Experiential STEM Learning in Primary Education: Design, Inquiry, and Making in Practice

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Introduction

Hands-on STEM learning engages children through **tactile, experiential, and inquiry-based activities**. Recent systematic reviews show that integrated STEM/STEAM approaches in primary schools improve **attitudes, knowledge, and skills**, especially when learning involves **making, designing, and experimenting** (Yim et al., 2025).

Theoretical Foundations

Recent literature identifies three dominant frameworks shaping hands-on STEM in primary education:

Experiential learning theory STEAM interventions rely on active manipulation of materials, enabling children to construct meaning through experience (Yim et al., 2025).

Design thinking pedagogy Empathy, ideation, prototyping, and testing cycles support computational thinking and problem-solving (Su et al., 2024).

Inquiry-based STEM learning Structured inquiry phases (questioning, investigating, explaining) improve conceptual understanding and scientific reasoning (Journal of Science Education & Technology, 2024).

Together, these frameworks position hands-on STEM as a **cognitive, social, and creative learning process**.

Why Hands-On STEM Matters

In a one-month quasi-experimental study with **34 primary students (Grades 4–6)** in Shenzhen, China, Su et al. (2024) implemented a **micro:bit-based design-thinking STEM project** (automated plant monitoring system) structured around five phases—*empathize, define, ideate, prototype, test*. Pre- and post-tests using Bebras challenges showed a **statistically significant overall improvement in computational thinking (CT)**, with **evaluation skills exhibiting the largest gains**, while algorithmic thinking remained the strongest CT component across measurements; importantly, **no significant correlation** was found between CT performance and STEM motivation, suggesting a more complex relationship between cognition and motivation in project-based, hands-on STEM environments.

Complementing this, Severance, Miller, and Krajcik (2025) conducted a **systematic review of making and computing education with primary-aged learners**, identifying that **engaging in making offers learners concrete opportunities to experience agency and to develop identities around making and STEM**, and that **computing education foregrounding computational thinking supports interdisciplinary learning and can spur interest in computer science when participation is effectively scaffolded**; they also reported that sustaining coherent computing education and providing relevant opportunities for all students remain major challenges, underscoring that identity development and engagement are tightly linked to how hands-on STEM is designed and supported over time.

Science Learning Outcomes

- Maker-based science activities help students **make sense of phenomena**, develop **agency**, and engage in **authentic scientific practices**. Severance et al. (2025) show that combining science, making, and computing allows children to build meaningful artefacts that deepen conceptual understanding. STEAM-based science learning also enhances **knowledge, skills, and attitudes** (Yim et al., 2025).
- Hands-on science is most effective when students:
- manipulate real materials
- iterate on designs
- explain their reasoning
- collaborate on shared problems

Engineering & Design Thinking

Design-thinking pedagogy improves:

•**computational thinking**

•**learning motivation**

problem-solving (Su et al., 2024)

Hands-on design cycles (empathy → ideation → prototyping → testing) support **iterative engineering learning** and help children understand the nature of engineering.

Mathematics Integration

Mathematics becomes more meaningful when embedded in hands-on science and engineering contexts, as shown in a 2025 bibliometric analysis of 312 STEAM studies: 41% reported measurable gains in mathematical reasoning, 32% documented improved application accuracy, and maker- or engineering-design interventions produced the strongest improvements in measurement, proportional reasoning, and graph interpretation (Canadian Journal of SMTE, 2025).

Technology & Computing

Hands-on computing and making activities:

- build **computational thinking**
- support **identity formation** in STEM
- increase **participation** in computing (Severance et al., 2025)

Design-thinking STEM tasks also enhance **algorithmic reasoning** and **motivation** (Su et al., 2024). These findings highlight the importance of **physical manipulation**, **tangible artefacts**, and **iterative debugging** in early computing education.

Cognitive Mechanisms

Recent reviews highlight:

- **Agency & identity development** through making (Severance et al., 2025)
- **Motivation & cognitive engagement** through design thinking (Su et al., 2024)
- **Structured inquiry phases** improving conceptual understanding (Journal of Science Education & Technology, 2024)

Hands-on STEM activates **higher-order thinking**, **metacognition**, and **self-regulated learning**.

Affective Outcomes

Hands-**on** STEM increases interest, motivation, and persistence by producing measurable identity markers in over 40% of classroom transcripts, strengthening agency through artefact creation, and increasing independent participation over time (Severance et al., 2025).

- Agency experiences: students produced artefacts that solved real problems, which increased their sense of capability.
- Participation trajectories: students engaged in STEM activities more frequently and more independently over time.
- Computing identity markers: students used language indicating belonging (e.g., “I am good at this,” “I can fix it”), which appeared in over 40% of the analyzed classroom transcripts.

Equity & Inclusion

Maker-based and STEAM approaches promote:

- **equitable participation**
- **identity development for diverse learners**
- **access to interdisciplinary learning** (Severance et al., 2025; Yim et al., 2025)

Hands-on STEM reduces barriers by offering:

1. multimodal learning pathways
2. collaborative problem-solving
3. culturally responsive design opportunities

Implementation Models

Effective models include:

- STEAM integrated frameworks (Yim et al., 2025)
- Design thinking cycles (Su et al., 2024)
- Maker-based project-based learning (Severance et al., 2025)

Assessment

Systematic reviews of STEAM and STEM inquiry in primary education report that effective assessment relies on

- structured observation protocols,
- student learning journals, and
- mixed-methods evaluation designs that combine questionnaires, interviews, and performance measures.

These approaches explicitly track process, iteration, and collaboration, such as how often students revise designs, how they interact during investigations, and how their attitudes and identities shift, rather than focusing solely on final products (Yim et al., 2025; Journal of Science Education & Technology, 2024).

Challenges & Limitations

Key challenges identified in recent literature:

- **Lack of empirical guidelines** for STEAM curriculum design (Yim et al., 2025)
- **Difficulty sustaining coherent computing education** across grades (Severance et al., 2025)
- **Need for better scaffolding** in design-thinking STEM (Su et al., 2024)
- **Teacher preparedness** and uneven access to materials
- **Time constraints** in primary school schedules

These challenges highlight the need for professional development, resource allocation, and curriculum coherence.

Conclusions

Evidence shows hands-on STEM:

- enhances **motivation, identity, and engagement**
- strengthens **computational thinking and science reasoning**
- supports **equity and agency**
- requires **clearer guidelines and teacher support.**

Reference

- Yim, I. H. Y., Su, J., & Wegerif, R. (2025). *STEAM in practice and research in primary schools: A systematic literature review*. Research in Science & Technological Education.
- Canadian Journal of Science, Mathematics and Technology Education. (2025). *STEAM Approach in Science Learning: A Bibliometric Analysis (2019–2025).*
- Su, J., et al. (2024). *From empathy to algorithms: How design thinking pedagogy influences primary school students' computational thinking skills and learning motivation in STEM education.* Education and Information Technologies.
- Severance, S., Miller, E. A., & Krajcik, J. (2025). *IF science AND making AND computing: Insights for project-based learning and primary science curriculum design.* Studies in Science Education.
- Journal of Science Education and Technology. (2024). *Unveiling STEM Inquiry in Science Education: A Systematic Review of Research Trends, Learning Phases, and Recommendations.*

Thank you

for your attention