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Learning STEM at the Intersection of Equity, Context, and Educational Opportunity

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Abstract

STEM education is frequently evaluated through instructional innovations, technological access, and learning outcomes, yet meaningful learning also depends on cultural recognition, pedagogical practices, material resources, and institutional capacity. Drawing on eight contributions to this issue and related literature, this editorial examines STEM education at the intersection of equity, context, and educational opportunity. Three interconnected themes emerge: authentic participation and STEM identity; practical learning beyond technological and resource constraints; and knowledge development, quality assurance, and institutional capacity. Synthesising these contributions, the editorial develops an opportunity-centred interpretation of STEM education that emphasises the conditions under which learners can participate meaningfully in disciplinary practices, rather than assuming that access or innovation alone ensures educational quality. It also emphasizes the importance of aligning educational claims with supporting evidence. Together, these perspectives position equitable STEM learning as an educational and institutional responsibility rather than an automatic consequence of technological provision.

Keywords: STEM education; educational equity; authentic inquiry; practical learning; culturally responsive pedagogy; institutional conditions

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INTRODUCTION

Contemporary discussions of STEM education often foreground the promise of new technologies, interdisciplinary curricula, and innovative instructional approaches. These developments are consequential, but their educational significance cannot be understood independently of the learners, teachers, schools, and communities in which they are enacted. The same instructional design may offer different opportunities where laboratory equipment is scarce, school routines are unstable, access to devices is uneven, or learners' cultural knowledge remains unrecognized. Conversely, relatively modest resources can support substantive inquiry when pedagogical design is purposeful, and learners are positioned as active participants.

The eight articles assembled in this issue of the International Journal of Research in STEM Education (IJRSE) examine different dimensions of this problem. Their empirical settings and methods vary, from a secondary engineering classroom in the United States and engineering graphics instruction in South Africa to physics education in the Philippines and Malawi, mathematical inquiry in Colombia, and school quality assurance in Cambodia. Two literature syntheses address the conceptual foundations of integrated STEM education and the conditional contribution of virtual laboratories. Taken together, these eight contributions provide the empirical, conceptual, and contextual foundations for this editorial. Rather than treating their findings as evidence of a single

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educational effect, the discussion draws on their distinct perspectives to examine how equity, context, and educational opportunity intersect in STEM learning.

Across the eight articles, three interconnected considerations emerge: the importance of authentic and culturally meaningful participation, the pedagogical adaptation of learning resources to contextual conditions, and the institutional capacity to sustain educational opportunities. These considerations provide the organising structure for the discussion that follows. These elements should not be treated as independent inputs whose presence guarantees achievement. Rather, they offer an interpretive lens for understanding why innovations become educationally consequential in some settings and remain constrained in others. Unlike approaches that primarily emphasise the distribution of educational resources, an opportunity-centred perspective examines how available resources, pedagogical practices, and institutional conditions interact to enable meaningful participation in STEM learning.

AUTHENTIC PARTICIPATION, CULTURE, AND STEM IDENTITY

Authentic participation in STEM education extends beyond students' engagement in instructional activities to include opportunities to question, investigate, represent, and interpret knowledge in ways that connect disciplinary practices with their cultural and social contexts. Such participation is closely associated with STEM identity, particularly when learners recognize themselves—and are recognized by others—as legitimate contributors to scientific and technological knowledge. Culturally relevant literature and inquiry-based activities can support this recognition (Collier et al., 2026), while educational experiences that explicitly address diversity, gender, and scientific identity can strengthen students' sense of belonging (Singer et al., 2020). Similarly, Funds of Knowledge and Critical Hip-Hop Pedagogy offer perspectives for recognizing cultural resources that conventional STEM instruction may overlook (McClain & Neri, 2022). These approaches suggest that educational opportunity is not simply a matter of providing access to STEM content, but also of establishing conditions under which diverse learners can participate meaningfully. This concern is reflected in three contributions to the present issue. Phipps (2026) examines students' perceptions of participatory engineering instruction, Mtshali (2026) explores the incorporation of indigenous knowledge into technical drawing, and Collazos Roa and Collazos Guzmán (2026) consider student-led mathematical inquiry using authentic climate data. Although differing in design and scope, these studies direct attention to the opportunities learners have to engage with disciplinary knowledge through participation, cultural recognition, and inquiry.

The relationship between participation and inclusion is illustrated by Phipps (2026), who examines secondary engineering students' perceptions of project-based and lecture-based approaches, with particular attention to female students' confidence, motivation, participation, and inclusion. The reported preference for project-based experiences, alongside broadly similar response patterns among female and male students, suggests that participatory instructional design can create shared opportunities without presuming fundamentally different pedagogical needs by gender. Nevertheless, because the findings concern students' perceptions, they should not be interpreted as causal evidence of improved achievement. This distinction is important: authentic participation involves not only opportunities to engage but also careful consideration of what available evidence demonstrates about the educational consequences of that engagement.

Cultural recognition provides another dimension of authentic participation. Mtshali (2026) examines the incorporation of indigenous knowledge into Engineering Graphics and Design through vernacular architecture, historical glyph practices, and storytelling. These examples demonstrate how technical representation can be connected to locally meaningful forms of knowledge without abandoning disciplinary expectations. The underlying question concerns whose experiences, representations, and intellectual traditions are recognized as legitimate resources for learning engineering. This concern resonates with research showing that culturally responsive educational environments can support students' identification with STEM, particularly when cultural identity and

scientific identity might otherwise be experienced as competing commitments (Chow-Garcia et al., 2022; Ponte et al., 2023).

Authenticity also concerns the relationship between classroom activity and the practices through which disciplinary knowledge is developed. Eijck and Roth (2009) emphasize the significance of experiences connected with scientific practice, while Adjapong et al. (2016) and Çolakoğlu et al. (2023) highlight the potential of authentic and informal STEM opportunities to support confidence, recognition, belonging, and STEM identity among underserved learners. These perspectives reinforce the importance of opportunities to participate in meaningful knowledge-making rather than merely completing predetermined exercises.

Collazos Roa and Collazos Guzmán (2026) illustrate this principle through a student-led International Baccalaureate mathematics investigation using open climate data to examine sea-surface temperature and hurricane frequency. Students engage with authentic datasets, formulate questions, and interpret relationships involving a consequential environmental phenomenon. Although the limited observational period restricts the strength of climatological inference, this limitation is itself educationally significant: authentic mathematical and scientific inquiry requires learners to recognize uncertainty, evaluate evidence, and distinguish plausible interpretations from conclusions that exceed the available data.

This interpretation is reinforced by research published in earlier IJRSE issues. Davidson et al. (2025) examine problem-based STEM learning, while Solehuddin et al. (2025) investigates process-oriented guided inquiry supported by digital resources. Asyhar et al. (2025) extend participatory learning to team-based projects involving environmental chemistry and entrepreneurship, and Mutseekwa and Manunure (2025) consider learner-centred robotics curriculum integration. Together, these studies provide different perspectives on how STEM learning can be organised around inquiry, problem-solving, collaboration, and disciplinary application. They also suggest that authenticity should be understood in relation to the intellectual demands and participatory opportunities of a learning activity, rather than its novelty or technological sophistication alone.

Yet meaningful participation cannot be separated from the conditions that enable learners and teachers to undertake such activities. Sanjito and Hyams-Ssekasi (2025) examine engagement in science practicals in Tanzanian public secondary schools, while Dacumos (2025) addresses research curriculum development in a specialized secondary education setting. Ogegbo et al. (2025), through their systematic review of assessment in inquiry-based science education, further position assessment as an important dimension of inquiry-oriented teaching and learning. These contributions draw attention to the institutional, curricular, and evaluative arrangements surrounding authentic STEM participation.

The relationship between participation and equity becomes particularly important when considering whose learning experiences are recognized and supported. Nwune et al. (2026) examine emotional intelligence and prospective science teachers' willingness to implement inclusive STEM education, while Ayik et al. (2026) review equity-oriented formative assessment in K–12 STEM classrooms. Yacoub (2026) adds a linguistic dimension by positioning language as an important consideration in undergraduate STEM curricula in non-Anglophone contexts. Although these studies address different educational settings and constructs, they collectively broaden the discussion beyond access to learning materials toward the pedagogical, assessment, and communicative conditions through which participation becomes possible.

Read together, these contributions suggest that authentic participation, cultural recognition, and STEM identity are interconnected but analytically distinct. Authenticity concerns learners' engagement with meaningful disciplinary questions and practices; cultural recognition concerns the legitimacy afforded to their knowledge, experiences, and identities; and STEM identity concerns how learners understand and experience their relationship with STEM fields. None can be assumed to follow automatically from the introduction of projects, digital tools, or culturally familiar examples. Their educational significance depends on how learning opportunities are designed, supported, and experienced. At the intersection of equity, context, and educational opportunity, the

central question is therefore not simply whether learners are present in STEM activities, but whether they are afforded meaningful opportunities to participate in, contribute to, and develop identification with STEM knowledge-making.

PRACTICAL LEARNING: BEYOND THE TECHNOLOGY–RESOURCE DIVIDE

Practical learning is fundamental to STEM education, yet opportunities for meaningful experimentation and applied learning remain unevenly distributed across educational contexts. Resource-constrained institutions frequently face limitations in laboratory equipment, digital infrastructure, connectivity, and instructional support. However, the distinction between technologically advanced and resource-limited learning environments does not necessarily correspond to a distinction between effective and ineffective practical education. Rather, the educational value of practical learning depends on how available resources are pedagogically organized, adapted, and connected to intended learning outcomes. This perspective shifts attention from technological provision alone towards the relationship between instructional design, material conditions, and equitable opportunities to develop scientific and technical competence.

Three articles in this issue approach these questions from complementary perspectives. Santos and Caballes (2026) investigate the development and classroom implementation of resource-adaptive physics laboratories; Tuhirirwe and Twinamatsiko (2026) synthesise evidence on the educational affordances and implementation conditions of virtual laboratories; and Mkandawire and Chagunda (2026) examine the material, relational, and organisational conditions surrounding physics learning in a resource-constrained school. Together, they shift attention from resource availability alone towards the conditions under which practical learning opportunities can be realised.

Santos and Caballes (2026) illustrate this relationship through the development and validation of resource-adaptive physics laboratory activities combining locally available materials, conventional equipment, and virtual simulations. Their one-group pre-test/post-test study reports improved scores following implementation, supported by favorable expert validation. Although the absence of a comparison group prevents the observed improvement from being attributed exclusively to the intervention, the study offers an important practical proposition: meaningful laboratory experiences need not depend on an exclusive choice between sophisticated technological equipment and locally improvised resources. A comparable principle is evident in Setiawaty and Tjahjono (2025), who report improvements in technical skills and work attitudes through cardboard-based engineering simulations supported by augmented reality. Their findings suggest that combining inexpensive physical materials with selective digital enhancement can create opportunities for technical learning without requiring fully equipped technological environments.

The educational potential of resource adaptation also extends to the organization of practical activities. Research on low-cost science experimentation highlights how inexpensive and readily available materials can expand opportunities for hands-on learning, particularly where conventional laboratory resources are insufficient (Σάλτα et al., 2026). Similarly, Nahrowi et al. (2026) describe adaptive project-based learning practices in resource-constrained software engineering education, including resource-sharing arrangements and teacher-developed digital materials. These approaches position resource limitations not simply as barriers to be overcome through additional expenditure, but as contextual conditions requiring deliberate pedagogical responses. Nevertheless, adaptation should not be confused with equivalence: locally available materials, digital simulations, and conventional laboratory equipment may support different dimensions of practical competence, and their educational adequacy must be evaluated against the specific knowledge and skills being developed.

Digital learning environments provide another means of extending practical opportunities, although their effectiveness remains dependent on pedagogical integration. Suparmin et al. (2025) describe how Moodle-based learning management systems can support vocational practical learning through instructional videos, case studies,

and collaborative digital activities when physical equipment is limited. Such approaches may strengthen preparation, conceptual understanding, and independent learning, but they do not necessarily reproduce the tactile, procedural, and material experiences associated with direct experimentation. Tuhirirwe and Twinamatsiko (2026), in their systematic narrative review of virtual laboratories, similarly distinguish conceptual learning, procedural competence, engagement, and equitable access. Their synthesis emphasizes that virtual laboratories should be evaluated in relation to their educational affordances and implementation conditions rather than regarded as universal substitutes for physical laboratory experiences. Devices, connectivity, electricity, accessibility, curriculum alignment, and teacher guidance all influence whether technological availability translates into meaningful participation.

This distinction is especially important when considering educational equity. The availability of digital tools does not ensure that learners can use them effectively, consistently, or for the intended educational purposes. Firman et al. (2026) highlights the relevance of adaptive leadership and resource-conscious digital management in addressing infrastructural inequalities. At the same time, the educational value of practical learning cannot be reduced to technological sophistication. Nabila and Insaniyah (2026), although examining vocabulary retention rather than STEM practical work, demonstrate the potential of mind mapping as a low-technology learning strategy. Their contribution offers a broader pedagogical reminder that carefully structured cognitive activities can support learning without substantial technological investment. Its relevance to STEM education is therefore conceptual rather than direct evidence of improved laboratory competence.

The wider school environment further shapes whether practical learning opportunities can be realized. Mkandawire and Chagunda (2026), through their case study of physics education in Malawi, examine students' experiences of infrastructure, teaching resources, safety, interpersonal relationships, and school regulations. These dimensions reveal how practical learning is situated within institutional and social conditions that may enable or constrain participation. Importantly, the study does not establish a statistically significant relationship between school climate and examination achievement. Its contribution instead lies in identifying the interconnected environmental conditions surrounding opportunities for physics learning. This perspective complements research on resource adaptation by demonstrating that the provision of equipment or digital resources is only one component of a broader educational environment.

Taken together, these studies challenge the assumption that practical STEM learning can be adequately understood through a binary distinction between technologically equipped and resource-constrained institutions. The central issue is not simply which resources are available, but how those resources are transformed into meaningful educational opportunities. Physical experimentation, virtual simulations, low-cost materials, adaptive project work, and supportive institutional environments can contribute differently to conceptual understanding, procedural competence, and learner participation. Their effectiveness cannot be presumed from availability or innovation alone; it must be examined through evidence appropriate to the learning outcomes being claimed. From the perspective of equity, this requires attention not only to the distribution of educational resources, but also to the pedagogical and institutional conditions under which learners can access, use, and benefit from them. Practical STEM education thus becomes a question of educational opportunity shaped jointly by technology, material resources, instructional design, and context.

KNOWLEDGE, QUALITY ASSURANCE, AND INSTITUTIONAL OPPORTUNITY

Meaningful STEM education depends not only on pedagogical innovation and access to resources, but also on the intellectual and institutional conditions through which knowledge is developed, educational quality is evaluated, and opportunities for learning are sustained. From an opportunity-centered perspective, knowledge development, quality assurance, and institutional capacity are interconnected dimensions of educational provision. Their significance lies not merely in improving institutional performance, but in enabling learners to participate in

disciplinary practices, develop competence, and engage with knowledge in educational environments that recognize their diverse circumstances.

Two contributions to this issue illuminate different dimensions of this relationship. Behera et al. (2026) examine the ontological and epistemological foundations of integrated STEM education, emphasising how scientific knowledge is constructed and justified. Kou et al. (2026), by contrast, investigate school inspection practices and the institutional challenges of implementing quality assurance recommendations. Considered together, these studies highlight distinct but complementary concerns: the intellectual foundations of meaningful STEM learning and the institutional processes intended to support educational improvement.

The epistemic dimension is illustrated by Behera et al. (2026), whose synthesis of 51 articles examines ontological and epistemological perspectives of science. Their analysis highlights the nature of scientific phenomena, the justification of knowledge claims, and the possibilities of transdisciplinary inquiry. For integrated STEM education, these considerations are consequential because combining disciplinary activities does not automatically establish meaningful interdisciplinary learning. Learners also require opportunities to understand how scientific explanations are constructed, how models represent phenomena, and how evidence is evaluated within and across disciplinary contexts. Such opportunities are shaped partly by foundational knowledge and educational resources. Badmus et al. (2024) identify prior knowledge and access to learning resources as important considerations in STEM achievement, while Al-Sharab and Matuk (2017) illustrate how hands-on activities and mentorship can create opportunities for scientific thinking and problem-solving. Together, these perspectives suggest that knowledge development requires both intellectual engagement and educational conditions that support meaningful participation.

Quality assurance provides an institutional mechanism for examining whether such opportunities are adequately supported. Turyahikayo (2019) emphasizes the relationship between knowledge management and internal quality assurance in higher education, including the role of institutional learning and the adoption of relevant practices. Corlu (2013) similarly addresses accreditation and its relationship with student-centered educational practices. However, quality assurance should not be understood solely as compliance with established standards or the completion of evaluation procedures. Its educational significance depends on whether assessment, accreditation, and institutional feedback contribute to improvements in teaching, learning, and the conditions under which competence can develop.

This distinction is particularly evident in Kou et al. (2026), who examine school inspection practices and implementation challenges in Cambodian lower secondary schools. Although teachers' assessments of principals' practices across inspection phases are generally favorable, the study identifies resource limitations, communication difficulties, and insufficient follow-up as obstacles to implementing recommendations. The research does not directly establish effects on STEM learning outcomes; rather, its relevance lies in demonstrating the institutional challenges associated with translating evaluation into educational improvement. The distinction between completing an inspection process and developing the capacity to act upon its findings is therefore central. Institutional accountability requires more than identifying deficiencies: it also involves interpreting evidence, mobilizing resources, coordinating responsibilities, and sustaining feasible responses.

Institutional capacity consequently becomes an important condition for educational opportunity. Vardanyan (2017) draws attention to stakeholder engagement, knowledge management, and the development of institutional quality cultures, while Hakim (2012) situates educational infrastructure and knowledge sharing within broader processes of globalization. These perspectives suggest that educational institutions must develop capacities not only to acquire resources and respond to external expectations, but also to adapt educational provision to their particular contexts. Nevertheless, such adaptation may be constrained by financial limitations, organizational arrangements, and the demands of maintaining educational quality under changing conditions (Aga,

2006). Institutional capacity should therefore be evaluated in relation to what schools and universities can meaningfully sustain, rather than solely through the resources or formal structures they possess.

Broader policy perspectives reinforce the importance of examining the purposes served by institutional development. Crippen et al. (2015) discuss STEM education in relation to recruitment, retention, and the preparation of a qualified workforce, while Li (2014) considers the growing prominence of STEM education within national priorities and educational investment. These perspectives demonstrate the significance attached to STEM education in wider economic and policy discussions. However, workforce preparation and national competitiveness, although important, do not exhaust the educational purposes of STEM learning. An opportunity-centered interpretation also requires attention to intellectual development, disciplinary understanding, critical judgement, and learners' capacity to engage meaningfully with scientific and technological knowledge.

Across the contributions to this issue, three interconnected priorities emerge. First, STEM educational quality should be examined through learners' opportunities to investigate, represent, reason, discuss, and evaluate evidence. Project-based engineering learning culturally situated technical drawing, and authentic climate-data inquiry illustrate different possibilities for connecting disciplinary knowledge with meaningful participation. Second, technological and material access should be assessed in relation to educational use. Virtual laboratories, resource-adaptive experiments, and school facilities can support learning, but their educational value depends on instructional integration, contextual support, and the particular competencies being developed. Third, sustainable improvement requires institutional capacity, including leadership, teacher preparation, safe learning environments, effective knowledge management, and quality assurance processes capable of informing action.

These priorities represent an interpretive synthesis across heterogeneous contributions rather than findings established through a common research design. The studies differ in population, disciplinary focus, methodology, and strength of inference. Students' reported preferences cannot establish causal effects on achievement; findings from a single-school case cannot support statistical generalization; and improvements observed in a one-group design cannot be attributed unequivocally to an intervention. Similarly, conceptual relationships between institutional quality assurance and STEM learning should not be presented as direct evidence of improved STEM outcomes. Maintaining these distinctions is essential to ensuring that educational claims remain proportionate to the evidence supporting them.

These findings highlight the need to connect epistemic and institutional accountability with educational opportunity, while recognising that improvements in one dimension do not necessarily produce improvements in another. Epistemic accountability concerns the justification and interpretation of knowledge claims, while institutional accountability concerns the capacity to translate educational evidence into responsible and sustained action. Both are relevant to the conditions under which equitable STEM participation becomes possible. Future research should therefore examine these relationships through comparative educational contexts, transparent assessment, longitudinal evidence, and stronger intervention designs where feasible, with explicit attention to differences in learning opportunities among students.

Ultimately, an opportunity-centered agenda moves beyond the assumption that technological innovation, curriculum integration, or institutional compliance alone can resolve the challenges of STEM education. It instead asks **under which conditions, for which learners, and through which intellectual, pedagogical, and institutional processes meaningful STEM learning becomes possible**. This perspective brings knowledge, quality assurance, and institutional capacity into a shared consideration of equity, context, and educational opportunity.

CONCLUSION

The eight contributions to IJRSE Volume 8, Number 2 demonstrate that meaningful STEM learning cannot be understood independently of the educational contexts in which it occurs. Studies of project-based engineering

education, indigenous knowledge, and authentic mathematical inquiry foreground opportunities for participation and disciplinary engagement. Research on resource-adaptive laboratories, virtual experimentation, and school climate draws attention to the material, pedagogical, and organisational conditions of practical learning. Contributions addressing the epistemological foundations of STEM education and institutional quality assurance further extend these considerations to knowledge development and educational governance. Although differing in purpose, methodology, and strength of evidence, these studies collectively inform an opportunity-centred interpretation of STEM education. Their shared implication is not that any single innovation or institutional arrangement guarantees equitable learning, but that educational opportunity depends on how participation, resources, knowledge, and institutional support are organised within particular contexts. Advancing STEM education therefore requires sustained attention to the conditions under which learners can meaningfully engage with, develop, and apply disciplinary knowledge.

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