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Editorial

Cultivating Teachers for STEAM Education: Preparing Educators for Integrated, Equitable, and Responsive Practice

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1. Introduction: The Need to Cultivate Teachers for STEAM Education

Science, technology, engineering, and mathematics (STEM) education has undergone a significant transformation over the past several decades. What began as an emphasis on strengthening disciplinary knowledge in science and mathematics has expanded into broader calls for integrated STEM education, in which students can apply their knowledge and practices across disciplines to investigate complex problems, design solutions, and engage in sensemaking about the world around them (National Academies of Sciences, Engineering, and Medicine, 2014). More recently, scholars and educators have increasingly advocated for the inclusion of the arts and humanities within this integrated framework, leading to the evolution of science, technology, engineering, the arts/humanities, mathematics or STEAM education (Quigley & Herro, 2016). By prioritizing creativity, ethical reasoning, communication, and the ability to represent complex ideas in multiple ways, the field has moved toward addressing problems that are not cleanly siloed into traditional boundaries (Bush & Cook, 2024).

STEAM education should not be understood as simply "STEM plus art". Too often, the "A" in STEAM has been treated as a secondary add-on, such as a colorful poster, craft activity, or a final product that is loosely connected to science or mathematics learning. When the "A" is meaningfully integrated through transdisciplinary instruction, the arts and humanities offer tools for inquiry, problem solving, and creative communication. Students may sketch prototypes, compose data visualizations, construct persuasive arguments, dramatize systems, or create multimodal representations that communicate scientific and engineering ideas (Quigley & Herro, 2016; National Science Teachers Association, 2023). In this sense, artistic and design practices are not decorative additions to otherwise unchanged STEM instruction. Instead, they are epistemic resources that support collective sensemaking, critique, reflection, representation, and the generation of new ideas.

This expanded understanding of STEAM also requires attention to disciplinary knowledge. High-quality STEAM learning experiences do not dismiss the importance of science, mathematics, technology, engineering, humanities, or the arts as distinct areas of knowledge. Rather, they require both discipline-specific and integrated approaches because content knowledge within disciplines remains essential for problem-based, transdisciplinary learning (European Commission Joint Research Centre, 2023). The challenge is not whether teachers should teach disciplinary knowledge or integrated STEAM, but how they can support learners in using disciplinary knowledge across contexts to investigate meaningful problems.

The shift from STEM to STEAM therefore represents not only a conceptual shift, but also a pedagogical one. Transdisciplinary STEAM asks teachers to design learning

Received: 16 June 2026
Accepted: 20 July 2026
Published: 2 September 2026

experiences in which students apply knowledge and practices across disciplines to address authentic, real-world problems (Bush & Cook, 2024). This requires more than coordinating themes across subjects. It demands a fundamental rethinking of how teachers plan, assess student learning, co-construct learning environments, and position students as competent sensemakers in classrooms. STEAM learning environments often center on student-led inquiry, iterative design, collaborative solution-seeking, and evidence-based argumentation (Jackson et al., 2023; Morrin & Liston, 2020; National Academies of Sciences, Engineering, and Medicine, 2014).

For the vision of STEAM to become a reality, educators must be prepared to do much more than combine content from multiple subject areas. Integrated STEAM teaching requires teachers to design tasks around authentic problems that are meaningful to both students and their communities. As Quigley et al. (2020) demonstrate, the process of designing and enacting STEAM curriculum in elementary schools is an iterative and complex undertaking that requires teachers to navigate disciplinary boundaries while maintaining a focus on student inquiry. Teachers support students in navigating uncertainty, revising their ideas, and "failing forward" as part of the overall learning process. Their role shifts from delivering content to facilitating collaboration, guiding discourse, and supporting the learners as they represent collective ideas mathematically, computationally, visually, orally, and in written text. Assessment must also evolve beyond measures of subject-area recall capturing processes such as ideation, revision, collaboration, communication, and transdisciplinary reasoning (Mao et al., 2024). This complexity is what makes STEAM teacher preparation both necessary and challenging.

Despite the promise of STEAM education, many teachers report feeling underprepared to design, facilitate, and assess integrated learning experiences. This challenge is especially significant for preservice and elementary teachers, who are often expected to teach across subject areas but may have limited opportunities to experience integrated STEAM as learners before they are asked to enact it as teachers. Preservice teachers need explicit opportunities to authentically experience integrated STEAM as learners before they can imagine teaching it (Morrin & Liston, 2020), and teacher preparation programs have a responsibility to provide these experiences. Research suggests that design-based learning experiences can produce measurable growth in preservice teachers' knowledge for integration and their confidence to facilitate integrated learning experiences (Chai et al., 2019). Similarly, sustained professional learning can support teacher self-efficacy for STEAM and STEM instruction (Jiang et al., 2024; Zhou et al., 2023). Without such intentional preparation and support, STEAM can remain an aspiration that is valued in theory but ultimately difficult to implement with fidelity in practice.

As educators cultivate teachers for integrated STEAM, the field must also consistently ask: integrated STEAM for whom? STEM education and the individual disciplines that comprise it have long histories of inequity. Students have not historically had equal access to high-quality STEM learning opportunities, and dominant narratives about who counts as a "STEM person" have too often marginalized students based on the intersections of their race, language, gender, immigration status, dis/ability, socioeconomic status, and geography. These inequities also shape whose knowledge is ultimately valued, whose communities are considered and used as sites of innovation, whose problems become the focus of design challenges, and who benefits from the technology and scientific advancement (Jong et al., 2020; Russo-Tait, 2022). If STEAM education does not explicitly attend to these questions, it risks reproducing the very inequities it has the potential to disrupt. Equity-oriented STEM and STEAM learning experiences center learners, their identities, their communities, and their lived experiences as resources for inquiry and design (Bush et al., 2022; Jackson et al.,

2021). In this way, equity cannot be treated as a peripheral consideration or a later addition to STEAM teaching. It must be a foundational design principle.

This Special Issue, "Cultivating Teachers for STEAM Education", responds to these opportunities and challenges by bringing together scholarship focused on teacher learning, instructional design, professional development, assessment, early learning, and socially relevant STEAM practice. Collectively, the articles in this Special Issue examine what teachers need to design and enact integrated STEAM learning experiences with the necessary depth, rigor, and coherence, and in ways that start with and center equity and justice. They also illuminate the conditions that can support or constrain STEAM implementation across educational contexts, including preservice teacher education, in-service professional learning, early childhood education, elementary classrooms, undergraduate learning environments, and broader policy systems.

The contributions in this Special Issue suggest that cultivating STEAM teachers requires more than just individual enthusiasm for integration. It requires coherent frameworks, sustained professional learning and coaching, opportunities to engage in design-based pedagogy as learners, tools for evaluating and refining instruction, and explicit attention to equity and justice. Across the articles, readers will find evidence that STEAM teaching develops through intentional preparation, collective reflection, and ongoing engagement with authentic problems that matter. The Special Issue also highlights the importance of expanding the broader field's understanding of STEAM beyond secondary and postsecondary contexts by attending to early childhood learning and developmental trajectories. Finally, the articles invite the field to consider how STEAM can become more transformative when connected to community concerns, social justice, and the learners' lived experiences.

This Special Issue advances a vision of STEAM teacher preparation that is integrated, creative, reflective, and justice-oriented. Our goal is not merely to help teachers add another acronym to their toolbox. Rather, the goal is to empower the field to cultivate educators who can design meaningful learning experiences in which students can leverage disciplinary knowledge, artistic practices, the humanities, technological tools, engineering design process, mathematical reasoning, other ways of knowing, and community wisdom to investigate consequential problems. As the field continues to define and refine STEAM education, attention to teacher learning must remain the focus. The vision of STEAM education depends not only on what students are asked to create, but also on how their teachers are prepared, supported, and sustained in the complex work of integration.

2. Persistent Knowledge Gaps in the Field

Despite the growing momentum surrounding STEAM education, several persistent knowledge gaps continue to shape the field and complicate efforts to prepare teachers for meaningful implementation. As Perignat and Katz-Buonincontro (2019) highlight in their integrative review, the field continues to grapple with a lack of consensus regarding what constitutes high-quality integration, how teachers develop competence and confidence in integrated instruction, and what forms of support are needed to sustain STEAM teaching across diverse contexts. These gaps are especially consequential because STEAM teaching requires educators to make complex pedagogical decisions about disciplinary knowledge, student inquiry, assessment, collaboration, creativity, and community relevance. Without clearer frameworks, shared language, and stronger systems of support, STEAM risks remaining an aspirational reform rather than a transformational classroom practice.

One persistent gap concerns the lack of consensus around integration. Although STEAM education is often framed as a response to complex, real-world problems, Perignat and Katz-Buonincontro (2019), alongside H. Plank and Chelednik (2025), argue that the

lack of a shared definition for "meaningful integration" remains a primary barrier to coherent teacher preparation. For example, in some contexts, integration might refer to thematic connections across standards in various content areas, while in others it involves students applying disciplinary practices across science, technology, engineering, the arts and humanities, and mathematics to investigate authentic problems. This variation can create ambiguity for teachers, teacher educators, and policymakers who are responsible for designing and evaluating STEAM learning experiences. This ambiguity is not merely academic; it has real-world consequences for classroom enactment. When the definition of integration remains unclear, teachers may receive mixed messages about whether STEAM should prioritize disciplinary learning, interdisciplinary connections, transdisciplinary problem-based learning, creative production, project-based learning, or broader social and civic aims. This lack of coherence makes it difficult to develop aligned preservice teacher preparation programs, in-service teacher education programs, professional learning experiences, assessment tools, and policy support.

A second gap involves insufficient preparation for preservice teachers, particularly those preparing to teach at the elementary level. Elementary teachers are often positioned as well-suited for integrated teaching because they teach across multiple subject areas and frequently organize instruction around themes, projects, and student interests (Boche et al., 2021). However, this structural opportunity does not automatically translate into confidence or competence in integrated STEAM instruction. Preservice teachers may have limited experience with engineering design, computational thinking, arts integration, or transdisciplinary problem-solving during their own schooling and teacher preparation. They may also enter the profession with varying levels of confidence in science and mathematics, which can shape their willingness to design and facilitate integrated STEM tasks (Cebesoy, 2026). As a result, teacher preparation programs must do more than introduce STEAM as a concept. They must also provide preservice teachers with opportunities to experience, design, enact, and reflect on integrated STEAM learning.

A third gap concerns the need for equity-centered approaches in STEAM teacher education. As Bush and Cook (2024) and Jackson et al. (2023) emphasize, while STEAM is frequently linked to innovation and identity development, these goals remain incomplete without an explicit focus on dismantling historical inequities. Students' access to high-quality STEM and STEAM learning opportunities has been shaped by race, language, gender, dis/ability, socioeconomic status, geography, and other intersecting forms of marginalization. The knowledge, histories, and concerns of students and their communities are too often treated as peripheral to disciplinary learning. If STEAM education is implemented without an explicit equity and justice orientation, it may reproduce dominant assumptions about whose knowledge matters, whose problems are worthy of investigation, and who belongs in STEM-related spaces. Equity-centered STEAM requires teachers to design learning experiences that humanize students, value community knowledge and other ways of knowing, and position learners as competent and capable sensemakers, designers, and contributors.

A fourth gap involves the limited availability and use of tools for assessing integrated STEAM teaching. STEAM instruction asks students to engage in complex processes such as inquiry, design, modeling, collaboration, communication, and revision. Many existing assessment approaches remain focused on isolated disciplinary outcomes or final products (Mao et al., 2024). Teachers need tools that help them examine the quality of integration, the role of disciplinary practices, the authenticity of the problem context, the depth of student engagement, and the alignment among learning goals, tasks, and assessments. Without such tools, it is difficult for teachers to evaluate whether an activity represents meaningful STEAM integration or simply places multiple subject areas side by side (H. Plank &

Chelednik, 2025). Assessment tools and design frameworks are therefore essential not only for measuring student learning but also for supporting teacher reflection, instructional improvement, and research on STEAM implementation.

Finally, the field needs more research on sustained professional learning for STEAM educators. Many teachers express interest in STEAM and recognize its potential value for students, yet they also face significant barriers to implementation. These barriers include limited instructional time, insufficient resources, uncertainty about assessment practices, disciplinary silos, accountability pressures, and a lack of access to sustained professional development and coaching (Margot & Kettler, 2019). One-time workshops may introduce teachers to STEAM activities or frameworks, but they are unlikely to provide the ongoing support needed for teachers to transform their practice. Because STEAM teaching involves shifts in planning, pedagogy, assessment, collaboration, and classroom discourse, teachers need professional learning opportunities that are sustained, collaborative, growth-oriented, and connected to classroom enactment. More research is needed to understand how such professional learning can support teachers across different career stages, grade levels, institutional contexts, and community settings.

These five main gaps point to the need for a more coherent and sustained research agenda focused on cultivating teachers for STEAM education. The field must continue to clarify what meaningful integration entails, strengthen preservice preparation, start with and center equity and justice, develop tools for evaluating integrated teaching, and study the forms of professional learning that support implementation over time. Addressing these gaps is essential if STEAM education is to move beyond isolated projects or short-term initiatives and become a meaningful approach to teaching and learning that supports curiosity, creativity, sensemaking, and community-responsive problem solving.

3. Contributions of This Special Issue/How This Special Issue Addresses These Gaps

This Special Issue, "Cultivating Teachers for STEAM Education", was developed in response to these persistent gaps in the field. Collectively, these articles examine the conceptual, pedagogical, programmatic, and systemic conditions needed to prepare and support teachers for integrated STEAM instruction. The contributions span multiple educational contexts, including policy, preservice teacher education, elementary and primary education, in-service teacher learning, early childhood education, and undergraduate learning environments. They demonstrate that cultivating STEAM teachers requires more than just enthusiasm for integration or transdisciplinary problem solving. It requires clear frameworks, intentional preparation, sustained professional learning, tools for evaluating integration, and explicit attention to equity, justice, and community responsiveness.

Table 1 provides an overview of the articles included in this Special Issue and illustrates how each contribution addresses one or more of the knowledge gaps identified above. The table summarizes the context, primary contribution, and related gap for each article, making visible the ways this collection advances the field's understanding of STEAM teacher education and implementation. Following the table, we synthesize cross-cutting insights across the Special Issue and then describe several overarching themes that emerged from the collection.

Table 1. Contributions of articles in the Special Issue to key gaps in STEAM teacher education [1].

Literature Gap	Articles Addressing the Gap	Key Contribution
Lack of clear integration frameworks	(Bondurant et al., 2025; Martínez-Martínez et al., 2026; Spyropoulou et al., 2025)	Clarify definitions, policy alignment, and implementation expectations

Table 1. *Cont.*

Literature Gap	Articles Addressing the Gap	Key Contribution
Insufficient teacher preparation research	(H. M. Plank et al., 2026; Rimbach-Jones et al., 2025; Erceg & Ivošević, 2025)	Build understanding of teacher readiness, attitudes, and capacity
Few tools for evaluating STEAM instruction	(Martínez-Martínez et al., 2026; Rimbach-Jones et al., 2025; Spyropoulou et al., 2025)	Support lesson evaluation and instructional improvement
Limited early childhood/ developmental perspectives	(Pinilla et al., 2025)	Expand developmental and pedagogical foundations of STEAM
Limited focus on transformative and socially relevant STEAM	(Sager et al., 2025; Spyropoulou et al., 2025)	Connect STEAM to social justice, community engagement, and equity

[1] This table displays how the Special Issue articles address the literature gap and provides the key contributions.

3.1. Cross-Cutting Insights Across the Special Issue

Several key themes emerged from this collection of research. STEAM teacher preparation must be intentional, meaning that we cannot assume that disciplinary expertise will automatically translate into competence in integration. The process of integration requires a pedagogical transformation in which educators engage in a fundamental rethinking and reimagining of authentic assessment, discourse, and their role as classroom teachers. The tools and frameworks are essential for bridging the gap between theory and practice, which provides teachers with the scaffolding they need to reflect on their work. Equity must be a foundational design principle rather than a peripheral consideration. As we see in this collection, STEAM is most powerful when it is humanized and responsive to the students and community it serves.

3.2. Overarching Themes Within the Special Issue

Theme 1: clarifying frameworks for integration (including policy and clear definitions).

Research has identified the need to clarify frameworks for STEAM integration and to provide policy guidance that connects theory to practice. In this Special Issue, Bondurant et al. (2025), Martínez-Martínez et al. (2026), and Spyropoulou et al. (2025) address this gap. Bondurant et al. (2025) bridge the gap between educational policy and implementation by synthesizing policy documents to show how integration has been addressed over time and by providing a policy-level framework that clarifies expectations for integrated STEM. Martínez-Martínez et al. (2026) move the field from abstract definitions toward operational frameworks by offering practical criteria for identifying authentic integration. Spyropoulou et al. (2025) found that teachers often support STEAM philosophically but lack clear guidance for implementation, thereby highlighting the continuing need for coherent frameworks that translate theory into practice.

Theme 2: preparing preservice and elementary teachers for integrated STEAM.

STEAM research has stressed the importance of teacher preparation to support integrated STEAM. However, few studies examine how preservice and elementary teachers develop readiness, confidence, and competence for integrated STEAM instruction. In this Special Issue, H. M. Plank et al. (2026), Rimbach-Jones et al. (2025), and Erceg and Ivošević (2025) have provided insights to address this gap in preparation. H. M. Plank et al. (2026) investigated how participation in an integrated STEAM course influenced preservice teachers' perceptions, addressing the lack of research on preservice teacher development. Rimbach-Jones et al. (2025) identified structural and programmatic features that support the building of teacher capacity and provided a model for sustained professional development. Erceg and Ivošević (2025) examined primary teachers' attitudes toward science and outlined affective factors influencing teachers' readiness to implement STEAM education.

Theme 3: supporting teachers' evaluation and improvement in STEAM learning designs.

Teachers often lack validated tools and frameworks to evaluate the quality of integrated STEAM lessons and to improve instructional design. In this Special Issue, Martínez-Martínez et al. (2026), Rimbach-Jones et al. (2025), and Spyropoulou et al. (2025) address this gap. Martínez-Martínez et al. (2026) directly address this gap by using evaluations of teaching and learning sequences as a professional development tool. This study showed how lesson analysis can deepen teachers' understanding of STEM integration and provides suggested evaluative criteria that could be used to develop practical assessment tools. Rimbach-Jones et al. (2025) provide insight into indicators of effective integrated STEM practice by showing how teacher support programs can monitor and improve instructional capacity. Spyropoulou et al. (2025) identified teachers' needs regarding resources, planning support, and evaluation processes and provided practitioner-informed evidence to inform future tool development. These studies move the field toward evidence-based mechanisms for assessing and refining STEAM learning designs.

Theme 4: expanding developmental and pedagogical understandings of STEAM learning (early childhood and developmental perspectives).

Research has revealed a need for more research for early childhood contexts, including developmental processes and pedagogical foundations. Most of the research focuses on upper elementary and secondary education. Pinilla et al. (2025) investigate the foundational cognitive skills of kindergarteners and connect spatial reasoning, mathematics, and inquiry-based learning. Pinilla et al. (2025) expand the understanding of developmental elements necessary for STEM achievement. This research broadens STEAM scholarship by emphasizing developmental trajectories and early learning experiences.

Theme 5: transformative STEAM teaching and learning.

Transformative STEAM teaching and learning to address the historical inequities is necessary and a clear gap in the research. We need research that moves beyond disciplinary integration and moves toward social transformation through equity, access, inclusion, and engagement. In this Special Issue, both Sager et al. (2025) and Spyropoulou et al. (2025) position STEAM as a vehicle for community engagement, equity, and social change rather than merely a vehicle for academic achievement. Sager et al. (2025) directly demonstrate how data science can be applied to community issues and social justice. Spyropoulou et al. (2025) found that teacher commitment alone is insufficient without systemic support and outlined the institutional conditions necessary for transformative STEAM practices.

4. Future Directions for Research and Practice

To continue the process of cultivating a robust STEAM teacher workforce, we propose the following research agenda focused on teacher learning over time, equity-centered pedagogy, emerging technologies, diverse contexts, and collaborative research–practice partnerships:

1. Longitudinal Studies: We need to move beyond measuring "perceptions" at the end of a course and begin studying teacher learning and classroom enactment from pre-service teacher education across the first three to five years of teaching. This will support the process of developing clearer models of integrated STEAM teacher preparation that can be used to assess and measure integrated STEAM practice.
2. Equity-Centered Pedagogy: Future research should focus on how teachers specifically dismantle oppressive structures in STEM through justice-oriented anchoring events and community-responsive design.
3. Emerging Technologies: As artificial intelligence and new digital tools enter the classroom, we must investigate how they can support, rather than hinder, transdisciplinary sense-making and equitable access.

4. Diverse Contexts: Expanding research into more diverse developmental levels and global contexts will ensure that STEAM education frameworks truly support all learners.
5. Research–Practice Partnerships and Collaborative Inquiry: Future research should prioritize research–practice partnerships (RPPs) and other collaborative, participatory models that bridge scholarship and classroom practice. Because STEAM education is so complex, transdisciplinary, and context-dependent, researchers need to study teacher preparation and implementation alongside the educators, schools, and communities who enact it. RPPs offer promising structures for organizing sustainable, mutually beneficial collaborations between researchers and practitioners while supporting the co-design and study of educational innovations in authentic settings (Coburn & Penuel, 2016; Penuel et al., 2015). Within these partnerships, university partners often serve as brokers, navigating the power dynamics, trust-building, and logistical challenges inherent in launching and sustaining collaborative, justice-oriented work (H. Plank et al., 2023). Models such as clinical partnerships, STEAM camps, and participatory design research (Bang & Vossoughi, 2016; Vakil et al., 2016) provide essential contexts for co-designing and refining integrated learning experiences. Future studies should examine how these collaborative inquiry models can strengthen teacher learning, support equitable implementation, and generate research that is both theoretically meaningful and practically useful.

5. Conclusions: A Call to Cultivate STEAM Teachers

The articles in this Special Issue collectively argue that the "A" in STEAM is not an add-on about decoration or making a poster. Instead, it is an important lens for inquiry and representation. However, the vision of STEAM education in preparing youth to address "wicked problems" with creativity and empathy can only be realized if we prioritize cultivating STEAM educators themselves. We hope this collection serves as both a resource and a call to action for teacher educators, researchers, and policymakers to invest in the sustained, equitable, and responsive preparation that our teachers and students deserve.

Author Contributions: Conceptualization, H.M.P., S.D.L. and T.R.; methodology, H.M.P., S.D.L. and T.R.; software, H.M.P.; formal analysis, H.M.P.; investigation, H.M.P. and S.D.L.; resources, H.M.P., S.D.L. and T.R.; data curation, H.M.P. and S.D.L.; writing—original draft preparation, H.M.P., S.D.L. and T.R.; writing—review and editing, H.M.P., S.D.L. and T.R.; supervision, H.M.P. and S.D.L.; project administration, H.M.P. and S.D.L.; funding acquisition, S.D.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Bowling Green State University (protocol code 2240224-3, with approval granted on 6 December 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets presented in this article are not readily available because the data are part of an ongoing study.

Acknowledgments: This study was supported by an internal grant, the Shanklin AI Innovation Award awarded by Bowling Green State University.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

RPP	Research–Practice Partnership
STEM	Science, technology, engineering, and mathematics
STEAM	Science, technology, engineering, the arts, and mathematics

References

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction*, *34*(3), 173–193. [CrossRef]

Boche, B., Bartels, S., & Wassilak, D. (2021). Reimagining an elementary teacher education preparation program: Striving for integrated teaching. *Educational Considerations*, *47*, 1. [CrossRef]

Bondurant, L., Fitts, L., Ivy, J., Franz, D. P., & Wan, A. (2025). A review of US education policy on integrating science and mathematics teaching and learning. *Education Sciences*, *15*(12), 1687. [CrossRef]

Bush, S. B., & Cook, K. L. (2024). *Step into STEAM, grades PreK-5: Your standards-based action plan for deepening mathematics and science learning* (2nd ed.). Corwin.

Bush, S. B., Edelen, D., Roberts, T., Maiorca, C., Ivy, J. T., Cook, K. L., Tripp, L. O., Burton, M., Alameh, S., Jackson, C., Mohr-Schroeder, M. J., Schroeder, D. C., McCurdy, R. P., & Cox, R., Jr. (2022). Humanistic STE(A)M instruction through empathy: Leveraging design thinking to improve society. *Pedagogies: An International Journal*, *19*(1), 60–79. [CrossRef]

Cebesoy, U. B. (2026). Exploring preservice primary teachers' understanding of the engineering design process through integrated STEM laboratory activities. *STEM Education*, *6*(3), 439–466. [CrossRef]

Chai, C. S., Jong, M. S. Y., Yin, H. B., Chen, M., & Zhou, W. (2019). Validating and modeling teachers' technological pedagogical content knowledge for integrative science, technology, engineering and mathematics education. *Journal of Educational Technology & Society*, *22*(3), 61–73.

Coburn, C. E., & Penuel, W. R. (2016). Research-practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48–54. [CrossRef]

Erceg, N., & Ivošević, T. (2025). Exploring Croatian in-service primary teachers' professional attitudes toward science using the dimensions of attitude toward science (DAS). *Education Sciences*, *15*(6), 692. [CrossRef]

European Commission Joint Research Centre. (2023). *STEM and STEAM education, and disciplinary integration*. Publications Office of the European Union. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC141438 (accessed on 15 April 2026).

Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Roberts, T., Yost, C., & Fowler, A. (2021). Equity-oriented conceptual framework for K-12 STEM literacy. *International Journal of STEM Education*, *8*(1), 38. [CrossRef]

Jackson, C., Roberts, T., Maiorca, C., Cook, K. L., Bush, S. B., & Mohr-Schroeder, M. (2023). *Simplifying STEM: Four equitable practices to inspire meaningful learning (PreK-5)*. Corwin.

Jiang, S., Jiang, Y., Li, Y., Xu, M., & Xu, S. (2024). Longitudinal analysis of teacher self-efficacy evolution during a STEAM professional development program: A qualitative case study. *Humanities and Social Sciences Communications*, *11*, 1059. [CrossRef]

Jong, C., Priddie, C., Roberts, T., & Museus, S. D. (2020). Race-related factors in STEM: A review of research on educational experiences and outcomes for racial and ethnic minorities. In *Handbook of research on STEM education*. Routledge.

Mao, G., Zhang, Q., Ma, T., Li, F., & Lan, M. (2024). Investigating how subject teachers transition to integrated STEM education: A hybrid qualitative study on primary and middle school teachers. *Humanities and Social Sciences Communications*, *11*, 1059. [CrossRef]

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*, 2. [CrossRef]

Martínez-Martínez, V., Ortiz-Revilla, J., & Greca, I. M. (2026). Supporting teachers' understanding of integrated STEM through the evaluation of a teaching–learning sequence. *Education Sciences*, *16*(3), 368. [CrossRef]

Morrin, A. M., & Liston, M. (2020). Engaging children with authentic STEAM learning experiences through design-based approaches. *Connected Science Learning*, *2*(4), 12318723. [CrossRef]

National Academies of Sciences, Engineering, and Medicine. (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. The National Academies Press. [CrossRef]

National Science Teachers Association. (2023). *STEM education teaching and learning*. Available online: https://www.nsta.org/nstas-official-positions/stem-education-teaching-and-learning (accessed on 15 April 2026).

Penuel, W. R., Allen, A. R., Coburn, C. E., & Farrell, C. (2015). Conceptualizing research–practice partnerships as joint work at boundaries. *Journal of Education for Students Placed at Risk (JESPAR)*, *20*(1–2), 182–197. [CrossRef]

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. [CrossRef]

Pinilla, R. K., Mehta, P. J., & Pineda Sanchez, E. (2025). Investigating the connection between spatial reasoning skills and Reggio Emilia-inspired kindergarten mathematics activities. *Education Sciences*, *15*(10), 1375. [CrossRef]

Plank, H., Anderson, E. R., & Quigley, C. (2023). Leveraging University partners as brokers to navigate research–practice partnerships during intertwined global pandemics. In R. M. Reardon, & J. Leonard (Eds.), *School-university-community research in a (post) COVID-19 world*. Information Age Publishing. [CrossRef]

Plank, H., & Chelednik, H. (2025). Transdisciplinary pedagogies in pre-service teacher preparation to address wicked problems. In *Wicked Problems in PreK-12 science education* (pp. 217–228). Routledge.

Plank, H. M., Livers, S. D., & Roberts, T. (2026). Preservice elementary teachers' perceptions of integrated STEM after participating in an integrated STEAM course. *Education Sciences*, *16*(2), 214. [CrossRef]

Quigley, C. F., & Herro, D. (2016). "Finding the joy in the unknown": Implementation of STEAM teaching practices in middle school science and math classrooms. *Journal of Science Education and Technology*, *25*(3), 410–426. [CrossRef]

Quigley, C. F., Herro, D., King, E., & Plank, H. (2020). STEAM designed and enacted: Understanding the process of design and implementation of STEAM curriculum in an elementary school. *Journal of Science Education and Technology*, *29*, 499–518. [CrossRef]

Rimbach-Jones, D., Harper, F. K., & Brown, C. L. (2025). Building primary teachers' capacity for integrated STEM education: A case study of programmatic features and structures. *Education Sciences*, *15*(12), 1657. [CrossRef]

Russo-Tait, T. (2022). Equity and social justice in STEM education. *Teaching in Higher Ed*. Available online: https://teachinginhighered.com/podcast/equity-and-social-justice-in-stem-education (accessed on 15 April 2026).

Sager, M. T., Wieselmann, J. R., & Petrosino, A. J. (2025). From classroom to community: Evaluating data science practices in education and social justice projects. *Education Sciences*, *15*(7), 878. [CrossRef]

Spyropoulou, N., Mathiopoulos, K., & Kameas, A. (2025). "We believe in STEAM education, but we need support": In-service teachers' voices on the realities of STEAM implementation. *Education Sciences*, *15*(10), 1300. [CrossRef]

Vakil, S., McKinney de Royston, M., Suad Nasir, N. I., & Kirshner, B. (2016). Rethinking race and power in design-based research: Reflections from the field. *Cognition and Instruction*, *34*(3), 194–209. [CrossRef]

Zhou, S. N., Zeng, H., Xu, S. R., Chen, L. C., & Xiao, H. (2023). The effect of professional development on in-service STEM teachers' self-efficacy: A meta-analysis of experimental studies. *International Journal of STEM Education*, *10*(1), 58. [CrossRef]