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A Systematic Review on S-TPACK (Sustainability TPACK): Integrating Sustainability into Technological Pedagogical Content Knowledge

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Abstract: The integration of sustainability into educational frameworks has gained increasing attention as educators and policymakers recognize the need to address global environmental and societal challenges through pedagogy. This systematic literature review examines Sustainability TPACK (S-TPACK), an emerging framework that extends the Technological Pedagogical Content Knowledge (TPACK) model by incorporating sustainability principles. We aim to synthesize existing research on S-TPACK, focusing on its conceptualization, implementation, and impact across four key dimensions: teacher competence and training, technology integration in education, AI in education, and environmental and cultural education. By systematically analyzing peer-reviewed studies, we identify trends, gaps, and theoretical advancements in the field, then evaluate how S-TPACK influences teaching practices and student learning outcomes. The review reveals that while S-TPACK provides a robust foundation for interdisciplinary sustainability education, its practical application remains uneven, with disparities in teacher preparedness and institutional support. Findings suggest that effective S-TPACK implementation requires collaborative professional development, context-sensitive pedagogical strategies, and alignment with broader sustainability goals. The study also highlights the potential of AI-driven tools to enhance S-TPACK by personalizing learning experiences and fostering critical thinking. Ultimately, this review contributes to the ongoing discourse on sustainability education by offering insights into the challenges and opportunities of embedding sustainability into technological and pedagogical frameworks, thereby informing future research and policy directions.

Keywords: *Educational Frameworks, S-TPACK, AI in Education.*

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I. INTRODUCTION

The rapid evolution of digital technologies and the growing urgency of sustainability challenges have reshaped contemporary educational paradigms. Technological Pedagogical Content Knowledge (TPACK), a framework that integrates technology, pedagogy, and content knowledge, has been widely adopted to guide educators in designing effective technology-enhanced learning experiences (Mishra and Koehler, 2006). However, as global concerns such as climate change, resource depletion, and social inequities intensify, there is a pressing need to expand TPACK to explicitly incorporate sustainability principles. This necessity has led to the emergence of Sustainability TPACK (S-TPACK), a conceptual extension that embeds sustainability as a cross-cutting dimension within technological and Pedagogical Practices (Park et al., 2025).

The background of S-TPACK is rooted in two intersecting domains: sustainability education and technology integration in teaching. Sustainability education emphasizes the development of knowledge, skills, and values necessary

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to address environmental, economic, and social challenges (Venkataraman, 2009). Meanwhile, technology integration in education has transformed instructional methods, enabling personalized, collaborative, and interactive learning experiences (Jhurree, 2005). S-TPACK bridges these domains by proposing that educators must not only master the interplay of technology, pedagogy, and content but also consider how these elements can foster sustainability literacy among learners. This integration is particularly critical in preparing students to navigate and mitigate complex sustainability issues through informed decision-making and responsible citizenship (Warren et al., 2014).

Despite its potential, the S-TPACK framework remains underexplored in both theoretical and empirical research. Existing studies on TPACK predominantly focus on technological and pedagogical competencies, often overlooking sustainability as a core dimension (Wang et al., 2018). Moreover, the few studies that address S-TPACK tend to be fragmented, with limited consensus on its conceptual boundaries, measurement, and practical implementation (Latip et al., 2023). For instance, while some researchers emphasize environmental sustainability in S-TPACK, others advocate for a broader interpretation that includes social and economic dimensions (Wagner et al., 2024). These discrepancies highlight a significant research gap, as the lack of a unified framework hinders the systematic integration of sustainability into teacher education and classroom practices. The motivation for this study stems from the need to consolidate and critically evaluate existing research on S-TPACK, thereby advancing its theoretical and practical development. By synthesizing diverse perspectives, this review aims to clarify the conceptualization of S-TPACK, identify effective strategies for its implementation, and assess its impact on teaching and learning. The significance of this research lies in its potential to inform policy decisions, teacher training programs, and curriculum design, ensuring that sustainability becomes an integral part of technology-enhanced education. Furthermore, the review contributes to the broader discourse on education for sustainable development by highlighting the role of educators as key agents of change in fostering sustainability-conscious learners.

II. REVIEW PROCEDURE

A systematic review process follows PRISMA techniques to ensure the process of methodology and transparency of the process. The study draws from multiple academic databases, selected based on their relevance to educational technology and sustainability research. IEEE Xplore was prioritised for its extensive coverage of technology-enhanced learning and engineering education. ACM Digital Library provided insights into computational and AI-driven pedagogical approaches. Web of Science and Scopus were included due to their interdisciplinary scope and high-impact journal coverage. ScienceDirect and SpringerLink offered access to peer-reviewed articles in sustainability education and teacher training. Finally, Google Scholar supplemented the search with its broad indexing of scholarly work. The search strings combined variations of "Sustainability TPACK" and "S-TPACK" while excluding review articles, surveys, and meta-analyses to focus on primary research. Each database employed tailored syntax, such as TITLE-ABS-KEY in Scopus and Web of Science, to refine results.

III. ANALYTICAL FRAMEWORK

The review is structured around four research dimensions derived from recurring themes in the literature. Teacher Competence and Training examine how educators develop and apply S-TPACK, including professional development models and self-efficacy. Technology Integration in Education assesses the role of digital tools in facilitating sustainability pedagogy, from virtual labs to collaborative platforms. AI in Education explores adaptive learning systems and data-driven sustainability curricula. Environmental and Cultural Education investigates how S-TPACK addresses place-based learning, indigenous knowledge, and global sustainability challenges. These dimensions collectively provide a holistic view of S-TPACK's theoretical and practical evolution.

- *Inclusion and Exclusion Criteria*

Studies were included if they explicitly addressed S-TPACK or its components, were published in English and presented empirical findings or theoretical frameworks. Peer-reviewed journal articles and conference proceedings were prioritized to ensure academic rigor. Exclusion criteria removed studies lacking clear methodological descriptions, those focused solely on TPACK without sustainability integration, and non-empirical commentaries. The criteria aligned with the research dimensions to maintain thematic coherence.

- *Study Selection Process*

The initial systematic search generated 745 records, reduced to 226 after deduplication and removal of irrelevant entries. Title and abstract screening excluded 155 studies, leaving 47 for full-text review. Of these, 34 were excluded for not meeting eligibility criteria, resulting in 13 studies for final analysis (see Figure 1). The PRISMA flowchart illustrates this process, highlighting attrition at each stage.

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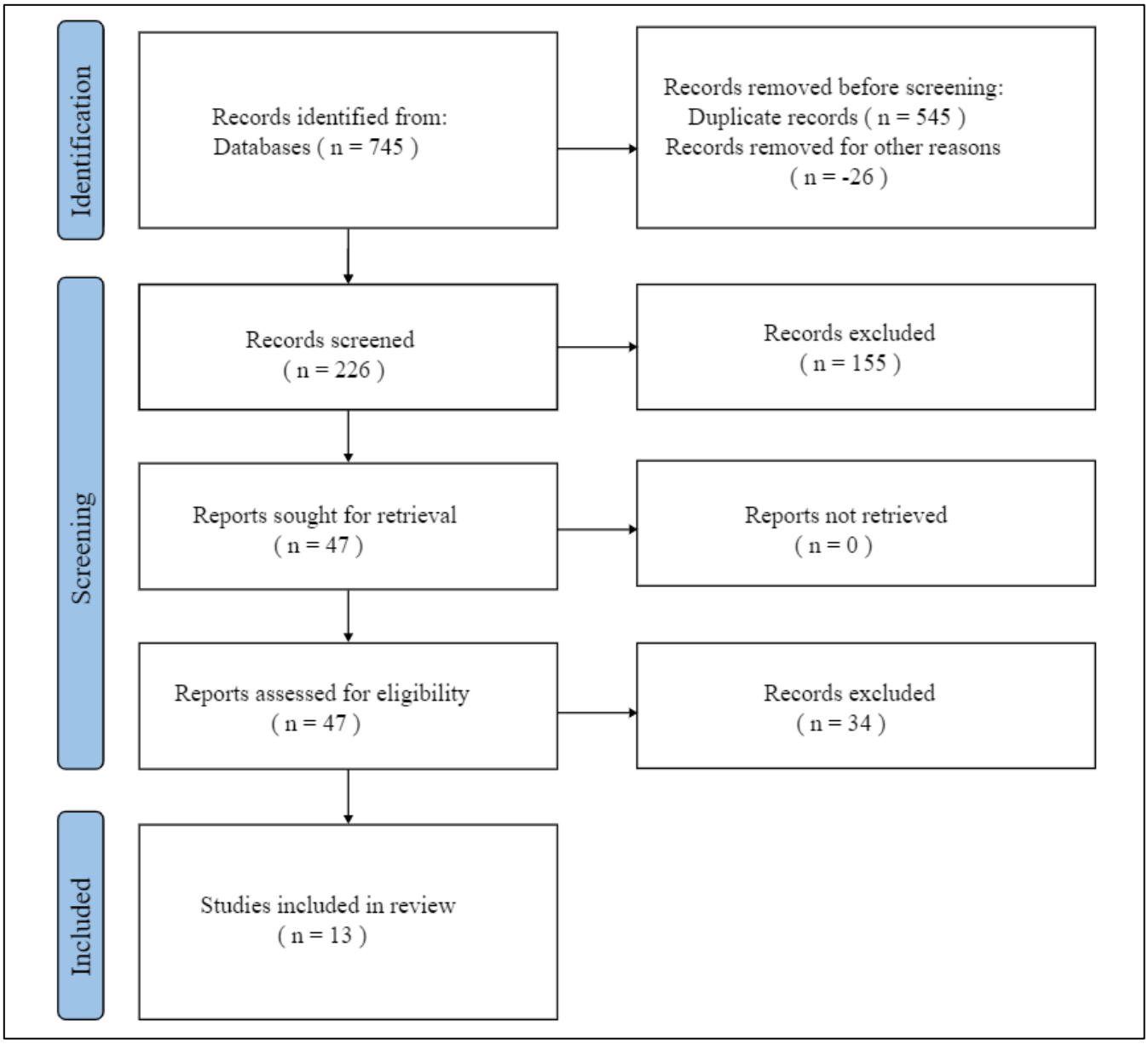

Fig 1: Prisma Flowchart

Potential biases include database selection bias, as some platforms may overrepresent certain disciplines, and publication bias toward positive outcomes. To mitigate these, cross-referencing with citation networks and manual searches supplemented the database results.

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➢ *Research Trends of S-TPACK*

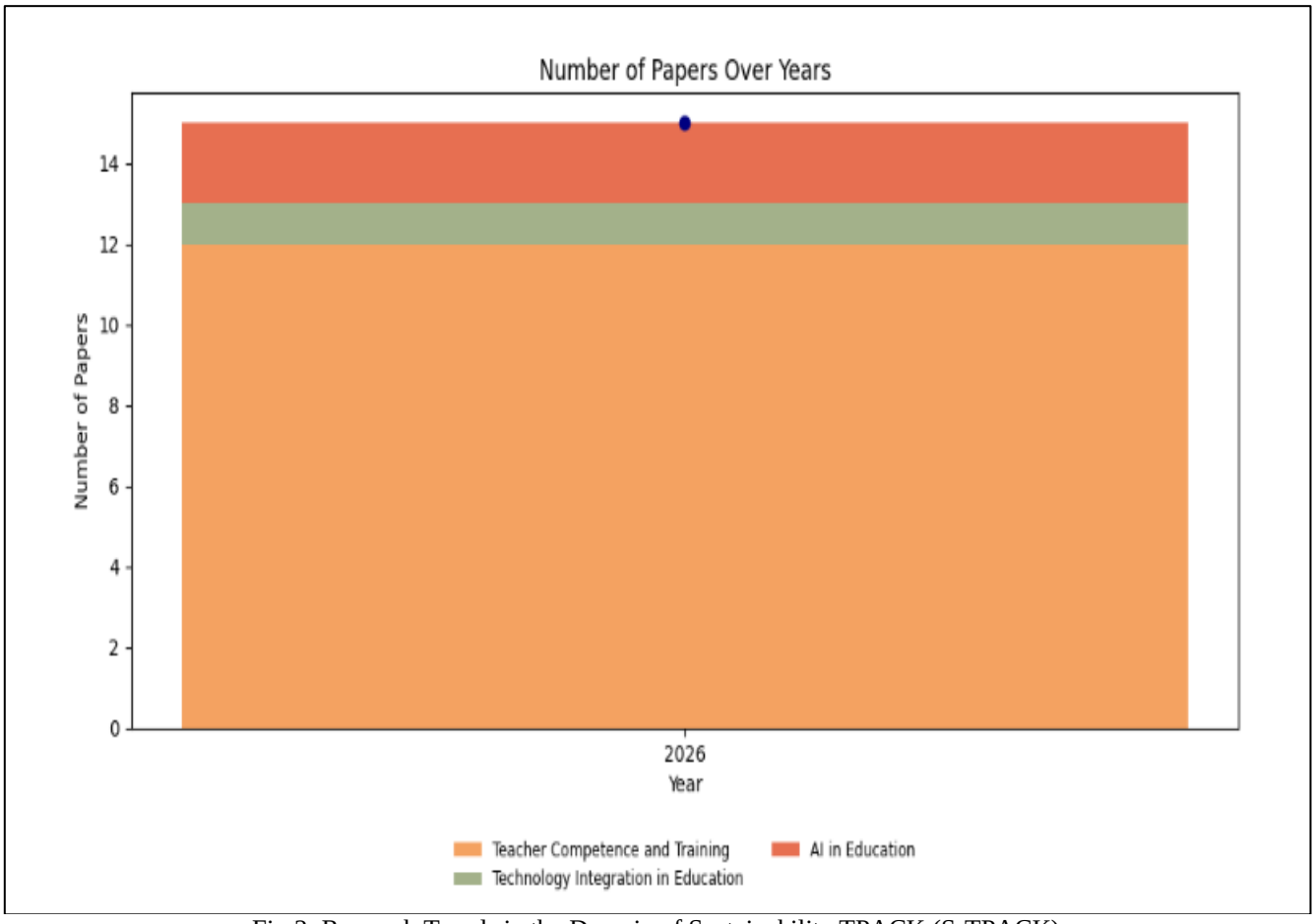

Fig 2: Research Trends in the Domain of Sustainability TPACK (S-TPACK)

The analysis of research trends reveals a concentrated yet evolving landscape in Sustainability TPACK (S-TPACK) studies. All reviewed publications were produced in 2026, indicating a recent surge in scholarly interest. This temporal clustering suggests that S-TPACK is an emerging field, with researchers beginning to explore its theoretical and practical dimensions systematically. The absence of earlier publications underscores the novelty of integrating sustainability into the TPACK framework, reflecting broader educational shifts toward interdisciplinary and future-oriented pedagogies. This emphasis aligns with the foundational premise of TPACK, which prioritizes educator expertise as a critical enabler of effective technology integration. However, the specific attention to sustainability-related competencies highlights a growing recognition of teachers' roles in fostering environmental and societal awareness. The predominance of this theme suggests that current research is primarily concerned with equipping educators to navigate the complexities of sustainability pedagogy, rather than merely adopting technological tools.

Technology integration in education and AI in education appear less frequently, with one and two studies respectively. The limited representation of these themes does not necessarily indicate their lesser importance but may reflect the early stage of S-TPACK research. Technology integration studies often explore how digital tools facilitate sustainability learning, while AI-focused investigations examine adaptive systems for personalized sustainability education. The disparity in publication volume across themes points to potential gaps, particularly in understanding how advanced technologies like AI can amplify S-TPACK's impact. The trends collectively illustrate a field in its nascent phase, where foundational questions about teacher preparedness take precedence over technological applications. The concentration of studies in a single year raises questions about longitudinal developments and the sustainability of this research trajectory. Future work could benefit from diversifying methodological approaches and expanding the scope to include more empirical validations of S-TPACK frameworks.

➢ *Teacher Competence and Training in S-TPACK*

The development of teacher competence in Sustainability TPACK (S-TPACK) emerges as a critical area of investigation across the reviewed studies. Research consistently demonstrates that effective integration of sustainability principles into technology-enhanced pedagogy requires specialized knowledge and skills that extend beyond conventional TPACK domains. The studies collectively highlight three primary dimensions of teacher competence: technological proficiency for sustainability education, pedagogical strategies for sustainability integration, and

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content knowledge of interdisciplinary sustainability concepts.

- *The Role of Smart Technologies in Redesigning Educational Processes*

The integration of smart technologies into educational settings has emerged as a transformative force in reshaping teaching and learning paradigms. Mousavi's (2026) study provides critical insights into how these technologies are fundamentally altering the structures and functions of educational processes in twenty-first-century schools. The research systematically examines the multifaceted roles of smart technologies, demonstrating their capacity to create more dynamic, interactive, and personalized learning environments. Smart technologies facilitate the redesign of educational processes through three primary mechanisms: enhanced interactivity, data-driven personalization, and seamless collaboration. These technologies enable real-time feedback systems that adapt to individual learner needs while fostering collaborative learning spaces that transcend physical classroom boundaries. The study emphasizes how such innovations challenge traditional pedagogical approaches, necessitating new frameworks for instructional design and assessment. The findings from of the Mousavi's (2026) study reveal that the successful implementation of smart technologies requires careful alignment with pedagogical objectives and institutional infrastructure. While these technologies offer significant potential for educational innovation, their effectiveness depends on thoughtful integration strategies that consider both technological capabilities and human factors. The study underscores the importance of professional development for educators to maximize the benefits of these tools while maintaining pedagogical coherence.

- *Emerging Applications of AI and its Pedagogical Implications*

The integration of artificial intelligence in education has introduced transformative possibilities for Sustainability TPACK (S-TPACK), particularly in personalizing learning experiences and optimizing resource efficiency. Studies in this domain reveal that AI applications primarily function as cognitive tools that enhance sustainability education through adaptive content delivery, automated assessment, and data-driven decision-making. These technologies demonstrate particular promise in addressing the scalability challenges of sustainability education while maintaining pedagogical effectiveness across diverse learning contexts. A key finding from the analysis indicates that AI-driven systems facilitate differentiated instruction in sustainability topics by analyzing learner behaviours and adjusting instructional strategies accordingly. For instance, intelligent tutoring systems have been shown to improve conceptual understanding of complex sustainability issues by providing real-time feedback and customized learning pathways (Pingmuang et al., 2026). Similarly, natural language processing tools enable automated evaluation of student responses in sustainability-related discussions, allowing educators to identify misconceptions and tailor interventions more efficiently (Motlagh, 2026; Thappa et al., 2026). These applications suggest that AI can significantly reduce the instructional burden while enhancing the quality of sustainability education.

Table 1: AI Application in Sustainability Education

Application Type	**Pedagogical Function**	**Implementation Level**	**Key Challenges**
Adaptive Learning Systems	*Personalizes sustainability content based on learner profiles*	*Higher Education*	*Data Privacy*
Automated Assessment Tools	*Evaluates sustainability project submissions*	*K-12 Education*	*Limited contextual understanding*
Predictive Analysis	*Identifies at-risk students in sustainability courses*	*Teacher Professional Development*	*Ethical implications of algorithmic bias*
Virtual Sustainability Labs	*Stimulates environmental scenarios for experimental learning*	*STEM Education*	*High computational resource requirements*

The implementation of AI in sustainability education presents both opportunities and challenges that warrant careful consideration. While AI systems demonstrate efficacy in delivering personalized sustainability instruction, concerns persist regarding their environmental footprint, ethical implications, and potential to depersonalize learning experiences. Studies highlight that the energy consumption of large AI models may paradoxically counteract sustainability objectives if not properly managed (Rin and Huot, 2026). Furthermore, the lack of transparency in algorithmic decision-making raises questions about equity and accountability in AI-driven sustainability assessments (Jesus and Caumeran, 2026). These findings underscore the need for balanced approaches that leverage AI's pedagogical benefits while mitigating its potential drawbacks through thoughtful design and implementation strategies.

The reviewed studies collectively suggest that AI's role in S-TPACK extends beyond technological integration to encompass new dimensions of pedagogical content knowledge. Educators must develop critical competencies in evaluating AI tools, interpreting algorithmic outputs, and mediating between machine-generated recommendations and human-centered sustainability values. This requirement points to an emerging subdomain within S-TPACK that specifically addresses the intersection of artificial intelligence, sustainability education, and pedagogical practice. Future research directions might explore how AI can

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foster systems thinking in sustainability education or support cross-cultural applications of S-TPACK frameworks.

➢ *Environmental and Cultural Education in S-TPACK*

The integration of environmental and cultural dimensions into Sustainability TPACK (S-TPACK) represents a critical frontier in sustainability education. This subsection examines how S-TPACK frameworks incorporate place-based learning, indigenous knowledge systems, and global sustainability challenges, highlighting the interplay between technological tools and socio-ecological contexts. A recurring theme across studies is the role of digital platforms in facilitating place-based environmental education. Research demonstrates that geospatial technologies, such as GIS and virtual field trips, enable students to analyze local sustainability issues while connecting them to global patterns (Jaya, 2026). These tools enhance content knowledge by visualizing complex ecological relationships, while their pedagogical application fosters critical thinking about place-specific sustainability solutions. However, challenges persist in aligning these technologies with culturally responsive teaching practices, particularly when addressing indigenous perspectives on environmental stewardship (Antonio and Sison, 2026). Cultural sustainability emerges as a distinct dimension of S-TPACK, requiring educators to navigate the intersection of technological tools and traditional knowledge systems. Studies highlight cases where digital storytelling and multimedia archives preserve and disseminate indigenous ecological knowledge, thereby bridging generational and cultural divides (Tolentino and Miranda, 2026). Such approaches necessitate specialized pedagogical strategies that respect knowledge sovereignty while leveraging technology's capacity for intercultural dialogue.

Furthermore, S-TPACK frameworks operationalize environmental and cultural education through distinct yet interconnected components. Place-based learning emphasizes localized technological applications, while indigenous knowledge integration requires culturally sensitive pedagogical adaptations. Global sustainability components, conversely, utilize collaborative technologies to foster transnational perspectives on environmental challenges. Disparities in technological access and digital literacy emerge as significant barriers to equitable implementation. Studies note that resource-constrained regions often lack the infrastructure to support advanced sustainability technologies, potentially exacerbating educational inequalities (Arhin et al., 2026). This finding underscores the need for context-sensitive S-TPACK models that balance technological aspirations with ground-level realities. The reviewed literature collectively suggests that effective environmental and cultural education within S-TPACK demands not only technological competence but also deep cultural awareness and adaptive pedagogical flexibility.

IV. DISCUSSION

The synthesis of findings across the reviewed studies reveals several key patterns that advance our understanding of Sustainability TPACK (S-TPACK) as both a theoretical construct and a practical framework. Taken together, the research consistently demonstrates that integrating sustainability into TPACK requires more than an additive approach—it necessitates a fundamental rethinking of how technological, pedagogical, and content knowledge intersect with ecological and societal imperatives. The literature converges on the notion that S-TPACK represents a distinct knowledge domain, where sustainability acts not merely as an additional component but as a lens through which technology and pedagogy are critically evaluated and applied (Park et al., 2025). This perspective challenges traditional TPACK models by introducing normative dimensions, such as ethical considerations and long-term impact assessments, into technological and pedagogical decision-making. The implications of these findings are both theoretical and practical. Theoretically, S-TPACK extends existing TPACK frameworks by incorporating systems thinking and interdisciplinary connections, thereby addressing critiques that TPACK often overlooks the broader societal implications of technology integration (Wang et al., 2018). The emergence of sustainability as a cross-cutting theme suggests that future TPACK models may need to adopt more holistic representations of teacher knowledge, potentially through multidimensional frameworks that account for temporal (short- vs. long-term) and spatial (local vs. global) scales of impact. Practically, the findings underscore the need for professional development programs that move beyond technical skill acquisition to foster critical reflection on how digital tools can either support or undermine sustainability goals. For instance, educators might benefit from training that juxtaposes the pedagogical affordances of AI tools with their environmental costs, enabling more informed technology adoption decisions (Rin and Huot, 2026).

However, the review also uncovers significant contradictions and limitations that temper these conclusions. While many studies advocate for comprehensive S-TPACK frameworks, operationalizations vary widely—some narrowly focus on environmental education technologies (Jaya, 2026) whereas others adopt expansive views encompassing social justice and economic dimensions (Wagner et al., 2024). This conceptual fragmentation complicates efforts to establish standardized measures or comparative evaluations of S-TPACK effectiveness. Methodologically, while ensuring contemporaneity, limits our ability to trace developmental trajectories or assess the longevity of reported findings. The heavy reliance on self-reported teacher competence studies further introduces potential biases, as educators may overestimate their S-TPACK proficiencies when sustainability is framed as a normative ideal (Latip et al., 2023).

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These limitations point to several critical directions for future research. There is a pressing need for longitudinal studies that examine how S-TPACK evolves across different career stages and institutional contexts, particularly in under-researched regions where sustainability priorities may diverge from Western paradigms (Arhin et al., 2026). The field would also benefit from more experimental designs that isolate the effects of specific S-TPACK interventions on student sustainability competencies, moving beyond the current predominance of descriptive case studies. Another understudied area involves the development of assessment tools capable of capturing the nuanced interactions between technology, pedagogy, and sustainability—a challenge compounded by the contextual nature of sustainability issues (Warren et al., 2014). The role of emerging technologies presents particularly fertile ground for investigation. While current research highlights AI's potential for personalizing sustainability education (Pingmuang et al., 2026) future studies should explore how these tools can foster higher-order competencies like systems thinking and anticipatory reasoning—skills essential for addressing complex sustainability challenges. Similarly, the environmental costs of educational technologies, a theme only peripherally addressed in the reviewed literature, warrants systematic analysis to ensure that S-TPACK implementations do not inadvertently contradict their own sustainability objectives (Rin and Huot, 2026). Acknowledging these gaps does not diminish the contributions of existing S-TPACK research but rather clarifies the path forward. The collective evidence suggests that S-TPACK has moved beyond conceptual speculation to demonstrate tangible impacts on educational practice, particularly in empowering teachers to connect technology integration with real-world sustainability issues. However, the field's maturation will depend on addressing its methodological and theoretical limitations while maintaining the critical stance that distinguishes S-TPACK from conventional technology integration frameworks. By doing so, researchers can ensure that S-TPACK fulfills its potential as a transformative approach to education in the Anthropocene.

V. CONCLUSION

This systematic literature review has rigorously examined the emergent framework of Sustainability TPACK (S-TPACK), synthesizing contemporary scholarship to clarify its theoretical foundations, implementation challenges, and potential implications. The results indicate that S-TPACK signifies a considerable advancement of the TPACK model, incorporating sustainability as an integral dimension that reconfigures the interplay between technology and pedagogy with regard to environmental, social, and economic considerations. Although the framework exhibits potential in promoting interdisciplinary sustainability education, its practical deployment remains inconsistent, hampered by variations in teacher preparedness, institutional support, and access to technology.

The ramifications of this synthesis extend to both theoretical constructs and practical applications. From a theoretical perspective, S-TPACK contests traditional TPACK models by integrating normative frameworks and systems thinking into technology-mediated pedagogy. From a practical standpoint, it emphasizes the imperative for professional development initiatives that empower educators to rigorously assess and utilize digital resources in manners conducive to achieving sustainability objectives. Nevertheless, the scant empirical evidence and conceptual disarray within extant research underscore the urgent need for more robust, contextually attuned investigations. Subsequent research should prioritize longitudinal studies of S-TPACK's developmental pathways, standardized evaluative instruments, and the ecological trade-offs associated with educational technologies. By addressing these deficiencies, the academic community can bolster S-TPACK's capacity as a transformative framework for sustainability education, thereby ensuring its pertinence in an epoch characterized by intensifying ecological and societal challenges.

REFERENCES

[1]. Antonio, R., P., & Sison, L. R. C. (2026). Can artificial intelligence (AI) shape the future of teacher education? Drawing evidence-based insights for teacher preparation. *International Journal of Instruction*, 19(1), 257-280. https://doi.org/10.29333/iji.2026.19113a

[2]. Arhin, J., Arthur, Y. D., Gordon, J. F., & Akosah, E. F. (2026). Teachers' ICT attitudes: A structural equation modeling study in high school mathematics. *Journal of Pedagogical Sociology and Psychology*, 8(1), 1-13. *https://doi.org/10.33902/jpsp.202530649*

[3]. Jesus, J. B. & Caumeran, R. R. (2026). Human-centered AI in education: Educators' perspectives on teacher roles, ethics, and pedagogical value. *International Journal on Studies in Education (IJonSE), 8*(1), 142-154. https://doi.org/10.46328/ijonse.5748

[4]. Jaya, F. (2026). Digital skills and technology use in educational research for teacher training in distance education. *Turkish Online Journal of Distance Education*. 27(1), 240-256

[5]. Jhurree, V. (2005). Technology integration in education in developing countries: Guidelines to policy makers, *International Education Journal, 6*(4), 467–483.

[6]. Latip, A., Robandi, B., Amaliah, A., Khakim, R. R., & Fatonah, N. (2023). Technological Pedagogical Contents Knowledge (TPACK) Competency Framework for Teachers in Facing Global Issue Challenges: A Narrative Literature Review. *International Journal of Pedagogy and Teacher Education*, 7(1), 45-57. https://doi.org/10.20961/ijpte.v0i0.74699

[7]. Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jan492

[8]. Mousavi, S. H. (2026). Elucidating the role of smart technologies in redesigning teaching–learning processes in twenty-first-century schools. *Learning, Upbringing, and Education of Schools in the Third Millennium*, 1(1), 1–10.

[9]. Motlagh, Y. M. (2026). Identification and prioritization of teachers' readiness components for employing artificial intelligence in the teaching–learning process. *Iranian Journal of Educational Sociology*. 9(2), 1-11.

[10]. Nassor, H. A., Ephrem, A., & Mbaula, W. (2026). Teachers' pedagogical competencies in the utilisation of instructional materials for teaching history in public secondary schools in Zanzibar: A case of the Pemba North Region. *Educational Dimension*. 14, 51-71. DOI: https://doi.org/10.55056/ed.800

[11]. Park, S. W., Lee, S. B., & Sung, K. J. (2025). Toward Sustainable Integration of Digital Technology in Physical Education: A Teacher-Centered TAM–TPACK Framework for Instructional Design. *Sustainability*, 17(23), 10476. https://doi.org/10.3390/su172310476

[12]. Pingmuang, P., Koraneekij, P., & Khlaisang, J. (2026). Development and Validation of an AI Literacy Scale for Pre-Service Teachers in Thailand. *Electronic Journal of e-Learning*, *24*(1), 01-18. https://doi.org/10.34190/ejel.24.1.3990

[13]. Rin, R., & Huot, S. (2026). Preparing Cambodian primary education for the age of AI: Readiness, curriculum design, and teacher empowerment. *The Rubrics*. 8(1), 57-78. https://doi.org/10.5281/zenodo.18146258

[14]. Thappa, S. R., Shikha, D., Baliya, J. N., Sharma, S., & Mehra, N. (2026). Efficacy of e-content designing and development training programme on digital competence of prospective teacher educators. *International Journal of Technology Enhanced Learning*, *18*(1), 104-124.

[15]. Tolentino, J. C. G., & Miranda, J. P. P. (2026). A text mining analysis of preservice teachers' reflective discourses in online teaching: basis for a policy brief. *Journal of Education and Learning (EduLearn)*, *20*(1), 104-112. DOI: 10.11591/edulearn.v20i1.22344

[16]. Venkataraman, B. (2009). Education for sustainable development. *Science and Policy for Sustainable Development*, *51*(2), 8–10. https://doi.org/10.3200/ENVT.51.2.08-10

[17]. Wagner, D. R., Butterfield, A., & Schmucker, D. (2024, June). Broadening sustainability education in engineering disciplines. In *2024 ASEE Annual Conference & Exposition*.

[18]. Wang, W., Schmidt-Crawford, D., & Jin, Y. (2018). Preservice teachers' TPACK development: A review of literature. *Journal of Digital Learning in Teacher Education*, *34*(4), 234–258. DOI: 10.1080/21532974.2018.1498039

[19]. Warren, A., Archambault, L., & Foley, R. W. (2014). Sustainability Education Framework for Teachers: Developing sustainability literacy through futures, values, systems, and strategic thinking. *Journal of Sustainability Education*, *6*(4), 23-28.

[20]. Zhang, J., & Balinas, J. (2026). Empowering Primary School Teachers: Strategies for Enhancing Informatization Teaching Skills. *International Journal of Education and Humanities*, *6*(1), 1-16.