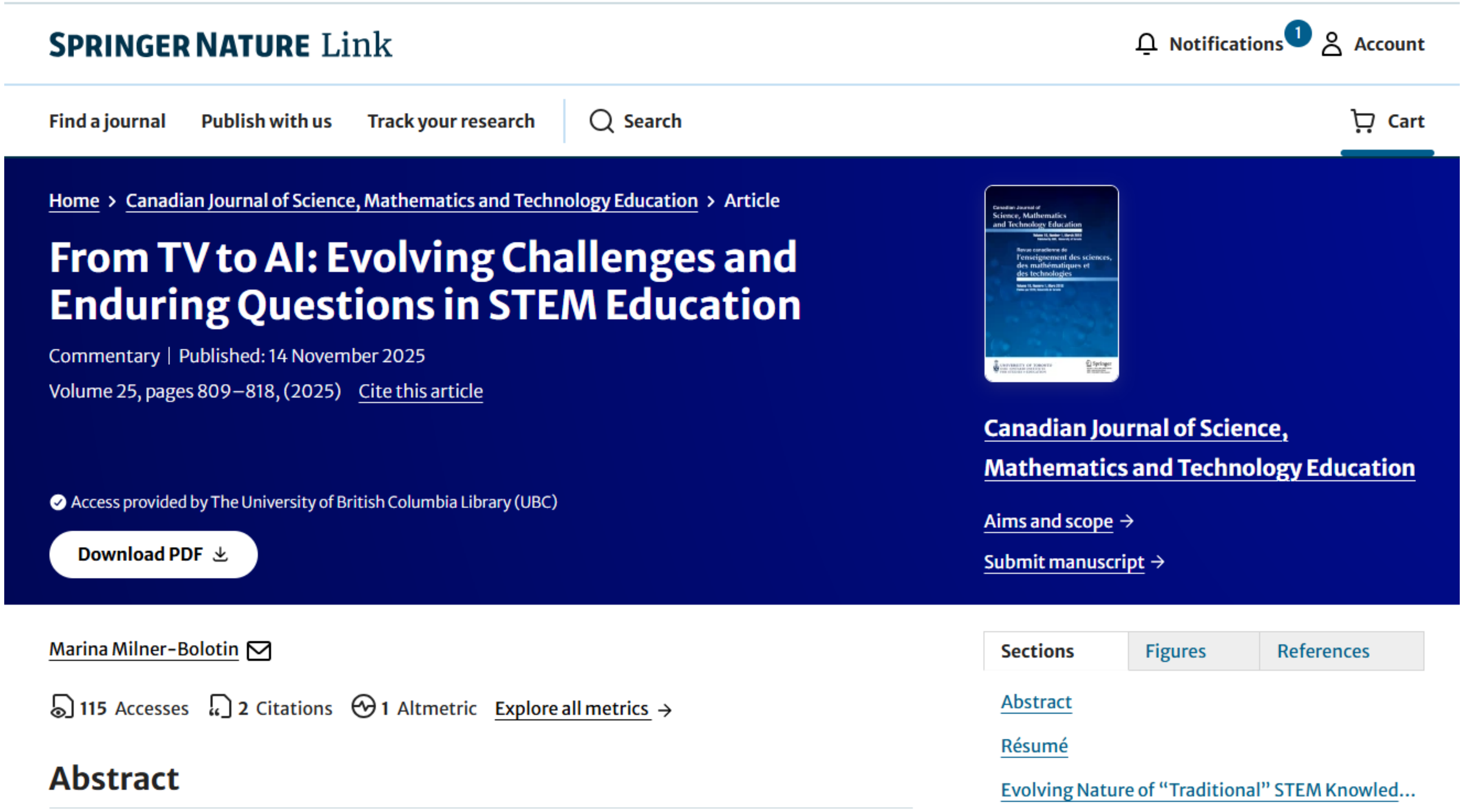
[Martinovic, D., & Milner-Bolotin, M. (2024). Re-imagining Professional Learning Communities in Education: Placing Teacher Leadership in STEM Context. *School Science and Mathematics*, 1-12. https://doi.org/10.1111/ssm.18315]

Paper 7: Teacher Leadership in STEM (analysis, implications for practice)



[Martinovic, D., & Milner-Bolotin, M. (2024). Re-imagining Professional Learning Communities in Education: Placing Teacher Leadership in STEM Context. *School Science and Mathematics*, 1-12. https://doi.org/10.1111/ssm.18315]

Paper 8: STEM Education in the Age of AI (analysis, implications for practice)



[Milner-Bolotin, M. (2025). From TV to AI: Evolving Challenges and Enduring Questions in STEM Education [Commentary]. *Canadian Journal of Science Mathematics and Technology Education*, 1-10. https://doi.org/https://doi.org/10.1007/s42330-025-00404-x]

Implications for Practice & Policy: When Research Meets Reality

- STEM education research matters only ***when it changes what happens in classrooms and informs the systems that support teachers and students.***
- Research must **guide instructional design**, **shape teacher education**, and **inform responsible technology integration**, including AI.
- For STEM education to thrive, **policy must be research-informed, practice must be evidence-based**, and **research must stay grounded in classroom realities**.
- Strong STEM education systems are built when research, practice, and policy move forward together—intentionally, critically, and responsibly.

Final Thoughts: Research-informed view of STEM Education