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EDITED BY
Álvaro Nolla,
Autonomous University of Madrid, Spain

REVIEWED BY
Eduarda Ferreira,
New University of Lisbon, Portugal

*CORRESPONDENCE
Manuela Paechter
manuela.paechter@uni-graz.at

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Expanding STEM capital: rethinking equity and engagement in primary education

Sabine Hasenhütl[1], Silke Luttenberger[1] and Manuela Paechter[2]*

[1]Institute for Education and Practice, University College of Teacher Education Styria, Graz, Austria,
[2]Educational Psychology, Institute of Psychology, University of Graz, Graz, Austria

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Who gets to succeed in STEM? Rethinking equity and engagement

STEM knowledge and competencies are crucial for understanding the world and for contributing to inclusive and sustainable societies (UNESCO, 2019). Beyond preparing students for future careers, STEM education fosters critical thinking, creativity, and problem-solving skills that are vital for informed citizenship and lifelong learning in a knowledge-based society. However, access to high-quality STEM learning opportunities and the development of positive attitudes toward STEM vary widely. Influencing factors include socioeconomic background, quality of instruction, availability of educational resources, cultural expectations, and parental support. STEM subjects are frequently perceived as difficult and abstract. Mathematics is often associated with negative emotions and low interest (Steidtmann et al., 2022; Paechter et al., 2020).

Efforts to counteract this trend often involve curricula-based or extracurricular programs intended to foster motivation and interest in STEM. The strength of the influence exerted by such activities, particularly over the long term, remains unclear, and the role of other contributing factors is not yet fully understood (Godec et al., 2024). A more systematic framework is required, one that considers both individual experiences and structural conditions that influence STEM engagement (Chowdhuri et al., 2022; Luttenberger et al., 2019a,b).

STEM capital: understanding engagement and identity development in primary education

One conceptual framework that captures the interplay of individual, social, and cultural factors in STEM participation is science capital (Archer et al., 2012, 2015). It provides a powerful perspective on how access to resources, science-related experiences, and social support shapes students' long-term engagement and it emphasizes the importance of family and extracurricular experiences. Factors such as family encouragement, out of school science-related activities shape children's STEM attitudes, competencies, and aspirations. These cumulative experiences foster a science identity and help students perceive science as "for them" (Archer et al., 2012; Ennes M. E. et al., 2023; Ennes M. et al., 2023). However, science capital primarily focuses on the natural sciences and does not fully account for the broader, interdisciplinary nature of STEM. To address this gap, the concept of STEM capital has been proposed as an expanded framework that incorporates all STEM domains and offers a more comprehensive understanding of participation and identity development in STEM education (Hasenhütl et al., 2024).

Building on the science capital framework, STEM capital includes four key dimensions that help explain how learners engage with and develop a sense of belonging in STEM fields. These dimensions integrate individual perceptions with social influences and contribute to understanding learners' motivation, persistence, and identity development (Hasenhütl et al., 2024):

- **STEM-related experiences** describe both tangible and intangible experiences with STEM. Tangible experiences involve STEM activities with the family or in the immediate social environment e.g., use tools, museum visits. Intangible experiences describe more theoretically oriented experiences that are conveyed through conversations or media, e.g., reading science books, watching television programs. Both forms of experience contribute to a deeper and more personal connection to STEM learning (Jones et al., 2022; Ennes M. E. et al., 2023; Ennes M. et al., 2023).
- **STEM achievement value** refers to students' self-concept and self-efficacy in STEM. Positive beliefs about their abilities in tasks such as problem-solving, experimenting, or modeling enhance persistence, engagement, and interest in STEM pathways (Jones et al., 2022; Luttenberger et al., 2019a,b).
- **Future STEM task value** denotes the perceived relevance and usefulness of STEM for students' education, daily life, and future careers. Recognizing this value increases motivation and sustained engagement (Jones et al., 2022).
- **Perceived STEM achievement value in the family** highlights the influence of family attitudes. When students perceive their families as valuing STEM, this strengthens their own confidence, interest, and motivation in these domains (Jones et al., 2022).

Together, these four dimensions form a framework of STEM capital and demonstrate how individual beliefs and social contexts shape learners' educational pathways and engagement. The accumulation of STEM capital is closely linked to the development of STEM identity. That is, a students' sense of belonging and perceived competence (Çolakoğlu et al., 2023). STEM identity begins to form from an early age on through interactions between external influence factors (such as family support or access to learning experiences) and internal perceptions (such as self-efficacy or personal values). Students with a strong STEM identity are more likely to pursue STEM education and related careers, while those who lack such identification may disengage despite academic ability and performance (Cheng et al., 2019; Gutfleisch and Kogan, 2022; Ennes M. E. et al., 2023; Ennes M. et al., 2023).

From learning objective to educational goal: integrating STEM capital in primary education classrooms

While STEM capital is largely built in out-of-school contexts through family, social networks, and informal learning experiences (Archer et al., 2012; Hill et al., 2024), access to these resources is unequally distributed. This results in disparities in engagement and aspirations (Chowdhuri et al., 2022; Ennes M. E. et al., 2023; Ennes M. et al., 2023). Factors such as gender stereotypes, socioeconomic status, and parental education strongly shape whether children encounter meaningful STEM experiences. Even families who value science may find it difficult to support their children's interests due to a lack of knowledge, resources, or cultural familiarity with STEM domains (Chowdhuri et al., 2022; Ennes M. E. et al., 2023; Ennes M. et al., 2023; Wang et al., 2023).

To promote equitable participation in STEM, primary schools should take an active role in fostering STEM capital in equalizing educational opportunities in STEM. Yet, in many education systems, including Austria's, this potential remains underutilized. Although inquiry-based and competence-oriented STEM instruction is acknowledged in both policy documents and Austria's revised primary school curriculum (BMBWF, 2024a), implementation often faces structural challenges. These include a lack of coordinated teacher education, limited professional development, and insufficient support for interdisciplinary collaboration (UNESCO, 2019; Luttenberger and Hasenhütl, 2025). However, the interdisciplinary character of primary education offers a valuable opportunity to embed STEM capital more holistically. Leveraging this potential requires targeted support and intentional instructional design that connects STEM learning across subjects and contexts (UNESCO, 2019).

The subsequent instructional design serves purely as an illustrative example, rather than as an empirically validated sequence, demonstrating how a familiar topic in the natural sciences may be systematically realigned according to the four dimensions of STEM capital. This conceptual blueprint is intended to exemplify the application of the framework in practice, without referring to empirical findings from an actual classroom implementation.

From theory to practice: promoting STEM capital in education

The concept of "floating and sinking" is well established in science education. Despite its conceptual complexity (Schichow and Zoupidis, 2024), it remains a popular and curriculum-anchored topic in primary classrooms. Traditionally, it is taught through teacher-led demonstration experiments that emphasize prediction and observation. While this may activate curiosity, it offers limited opportunities for autonomy, inquiry, and real-world relevance. From a STEM capital perspective, such approaches fail to address core motivational and identity-related factors (Ryan and Deci, 2000).

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In contrast, a revised instructional approach can transform this topic into a meaningful opportunity for STEM capital development by explicitly addressing the four key dimensions:

STEM-related experiences

In the exploratory phase, students engage with pre-selected materials and test whether they float or sink. They formulate hypotheses, conduct hands-on investigations, and document their ideas creatively in research journals or posters. These tangible and emotional experiences foster curiosity and build positive associations with scientific practice (Ennes M. E. et al., 2023; Ennes M. et al., 2023). To reduce stereotype threat and promote participation, the learning environment includes stories and images of diverse scientists, especially female and migrant role models. Culturally inclusive materials encourage group reflection and ensure that all voices are heard.

STEM achievement value

At researcher stations, students work independently or in pairs to explore how factors such as shape or density affect buoyancy. For example, they test whether a ball or boat made from the same clay material behaves differently in water. Through experimentation and peer discussion, students refine their hypotheses and build scientific reasoning. This phase strengthens self-efficacy and confidence in problem-solving abilities (Jones et al., 2022; Luttenberger et al., 2019a,b). Generally, teacher feedback should emphasize a child's effort and cognitive processes rather than innate ability or talent (Paechter et al., 2020).

Future STEM task value

The topic is extended to real-world contexts. Questions like "Why do metal ships float?" introduce applications from shipbuilding, diving technology, or marine engineering. Students explore these through guided research, optional excursions, or storytelling formats. These activities help students recognize the relevance of STEM in daily life and future careers, strengthening their motivation to remain engaged (Jones et al., 2022). To broaden future perspectives, career stories feature female engineers and technicians from diverse backgrounds, with a focus on local community members. A "STEM career of the week" introduces relatable, female role models, showing that science is for everyone.

Perceived STEM achievement value in the family

To integrate the family, especially female family members as a source of support, students are encouraged to replicate simple experiments at home using common household materials. Families are invited to observe and discuss the process. Children present their findings in class or at a mini exhibition, reinforcing the perception that STEM is valued and approachable in everyday life (Jones et al., 2022; Ennes M. E. et al., 2023). To reduce barriers, instructions could be multilingual and resource sensitive. Families can participate flexibly for example by submitting photos or messages, increasing engagement even in household with limited time or resources.

In a final phase, students develop their own research questions and design small experiments in groups. These are presented to classmates and families during a "Day of Exploration" event. This culminating experience reinforces autonomy, identity, and science communication skills, supporting long-term engagement in STEM. Girls and children from marginalized groups are encouraged to take leadership roles and receive targeted support when presenting their ideas, helping to strengthen diverse, positive science identities.

By connecting classroom learning with home and community contexts, this redesigned sequence models how everyday science can actively build STEM capital. It shows how shifting from content transmission to inclusive, identity-supportive teaching helps address educational disparities from the start of schooling.

Conclusion: rethinking STEM instruction in primary education

Building STEM capital is essential for supporting equitable and sustained participation in STEM education. Long-term engagement is shaped by access to meaningful learning experiences, supportive social environments, and opportunities to develop confidence and identity in STEM (Archer et al., 2012; Çolakoğlu et al., 2023; Jones et al., 2022).

The STEM capital framework provides a comprehensive basis for addressing the multiple personal and structural factors that influence engagement, particularly among underrepresented student groups. By aligning instructional design with the four core dimensions, STEM-related experiences, STEM achievement value, future STEM task value, and perceived family STEM achievement value, teachers can create inclusive, sustainable environments that promote strong, lasting STEM identity and engagement (Jones et al., 2022; Ennes M. E. et al., 2023; Ennes M. et al., 2023; Ryan and Deci, 2000; Archer et al., 2022).

The reconceptualized instructional design on "floating and sinking" exemplifies how traditional science topics can be transformed into opportunities for building STEM capital and support children with less access to STEM capital. Through inquiry-based learning, real-world applications, and meaningful family involvement, students are empowered to develop scientific competence, motivation, and a sense of belonging (Minogue and Borland, 2016; Luttenberger et al., 2019a,b; Schichow and Zoupidis, 2024; BMBWF, 2024b; Howitt and Rennie, 2021). It should be noted that the examples and the reconceptualized instructional design on floating and sinking are conceptual only and their practical effectiveness remains to be empirically validated.

Systemic change requires structural support. This includes reforms in teacher education, e.g., integrating the STEM capital framework into pre-service curricula and targeted professional training (Adamina et al., 2018; Lin et al., 2025). Such programs should promote gender-sensitive, identity-affirming pedagogy through modules on stereotypes or contextually relevant tasks. Equally important is awareness of underserved children from disadvantaged socio-economic backgrounds, who face compounded barriers from limited resources, STEM familiarity, or parental education. Teacher education must prepare professionals to address gender and socio-economic inequalities in classrooms (Chowdhuri et al., 2022; Archer et al., 2022). Curricula should embed STEM capital dimensions in primary learning goals, e.g., via project-based learning or links to socially relevant issues. Flexible teaching and interdisciplinary collaboration are crucial to democratize STEM capital and ensure equal benefits across social strata.

Future research should empirically test the framework in classrooms through intervention studies on students' STEM identity, engagement, and achievement, especially among underrepresented groups, including girls and those from disadvantaged backgrounds. Complementary qualitative studies should capture teacher and student perspectives on implementation challenges.

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