The Technical Capability Fallacy

A Case for Pedagogy-Centered Design in Assistive STEM Education

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A Persistent Gap

81.4%
mean accuracy in labs

88% of barriers:
pedagogical / institutional

rare
sustained classroom adoption

The **Technical Capability Fallacy**: assuming that accuracy and speed in controlled settings guarantee effective classroom use.

Accessible $\neq$ educationally effective.

Corpus: 25 empirical studies

Period	2015–2025
Sources	ACM / IEEE / PubMed / WoS
Agreement	Cohen's $\kappa = 0.84$
Method	Thematic analysis (2 coders)

Three Patterns Driving the Fallacy

1 / Evaluation Mismatch

76% of studies foreground technical metrics.

24% measure learning outcomes.

Adoption barriers are pedagogical, not technical.

2 / Learning Objective Imbalance

56% analytical reasoning.

4% procedural fluency.

Foundational STEM skills are neglected.

3 / Context-Blind Design

Tools specify no educational context.

Elementary $\neq$ Secondary $\neq$ Postsecondary.

All three patterns converge on a single root cause:
tools are optimised against the wrong metrics.

Pattern 1 — Evaluation-Practice Mismatch

76%
foreground technical metrics

24%
measure learning outcomes

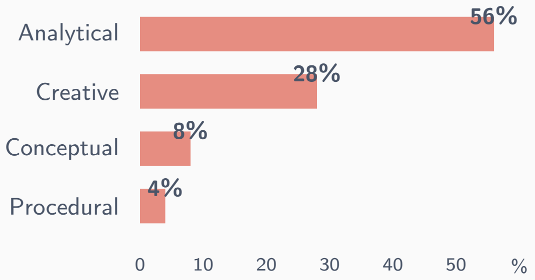
What actually blocks adoption

Teacher preparation time	**88%**
Funding instability	**72%**
Curriculum alignment	**32%**
Assessment format mismatch	**28%**
Technical usability (barrier)	**1 study**

Only **4/25** studies used evaluations >1 month. Adoption failures take months to emerge.

Exemplar (n=14 analytical tools): mean lab accuracy 81.4%. All 14 showed low adoption due to curriculum pacing (32%), assessment mismatch (28%), logistics (24%).

Pattern 2 — Learning Objective Imbalance



The consequence

STEM learning typically builds **procedural fluency** and **conceptual understanding first** — they are the foundation.

Research emphasises the top floor while neglecting the ground floor.

Measurability bias: analytical reasoning can be scored in one controlled session. Conceptual transfer requires months of classroom observation.

Pattern 3 — Context-Blind Design

Elementary (K–5)

Mode: teacher-mediated

Main barrier:
teacher preparation time

89% accuracy in labs
– 12% sustained adoption

Secondary (9–12)

Mode: assessment-driven

Main barrier:
test format compatibility

+34% spatial reasoning
– tool discontinued

Postsecondary

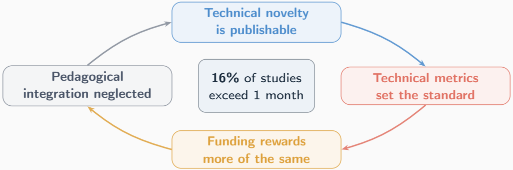
Mode: professional workflow

Main barrier:
funding sustainability

7/11 studies cite
cost / licensing barriers

A tool designed for postsecondary independent use may fail entirely in teacher-mediated elementary settings — **not because it is technically inadequate, but because it was built for a different context.**

Why the Fallacy Persists



The mechanism

Technical metrics are:

- quantitative and immediate
- well-aligned with conference timelines

Pedagogical outcomes require:

- months of classroom observation
- teacher and cohort variation

Technical capability is a prerequisite, not a guarantee.

FOCAL — Inverting the Design Sequence

Traditional approach

Feature → Capability → Application?

⇓ **invert**

FOCAL approach

Objective + Context
→ Requirements
→ Tool design

Theoretical grounding

CLT	modality allocation per objective
UDL	which representations support which learning goals
Activity Theory	why institutional constraints cause adoption failure

FOCAL is **not a validated instrument**. It is a corrective heuristic that forces *pedagogical diagnosis before technical development*.

The FOCAL Decision Matrix

Objective/Context	K–5 Elementary	9–12 Secondary	Postsecondary
Procedural Fluency	Game-like feedback, error correction, progress tracking. *Barrier: teacher prep.*	Shortcuts, test-compatible outputs. *Barrier: assessment align.*	LaTeX/IDE macros, version control. *Barrier: funding.*
Conceptual Understanding	Virtual manipulatives, audio-tactile feedback. *Barrier: ped. training.*	Sync. multi-format views, dynamic params. *Barrier: curriculum integ.*	Sonification, simulation, formal models. *Barrier: prof. dev.*
Analytical Reasoning	Sorting/filtering, pattern salience. *Barrier: complexity.*	Hypothesis testing, argument construction. *Barrier: rubric align.*	Stats tools, professional export. *Barrier: licensing.*
Creative Expression	Constrained blocks, undo/redo. *Barrier: open-ended assess.*	Templates, version history. *Barrier: subj. evaluation.*	Full authoring, collaboration. *Barrier: standards.*

FOCAL in Practice — 5-Step Decision Protocol

The five steps

1. **Pedagogical Diagnosis** – identify the target learning objective
2. **Context Mapping** – K–5, 9–12, or postsecondary?
3. **Framework Consultation** – extract required features and main barrier from the matrix
4. **Tool Evaluation** – *eliminative*: missing a required feature? Reject, regardless of technical quality
5. **Barrier Mitigation** – address the main obstacle upfront, not as an afterthought

FOCAL is iterative.

Conflicting requirements between steps signal that the initial objective identification needs revisiting.

FOCAL in Action — Two Illustrative Cases

✓ MathMelodies

Obj.: Procedural fluency
Ctx.: K–5, teacher-mediated

Musical rewards, error correction, progress tracking.

Result: Sustained engagement; teachers requested continuation.

FOCAL alignment: complete.

× Haptic Diagram Tool

Obj.: Conceptual understanding
Ctx.: Secondary

PHANTOM Omni + tactile display + speech. Technically successful.

Result: Abandoned. Hardware costs and training made classroom deployment infeasible.

Wrong barrier addressed for this context.

Pedagogically aligned tools **persist**. Contextually mismatched tools **fail** – regardless of technical quality.

Implications for Researchers, Developers, and Funders

Researchers

- Longitudinal, objective-aligned evaluation protocols
- Study procedural fluency and conceptual understanding
- Report both technical and pedagogical outcomes

Developers

- Engage learning theory before writing code
- Use the FOCAL matrix to prioritise features
- Address contextual barriers in the design spec

Funders

- Reward integration over novelty
- Support multi-year evaluation horizons
- Require objective–context spec in proposals

Validation agenda: Does designing from learning objectives and educational contexts produce better classroom outcomes than designing from technical features? *This question is empirically testable.*

Take-home message

Gap: strong lab performance rarely translates to sustained classroom adoption.

Cause: the Technical Capability Fallacy – optimising against the wrong metrics.

Solution: FOCAL – design starts from pedagogical objectives and institutional contexts.

Three questions first

Before any design decision:

Which learning objective does this tool serve?

Which educational context will it operate in?

Which adoption barrier must it address first?

"Closing the adoption gap requires redefining success – not as technical accessibility, but as fit within the instructional, evaluative, and institutional constraints that govern classroom use."

FOCAL – ANR COOBRA (ANR-24-SARP-0006).

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