

STEM Education in Pakistani Schools: Teachers' Awareness, Pedagogical Readiness,
And Barriers to Integrated Practice—A Critical Narrative Review

Huma Rizvi

humarizviehsan05@gmail.com

M. Phil. Education, Lahore Leads University

Iqra Malik

iqramalik1410@gmail.com

PhD Scholar, Educational leadership and Policy development, University of Education, Township Lahore

Hafiz Rana Qamar Javaid

qamar2756@gmail.com

Primary School Teacher, Government Primary School Line Subhan Khan Lahore

Corresponding Author: Huma Rizvi humarizviehsan05@gmail.com

Received: 17-02-2026

Revised: 12-02-2026

Accepted: 22-03-2026

Published: 30-03-2026

ABSTRACT

Integrated science, technology, engineering, and mathematics (STEM) education is promoted for its ability to bridge science classroom learning with inquiry, design, and real-world problems. However, the acronym STEM alone is not sufficient to ensure teachers can plan, teach, and assess interdisciplinary lessons. This critical narrative review explores the relationship between teachers' awareness, pedagogical readiness, and institutional conditions in school education in Pakistan. It is based on a review of 78 publications completed in 2024 across multiple countries, including an in-depth literature search of empirical and descriptive studies relevant to Pakistan, as well as independent literature identified by the authors and policy documents. The evidence aligns with the following: conceptual understanding, teacher preparation, curriculum and assessment, inquiry and technological resources, leadership, and equity. Barriers to enacting integrated STEM can only be reasonably explained by the interaction between teachers' professional learning and the school environment's curriculum opportunities and supports. In response, the paper suggests a contextual STEM Readiness-to-Practice Framework that defines the elements of awareness, design competence, enacted practice (including evidence of student learning), and enabling conditions at institutional and system levels. The paper suggests practice-based teacher education and curriculum-aligned, low-cost tasks, collaborative teaching, assessing processes and products, and context-sensitive assessment. This is a narrative review that does not attempt to estimate national prevalence nor claim new field results. It offers a Pakistan-related analysis that is analytically explicit and contributes to how integrated STEM can be translated from policy into viable classroom practice.

Keywords: *Integrated STEM education, teacher awareness, pedagogical readiness, interdisciplinary pedagogy, teacher education, school implementation, Pakistan.*

INTRODUCTION

In today's educational environments, science and mathematics programs are expected to equip students with the knowledge and skills to explore new and complex problems, make evidence-based inferences, and create functional solutions. Integrated STEM education addresses these goals by creating meaningful connections among science, technology, engineering, and mathematics. A learner designing a simple water filter might need knowledge of material properties, quantity calculations, experimenting with various designs, and communicating decisions based on evidence. It is not just using a computer during a science lesson or placing four subjects side by side; the disciplines must contribute to a common learning challenge (Kelley & Knowles, 2016; Thibaut et al., 2018).

However, integrated STEM does not happen simply because curriculum statements mention it. Teachers need to recognize potential disciplinary connections, identify questions suitable for learners, use appropriate tools and classroom interactions, and assess both content learning and reasoning skills. International evidence suggests that teachers can support the conception of STEM while also raising concerns about time, curriculum, resources, assessment, and unfamiliar content in STEM fields (Margot & Kettler, 2019). These findings show that the difference between awareness and readiness is analytically significant.

This is especially important in Pakistani schools, where instructional environments vary by locality, school sector, grade level, and institutional arrangement. Sahito and Wassan (2024) cite resource constraints and examination-oriented teaching and learning needs as concerns in Pakistan-related literature on STEM implementation. In Quetta, Kiazai et al. (2020) also reported implementation challenges and the potential contribution of teacher education programs for pre-service teacher educators. These sources provide information but are not a nationally representative assessment of STEM implementation. Local or secondary evidence should not be equated with a national census.

Sahito and Wassan (2024) classified 78 published studies into 11 themes, ranging from teachers' awareness and implementation issues to curriculum, inquiry, technology, integration models, blended learning, problem-solving, and research trends. The review provides a valuable overview of the field and brings together international contexts. In this article, the authors explicitly cite that scholarship as the foundation for the question now proposed: How will Pakistani teachers move from understanding STEM to a defensible approach to interdisciplinary instruction? The review introduces a new concept: It puts teacher-level and institutional conditions together in an implementation pathway. It does not repeat the figures from the earlier paper for a new search, nor does it claim to have repeated the systematic procedures.

Purpose and Review Questions

This paper aims to draw inferences from the existing literature on integrated STEM from the perspective of classroom teaching in Pakistan and to identify conditions in which teacher awareness could lead to successful integration of STEM in the classroom. How do we differentiate between teacher awareness and readiness for integrated STEM? (2) What is the difference between "content" and "process" integrated STEM? (3) What is the rationale for teaching integrated STEM? (4) How do we build teacher awareness and readiness for integrated STEM? (2) What are the most important pedagogical, curricular, and organizational challenges to understanding the Pakistani literature? (3) What are the possibilities for teacher education and school leadership to develop feasible opportunities for enacting in the classroom? (4) What is a conceptual framework and evaluative criteria for supporting future implementation and research?

METHODOLOGY: CRITICAL NARRATIVE REVIEW

This article is a critical narrative review, not a systematic review or meta-analysis. The central source is the published synthesis by Sahito and Wassan (2024), which identified 78 included studies and 11 broad themes derived from literature available up to 2022. It was not a new dataset, but it used its thematic structure as a starting map. The works identified through the same review and found relevant to the specific context were given special consideration in Pakistan. Other literature on STEM integration, teacher perception, and educational technology was purposefully selected to clarify concepts and for comparison, such as Kelley and Knowles (2016), Margot and Kettler (2019), Thibaut et al. (2018), and UNESCO (2023).

The four analytic concerns of interpretation followed an argumentative matrix: what integrated STEM means; the teacher's role in integrated STEM; the enabling and constraining conditions in schools for integrated STEM implementation; and what this means for equitable implementation. The synthesis distinguishes directly reported findings from contextual interpretation and proposed action for each

concern. The study reporting teachers' perceptions is not treated as fact, and findings from another country are not assumed to apply to Pakistan. Sources were not pooled statistically: they were compared for convergence or conceptual tension.

No new survey, interview, classroom observation, or student assessment data were gathered. The author does not claim to have carried out an exhaustive search of the literature in the databases or to have set defined inclusion criteria in the various databases, nor to have screened duplicate literature, nor to have conducted formal quality appraisal, nor to have applied the PRISMA guidelines for the selection of the studies included in the present article. The numbers in the 78 studies only refer to the 2024 source review. Thus, the desired result is a reasoned synthesis and a proposed framework, not prevalence estimates, national rankings, effect sizes, or verified causal conclusions.

Conceptual and Theoretical Foundations

Integrated STEM as a form of interdisciplinary learning

STEM integration can take many forms: a science topic could be enhanced by mathematics; an engineering challenge could draw on science concepts; or a real-world problem could structure contributions from multiple subjects. Kelley and Knowles (2016) emphasize that situated learning, engineering design, and connections between disciplines are integral to an overall conceptual framework. The key question in the main educational test is whether disciplinary knowledge is needed to understand the task. A technology component used for decoration, or an activity where students build a model but do not explain the concepts, could be interesting, but it is still not strong evidence of integrated STEM.

One important difference is between teaching STEM disciplines in parallel and building a lesson that brings disciplinary knowledge together around a common problem. English (2016) stated that STEM integration should be more equitable across disciplines. Similarly, the National Academy of Engineering and National Research Council (2014) noted that the goals, shape, and products of integration should be clearly defined. These insights suggest that Pakistan's teacher education should prioritize well-defined disciplinary learning goals rather than labeling learning activities STEM simply because they involve technology.

Thibaut et al. (2018) list secondary-level teaching practices they believe accompany integrated STEM. They see integration as a classroom design approach, rather than an add-on to current lessons. In Pakistan, this implies that teachers can identify concepts and learning outcomes common across subjects, which can serve as a basis for integration if they do so systematically. Meanwhile, curricular connections should be developmentally appropriate and should not diminish the clarity of learning goals across subjects.

Roehrig, Dare, Ellis, and Ring-Whalen (2021) identified the following as key characteristics of integrated STEM: engineering design, authentic problems, disciplinary content connections, and STEM practices. A review of related curriculum research revealed significant differences in how engineering challenges connect to underlying science concepts (Roehrig, Dare, Ring-Whalen, & Wieselmann, 2021). Therefore, any lesson, regardless of how many STEM labels it has, should be evaluated by how well it connects to concepts.

Awareness, self-efficacy, competence and practice

In discussions about STEM, the terms awareness, confidence, knowledge, readiness, and implementation are often treated as synonymous, but they are not. A teacher is aware of and can articulate the "how and why" of integrated STEM. Self-efficacy is confidence in successful teaching; it can promote experimentation, but it is not performance. Design competence is "the ability to develop a learning sequence that incorporates cross-subject goals, student inquiry, meaningful tasks, and aligned

assessment. Enactment refers to what occurs in the classroom, and effectiveness relates to the quality of the evidence of learning in the classroom. In concept, one stage links to the next, but no stage is guaranteed to lead to the next.

This separation helps avoid common pitfalls in needs assessment. The questions on a questionnaire relating to respondents' familiarity, attitude, and self-description of STEM use are "familiarity," "agreement that STEM is valuable," and "reported use. A percentage of competent STEM teachers should automatically replace no one. Lesson plans, observation records, and examples of student explanations and feedback on learning decisions will be required to help researchers and school leaders better evaluate practice.

Researchers gathered classroom evidence to distinguish teacher endorsement from enactment. In Dare et al. (2018), they examined nine middle school science teachers. They explained various strategies for integrating science, mathematics, and engineering, highlighting practical challenges faced by middle school teachers who have not been deeply involved in science. These results support using lesson plans, observations, pupil work, and teacher self-reported confidence to measure preparedness.

An ecological understanding of instructional change

The teaching context influences teacher performance. Even a motivated teacher may lack the time, materials, working space, colleague support, or permission to vary textbook pacing to arrange a practical investigation. At the same time, hardware availability does not promote good instruction if teachers are not pedagogically prepared. According to Margot and Kettler (2019), teachers report instructional, curricular, and structural barriers. This article thus reads STEM readiness ecologically: teacher agency matters, but teacher preparation, school leadership, assessment expectations, and resource allocation also shape educational opportunities.

Critical Synthesis of Literature

Teacher awareness: promise and limits

In the reviewed synthesis, STEM awareness is a common theme, and STEM is associated with inquiry-based learning activities, problem-solving, and engagement (Sahito & Wassan, 2024). However, the constituent studies vary widely in samples, methods, and educational settings. A positive attitude at the end of a survey or workshop does not necessarily indicate better classroom teaching. A defensible explanation is that awareness can increase receptivity to change, but it must be followed by opportunities to experiment with instruction and demonstrate learning.

Awareness-raising activities might help to explain in the Pakistani context what each element of STEM is – for example, engineering design is a process of defining a problem, developing and testing a solution, and revising that solution based on evidence. Training must address misconceptions: STEM is not about the cost of robotics equipment, nor is it about abandoning subject knowledge for projects. However, while schools can complete low-cost tasks, they should not use this as an excuse for a lack of infrastructure.

Teacher education and professional-development design

Kiazai et al. (2020) explored perceived challenges in implementing STEM education and its potential contribution to mitigating these challenges through teacher education programs in Balochistan. They used a non-probability sampling technique, and their sample included 202 respondents from three public universities in Quetta involved in pre-service teacher education. The findings point to teacher preparation as a potential entry point, as the setting and sampling process do not allow for national generalization. The study is best used to understand the context in which one should consider entering

the profession and areas for professional learning, rather than to calculate the prevalence of specific barriers in Pakistan.

Disciplinary and pedagogical uncertainty is also a professional-learning issue. Shernoff et al. (2017) explored the professional-development needs of integrated STEM, and the need to prepare teachers to move STEM concepts into teaching. Ryu and colleagues (2019) investigated pre-service teachers' experiences integrating STEM and summarized implications for teacher preparation. These studies do not support information-based orientations; instead, they emphasize guided lesson design, rehearsal, feedback, and revision.

Single awareness seminars are insufficient to create long-term pedagogical change. A successful professional learning sequence would first clarify concepts of integrated STEM, then model an authentic task, provide an opportunity to redesign curriculum-linked tasks, include microteaching and peer feedback, and test on a small scale in real school settings. Reflection questions include which disciplines students actually used, whether participation was fairly represented, what misconceptions came up, and what the teacher would change. The professional-development output should therefore be an updated teaching artifact and observed teaching practice, rather than a certificate.

Zhou et al. (2023) conducted a meta-analysis on the effect of professional development on in-service STEM teachers' self-efficacy in the research studies they analyzed; they found that overall, professional development had a positive effect on in-service STEM teachers' self-efficacy. While this evidence supports enhancing teacher confidence through professional learning, it does not necessarily mean a specific workshop will change classroom practice or student achievement in Pakistan; that can only be tested locally.

Curriculum organization and examination alignment

High-stakes tests and subject timetables can lead to coverage of isolated content, particularly if practical work seems to take time away from test preparation. These constraints, along with equipment, instructional materials, and teacher training challenges, are described in the publications discussed in Sahito and Wassan (2024), which are focused on Pakistan. Such reports should not be understood only as evidence that all schools use rote learning as the measure of success, but also as raising a plausible implementation problem: If success is judged purely in terms of recall, then interdisciplinary design tasks might not be rewarded in the institutional sense by teachers.

Curriculum mapping is a good candidate for a response. Based on the teacher's knowledge of existing learning outcomes in science and mathematics, a task can build on them and then develop them, for example, by measuring water use, comparing insulation materials, or analyzing rainfall. The assessment should be based not only on correctness within the discipline but also on explanations of design choices. This allows integrated learning without assuming that a new STEM subject, new book, or significant timetable change is needed immediately. It also reduces the risk that appealing project work will supplant mathematical and scientific background knowledge.

The integration of curricula is coherent. Roehrig et al. (2021) analyzed 50 curriculum units and distinguished between superficial and conceptually integrated curriculum designs. The activity should therefore indicate where mathematics is used to explain a scientific phenomenon or to make an engineering choice, and which aspects of the existing learning outcomes it covers.

Inquiry, engineering design and problem-solving

Problem-based learning and inquiry-based learning are both common features of integrated STEM, but they are not the same. Inquiry emphasizes developing questions, collecting data, and interpreting evidence; engineering design emphasizes developing a response to a problem within constraints. Both can be used in a meaningful classroom task. The potential benefits for student engagement and problem-

solving that Sahito and Wassan (2024) propose draw on international research. However, the variety of interventions and outcome measures makes it difficult to make a universal claim about effect.

Think of a task where students must minimize heat transfer in a small model room. Scientific understanding: heat and material properties; Mathematics: measurement, tables, and comparison; engineering: prototypes and redesign; Technology: thermometers or digital records (if available). The student should anticipate, experiment, document, explain, and justify a design decision. This is an example of an instructional illustration that has been proposed, not an intervention or empirical finding from this review.

Technology, resources and the equity question

The 2024 review discusses digital devices and games, cloud-based applications, and blended approaches as resources that can support instruction. However, a critical difference exists between using technology and integrating it into disciplines. UNESCO (2023) likewise argues that educational technology must be appropriate, equitable, sustainable, and evidence-based. If access to stable electricity, devices, connectivity, or technical support is not assumed, then a technology-first definition of STEM education risks leaving the schools most in need of support behind.

Also, teacher capacity for technology needs to be measured independently of overall enthusiasm for digital learning. Chai et al. (2020) created and tested a survey on technological pedagogical content knowledge (TPCK) for STEM teachers and emphasized the interaction among technological, pedagogical, and subject knowledge. The relevance here is conceptual, because teachers can use digital equipment for an integrated task only if they can explain the task's purpose in the lesson and connect it to the discipline's content.

The design principle is proportionality. The teacher should choose the simplest tool that can accomplish a stated learning objective. Rigorous inquiry can be supported by locally available materials, measuring containers, reusable cardboard, and simple balances and paper data tables. Digital tools can support the task when they provide a real educational benefit, e.g., graphing repeated observations, modeling a complex phenomenon. Policymakers do need to differentiate constructive local adaptation from structural inequity, however, and plan for progressive improvements in laboratories, accessibility and teacher support.

Leadership, collaboration and institutional capacity

Teachers do not usually have complete control over all the settings needed to achieve interdisciplinary learning. School leaders set expectations, pacing, access to teaching resources, and common planning time. Science and mathematics teachers may need collaborative planning time to avoid disjointed activities. Consistent with the broader argument that context and collegial support matter for implementation, Thibaut et al. (2018) and Margot and Kettler (2019) agree.

It is not an attitude; it is an organizational challenge. Wang et al. (2020) found that team size, shared teaching goals, and collaboration structure influenced the collaboration model in two high school teacher teams. This observation supports the view that teachers should be given agreed planning tasks that are not too large in scope and should not assume that a model validated elsewhere would be effective in Pakistan without modification.

For Pakistani schools, a simple start might be a STEM planning group that meets regularly to choose one curriculum-aligned problem, develop a few measurable learning outcomes, and review student work after a period of using the program. If the exhibition shows no evidence of learning outcomes, it would be more worthwhile for the school to coordinate such an event than for a single STEM exhibition to occur in isolation. Schools can have some flexibility, while teacher education institutions can help develop model tasks, train teachers, and ensure fair assessment.

Interpreting the evidence base cautiously

Some common shortcomings should be addressed. First, the literature draws on international sources; therefore, it is diverse in age and discipline and cannot be transferred without considering local curriculum, language, and resources. Second, studies are typically based on self-report, which can lead to an overestimation of enacted practice. Thirdly, pilot projects can be very difficult to transfer to other contexts if they rely on unique staff or external assistance. Fourth, the evidence does not consistently report gender, disability, or language differences, or differences between school sectors. Last but not least, enthusiasm or attendance at school, or project completion, does not indicate the quality of the education offered. These constraints inform the following proposed framework.

Proposed STEM Readiness-to-Practice Framework

This article proposes a STEM Readiness-to-Practice Framework (SRPF) based on the synthesis of integrated teaching in Pakistani schools. It is for conceptual organization, not statistical prediction. The framework identifies four stages of evidence that a teacher must demonstrate and links these stages to the enabling conditions in the school and the system.

Table 1; Details of the framework of STEM Readiness to Practice

Dimension	Core question	Possible evidence
1. Conceptual awareness	Does the teacher understand what makes a task genuinely integrated?	Explanation of STEM; ability to distinguish integration from parallel subject teaching
2. Design readiness	Can the teacher plan aligned outcomes, inquiry, and assessment?	Lesson plan; concept map; task and rubric; peer review
3. Classroom enactment	Can students engage in disciplinary reasoning and iterative inquiry?	Structured observation; student work; teaching reflection
4. Learning evidence	What did students explain, calculate, design or revise?	Pre/post concept tasks where appropriate; portfolios; rubrics
Enabling school conditions	Are time, leadership, materials and collaboration available?	Timetable analysis; resource audit; leadership and staff interviews
System conditions	Do curriculum, assessment and professional learning support the work?	Policy/curriculum mapping; training design; evaluation criteria

Teacher awareness increases the likelihood of engagement but does not, by itself, lead to effective classroom practice. Design readiness needs joint preparation and the right preparation materials; enactment needs to be recorded separately from the teacher's confidence level; and learning evidence needs to take the form of conceptual understanding and real-life application. Good practice can be seen in an under-resourced school, for example, through the design of low-cost tasks, but also in a technologically well-equipped school, where poor-quality integrated learning might show up in a lack of care and attention in task design. These are only hypotheses and interpretive propositions—not relationships tested by this paper.

PRACTICAL APPLICATION FOR PAKISTANI SCHOOLS AND TEACHER EDUCATION

A context-responsive teacher education sequence

Five phases could be proposed for a teacher education module. The introductory phase explains subject integration through contrasting lesson examples. Pairs of pre-service or in-service teachers will identify curriculum outcomes in two or more STEM subjects during the planning process. The design phase yields an inquiry or engineering challenge and an assessment rubric. Practice occurs by microteaching followed (as far as possible at the institution) by a classroom trial. The reflection phase focuses on learners' responses, misconceptions, equity of participation, and required changes. Produce assessable evidence in each phase, and do not rely only on participants' perceptions.

Example of a curriculum-linked instructional task

One potential example that may be adapted to various grade levels is a water-conservation investigation. Students can estimate water use in a familiar context, make observations and record measurements in a table or graph, explain the relevant science, suggest a realistic reduction plan, and explain why it could be feasible. For younger students, teachers can simplify the calculations and use less complex equipment; for older students, they can make it a rate question, a proportional reasoning exercise, and/or a prototype-testing task. Assessment criteria might include accurate measurement, scientific explanation, mathematical interpretation, and the quality of design reasoning and reflection. There are no stated or implied student outcomes in this proposed task.

Assessing participation and achievement fairly

The rubric should be balanced and should not be awarded the highest marks for visual presentation or the use of purchased resources. Criteria can be weighed equally for scientific accuracy, mathematical justification, investigation or design process, explanation of evidence, and collaborative responsibility. Group products could conceal differences in understanding; therefore, individual questioning is important. In multilingual classrooms, students may need the chance to articulate the concept using easily understood terminology before being assessed using formal technical language. Equity needs to be built into the assessment from the start, not only addressed when issues emerge.

POLICY AND LEADERSHIP PRIORITIES

At the institutional level, attention should focus on protected joint-planning time, smaller reusable equipment kits, safer activity spaces, and supportive observation, rather than inspection based on the teacher's use of a STEM label. At the university level, teacher education institutions can create model lesson repositories and strengthen supervision for classroom trials. Implementation guidance should align with current learning outcomes and assessment, be developed at the education authority level, and consider access inequalities between public and private sectors and urban and rural settings. Decisions to improve resources should be transparent, and implementation should be incremental.

RESEARCH IMPLICATIONS

The framework generates researchable propositions. Further research can investigate conceptual awareness using an instrument separate from design competence and enacted teaching, with a distinct attitude scale. To compare across school sector, area, teaching experience, and access to materials, multi-site studies would be necessary. Relying solely on teachers' reports would be enhanced by classroom observations and analysis of student work. With sufficient sampling, ethics approval, baseline measures, and clear outcomes, an intervention study might compare a practice-based coaching model with traditional professional development.

The biggest methodological tip is not to mistake implementation for intention. A school does not need to adopt STEM to have adopted it, a teacher who says he/she is confident has not necessarily shown integration, and a model-completed school does not constitute conceptual learning. Future evidence should be linked to the type of observation that can validate it.

LIMITATIONS

This paper is a critical narrative review of the literature and relies heavily on a previous multinational review. This is not a new systematic search nor an independently quality-evaluated review of all research on Pakistan. Some studies mentioned in the foundational review were carried out in different curriculum and resource settings. For this reason, this paper cannot calculate the national prevalence of STEM awareness, link it to causal effects on learning, or rank school sectors. The SRPF is an ill-formulated conceptual model and has never been psychometrically tested and evaluated in Pakistani classrooms. These limitations do not impede empirical statements, but they do allow a clear conceptual synthesis of implementation requirements.

CONCLUSION

Integrated STEM education is a useful way to connect school subjects to inquiry, design, and reasoned problem-solving; however, the benefits of integrated STEM education cannot be claimed simply by focusing on the acronym. The literature reviewed here suggests that pedagogical preparation, curriculum organization, assessment expectations, materials, and institutional support influence teachers' opportunities to provide integrated instruction. It is imperative to examine studies with a Pakistani focus, while avoiding sample-specific conclusions. This article's central contribution is the STEM Readiness-to-Practice Framework, which relates STEM teacher awareness, design competence, enacted STEM practice, and evidence of STEM learning to enabling school and system conditions. A credible pathway starts with activities that engage students in curriculum-aligned work, professional learning opportunities, and fair assessments, along with continuous efforts to address inequities in resources and opportunities for Pakistani schools. Evaluation should ultimately consider what learners can explain, investigate, and improve, not just whether a school reports providing STEM activities.

REFERENCES

- Chai, C. S., Jong, M., & Yan, Z. (2020). Surveying Chinese teachers' technological pedagogical STEM knowledge: A pilot validation of STEM-TPACK survey. *International Journal of Mobile Learning and Organization*, 14(2), 203–214. <https://doi.org/10.1504/IJMLO.2020.106181>
- Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education*, 5, Article 4. <https://doi.org/10.1186/s40594-018-0101-z>
- English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3, Article 3. <https://doi.org/10.1186/s40594-016-0036-1>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3, Article 11. <https://doi.org/10.1186/s40594-016-0046-z>
- Kiazai, A. N., Siddiqua, N., & Waheed, Z. (2020). Challenges in implementing STEM education and the role of teacher education programs in mitigating these challenges. *International Journal of Distance Education and E-Learning*, 5(2), 123–137. <https://doi.org/10.36261/ijdeel.v5i2.1047>

- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, 6, Article 2. <https://doi.org/10.1186/s40594-018-0151-2>
- National Academy of Engineering & National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. The National Academies Press. <https://doi.org/10.17226/18612>
- Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: A detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, 3, Article 11. <https://doi.org/10.1186/s43031-021-00041-y>
- Roehrig, G. H., Dare, E. A., Ring-Whalen, E., & Wieselmann, J. R. (2021). Understanding coherence and integration in integrated STEM curriculum. *International Journal of STEM Education*, 8, Article 2. <https://doi.org/10.1186/s40594-020-00259-8>
- Ryu, M., Mentzer, N., & Knobloch, N. (2019). Pre-service teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education*, 29, 493–512. <https://doi.org/10.1007/s10798-018-9440-9>
- Sahito, Z., & Wassan, S. H. (2024). Literature review on STEM education and its awareness among teachers: An exploration of issues and problems with their solutions. *SAGE Open*, 14(1), 1–21. <https://doi.org/10.1177/21582440241236242>
- Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, 4, Article 13. <https://doi.org/10.1186/s40594-017-0068-1>
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1), Article 02. <https://doi.org/10.20897/ejsteme/85525>
- UNESCO. (2023). *Global education monitoring report 2023: Technology in education—A tool on whose terms?* UNESCO. <https://doi.org/10.54676/UZQV8501>
- Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education*, 7, Article 3. <https://doi.org/10.1186/s40594-019-0201-4>
- Zhou, X., Shu, L., Xu, Z., & Padrón, Y. (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, Article 37. <https://doi.org/10.1186/s40594-023-00422-x>