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THE NEXUS OF TPACK, SAMR, AND 21ST-CENTURY SKILLS IN DIGITAL MATHEMATICS EDUCATION: AN INTEGRATIVE REVIEW

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ABSTRACT

The current 21st-century Mathematics curriculum has raised major questions regarding the fostering of analytical reasoning, problem-solving, and the application of mathematical skills in practice. Digital technologies, particularly digital mathematics tools, have a significant impact on the creation and enhancement of quality, relevance, and engagement in mathematics learning, in line with Education 4.0. This study conducts an integrative literature review (ILR) and a conceptual synthesis using the TPACK, SAMR, and 21st-century skills (4Cs) frameworks. A systematic review of peer-reviewed literature published between 2015 and 2025 was carried out, leading to the selection of 26 research papers from international and Thailand-based databases, including Scopus, Web of Science, ERIC, and ThaiJO. Data were extracted and coded based on (i) integrated TPACK characteristics, (ii) SAMR-categorized task transformation degrees, and (iii) 4Cs outcome benchmarks. Findings indicate that while digital tools support conceptualization, higher-order 4Cs outcomes emerge most consistently when technology use reaches the Modification and Redefinition levels, mediated by strong integrated TPACK. Conversely, Substitution or Augmentation levels tend to yield functional improvements without producing transformational outcomes. The review concludes by recommending holistic instructional design principles that explicitly connect technology affordances to intended 4Cs outcomes, offering practical implications for teacher professional development and digital mathematics education in Thailand and beyond.

Keywords: Digital technology, Digital mathematics education, 21st-century skills, TPACK framework, SAMR model

I. INTRODUCTION

In the 21st century, digital technologies have become indispensable in every branch of human life, and not only in the field. As a result, contemporary schools are focused on developing skills that are fundamental to life and career among a growing group of students, collectively referred to as 21st-century skills. The 4Cs (Critical Thinking, Collaboration, Communication, and Creativity) are most important among these; mathematics instruction must move away from procedural fluency and toward deeper analytical reasoning and application in the real world. This educational transformation supports Thailand's national strategy, "Thailand 4.0", which aims to drive the country's development as a result of innovation and enhance the capabilities of high-quality human capital for the digital era. Accordingly, technology integration is no longer a choice but an essential pedagogical necessity that influences curriculum and instructional practices in mathematics education.

Over the last 20 years, international interest in the transformative power of digital tools to support mathematical education has increased. Indeed, the potential positive effect of technology on student understanding and inquiry-based learning via tools like visualization, dynamic manipulation, and immediate feedback is evidenced (Cheung & Slavin, 2013, pp. 88-113; Drijvers et al., 2010, pp. 213-234; Hoyles, 2018, pp. 209-228). The use of dynamic mathematical software such as GeoGebra, Desmos, and other Dynamic Mathematics Software (DMS) tools has been reported to empower learners to problem-solve, understand mathematics, and engage in high-level thinking through exploratory modeling activities (Drijvers et al., 2010, pp. 213-234; Hoyles, 2018, pp. 209-228). In fact, DMS reduces cognitive load (difficult calculations and visualizations), freeing up mental power for analytical thinking and deep conceptual exploration. Additionally, meta-analytic studies indicate that learning environments enhanced by technology offer greater educational benefits than traditional teaching methods, especially when technology supports the interactive construction of knowledge. (Cheung & Slavin, 2013, pp. 88-113). Yet, despite all this evidence supporting integration, several reviews indicate that the use of technology in mathematics teaching is generally cosmetic and not meaningful enough for the 4Cs of transformation to take place (Critical Thinking, Collaboration, Communication, Creativity). Such failure is often directly associated with the marginal use of pedagogical interventions informed by the SAMR (Substitution, Augmentation, Modification, Redefinition) model, where the use of technology seldom progresses beyond the Substitution (S) or Augmentation (A) level (Aldosemani, 2019, pp. 46-53; Hamilton et al., 2016, pp. 433-444). Hence, the literature underlines that the successful application of technology potential to 21st-century skills development is an overall reflection on the teacher's integrated knowledge base, as proposed by the TPACK framework of Koehler et al. (2011, pp. 13-19). This calls for coherent pedagogical frameworks which directly foreground the thoughtful and transformative contribution of the emergence of new technologies to mathematics teaching.

There have been rapid changes in the digital transformation of education in Thailand from 2010 through the emergence of mobile and hybrid learning in the post–COVID-19. Despite the significant usage of digital tools, empirical evidence from the Office of the Education Council (Office of the Education Council [OEC], 2023) points to an ongoing implementation gap where technology is embedded in lower substitution and augmentation levels of mathematics classrooms. This is not simply a lack of technology, but rather an extreme pedagogical deficiency, characterized by the absence of strategic, purposeful, and powerful infusion to promote the learning of the 4Cs. To address this challenge, teachers need to intentionally build their capacity to integrate technology through expertise with TPACK in a deliberate way — via ongoing professional development and reflective practice to achieve meaningful and innovative learning experiences (Drugova et al., 2021, pp. 4923–4948; Muslimin et al., 2023, pp. 1-15; Polly & Orrill, 2012, pp. 1-32).

In response to the growing educational demands, this article presents an Integrative Literature Review (ILR) on the connections between the TPACK framework (Technological Pedagogical Content Knowledge), the SAMR model (Substitution, Augmentation, Modification, and Redefinition), and 21st-century skills, within digital mathematics education. A total of 26 peer-reviewed papers from international and Thai-based databases, such as Scopus, Web of Science, ERIC, and ThaiJO, were chosen from a systematic review of peer-reviewed studies published between 2015 and 2025. The objectives of this study are to: (1) synthesize evidence on how digital mathematics tools are integrated in mathematics teaching and learning; (2) categorize reviewed studies according to integrated TPACK characteristics, SAMR-categorized degrees of task transformation, and 4Cs outcome benchmarks; (3) identify cross-study patterns indicating the conditions under which higher-order 4Cs results most reliably appear, especially when technology use reaches the Modification and Redefinition levels and is mediated by strong integrated TPACK; and (4) propose design principles aligning technology affordances with 4Cs outcomes to inform teacher professional development and digital mathematics education.

II. LITERATURE REVIEW

The 21st-century skills model presents it as an underlying model to facilitate the preparation of learners to succeed in a digital, knowledge-dominated society. Within this framework are the "4Cs" – Critical Thinking, Creativity, Communication, and Collaboration – which are at the heart of global educational transformations including those practiced in Thailand, to develop innovative and self-motivated learners (Binkley et al., 2012, pp. 17-66; Scott, 2015, Online; Voogt & Pareja Roblin, 2012, pp. 299-321). In mathematics education, these skills necessitate a pedagogical shift away from procedural fluency toward the building of analytical reasoning, complex problem-solving, and collaborative inquiry (Hoyles, 2018, pp. 209-228). Digital technologies—such as GeoGebra and the Desmos suite — are crucial for helping students visualize mathematical processes, work with real-world datasets, and dynamically alter variables, all of which contribute to better conceptual comprehension. There is broad evidence that technology-enriched learning environments encourage conceptual understanding, exploratory thinking, and higher-order decision-making (Steenbergen-Hu & Cooper, 2013, pp. 970-987). Research using Dynamic Mathematics Software (DMS) has shown its potential to help students to construct and test mathematical relationships interactively (Drijvers et al., 2010, pp. 213-234; Juandi et al., 2021, pp. 1-8). Additionally, simulation, modeling, and game-based simulations may activate inquiry, perseverance, and problem-solving—the essential aspects of the 4Cs in particular (Ke, 2014, pp. 26-39; Tishkovskaya & Lancaster, 2012, pp. 1-56). Together, these empirical studies underscore the importance of planning mathematics-rich, technology-engendered tasks that facilitate rich, deep, and holistic engagement as well as conceptual understanding, a need that remains paramount in Thailand, given that national evaluations remain dominated by struggles in terms of students' comprehension and problem-solving skills (OEC, 2023).

In support of this empirical evidence, theoretical frameworks such as Technological Pedagogical Content Knowledge (TPACK) and the SAMR model (Substitution, Augmentation, Modification, Redefinition) provide solid analytical bases for analyzing (and categorizing) teachers' meaningful integration of technology in mathematics teaching (see Koehler et al., 2013, pp. 13-19). Research incorporating TPACK underscores that successful integration necessitates that educators synthesize technology, pedagogical, and content knowledge, and plan learning activities aimed at fostering critical thinking ability, inquiry, and discourse, instead of simply using mechanical materials (Chai et al., 2013, pp. 31-51; Tondeur et al., 2017, pp. 555-575). In contrast, research using the SAMR framework often demonstrates that classroom technology use remains marginal, focusing on the lower-level Substitution or Augmentation stages, with limited pedagogical impact (Hamilton et al., 2016, pp. 433-441; Aldosemani, 2019, pp. 46-53). To support the 4Cs, the above integration levels (Modification and Redefinition) must be attained, however, this transformation needs combined TPACK competence across teachers (Drijvers et al., 2010, pp. 213-234; Abbitt, 2011, pp. 281-300). Although Thailand's Education 4.0 emphasizes 21st-century competencies, empirical evidence has shown that most Thai mathematics teachers still remain primarily at the augmentation stage, and only a small group progresses to the redefinition stage (OEC, 2023; Muslimin et al., 2023, pp. 1-15). To develop efficient technology integration in education and student-centered learning outcomes, this gap remains, and sensible policies and PD supported by empirical studies to show how TPACK, SAMR, and the 4Cs relate are required. (Abar & Almeida, 2025, pp. 1-8; Drugova et al., 2021, pp. 4923–4948; Theodorio et al., 2024, pp. 1-18). The objective of this integrative review is to synthesize theoretical and empirical views, establishing an integrated and practical perspective that advances digital mathematics education in Thailand and the broader educational environment, and ultimately contributes to supporting both educators and policymakers in the effective use of digital mathematical tools.

III. RESEARCH METHODOLOGY

This study utilized an intensive approach of an Integrative Literature Review (ILR)—a systematic framework used to collect, analyze, and synthesize knowledge from multiple academic sources. By using the ILR method, an all-inclusive, evidence-based picture of digital technologies—specifically digital mathematics tools—was developed regarding digital mathematics education. This analysis was firmly rooted in the theoretical context of TPACK (Technological Pedagogical Content Knowledge), the SAMR model (Substitution–Augmentation–Modification–Redefinition), and 21st-century skills, which were specifically identified by means of the 4Cs (Critical Thinking, Communication, Collaboration, and Creativity). The ILR approach was chosen because it enables the combination of findings from different research perspectives (both theoretical and empirical) and generates new interpretation results and conceptual insights beyond those of individual studies.

3.1 Literature search strategy and selection criteria

To ensure methodological rigor, relevance, and currency, a systematic search was conducted using major academic databases (Scopus, Web of Science (WoS), ThaijO, and ERIC) for the period 2015–2025. This era was selected to ensure up-to-date research on the current state of digital transformation in mathematics education, capturing recent trends, innovations, and empirical findings relevant to the integration of technology in classrooms. Boolean operators (AND, OR) were used to generate multiple search terms of these three main conceptual bases (Technology, Pedagogy/Content, and Frameworks). The representative search strings included: [Domain 1: Technology] ("Digital Technology" OR "Digital Tool" OR "App") AND [Domain 2: Content/Context] ("Mathematics Education" OR "Mathematics Teaching") AND [Domain 3: Conceptual Frameworks & Skills] ("TPACK" OR "SAMR" OR "Critical Thinking" OR "Collaboration" OR "21st Century Skills"). To guarantee quality, focus, and consistency, explicit inclusion/exclusion criteria were specified. For inclusion criteria were: (a) the application of digital technologies or digital mathematics tools in mathematics teaching and learning; (b) implementation or discussion of the TPACK and/or SAMR models; (c) a tangible emphasis on the cultivation of 21st-century skills – in particular the 4Cs; (d) peer review of and publications within credible academic journals (e.g., indexed in Scopus, Web of Science, ERIC and Thai Journals Online), and (e) published in English or Thai languages within the identified time frame. Studies that (a) did not focus on any digital technology integration directly into mathematics education, (b) were not methodologically transparent or did not provide in-depth empirical evidence, (c) were based mainly on opinions, or (d) had redundant data or repeated their findings were discarded.

3.2 Analytical process and conceptual synthesis

A rigorous three-phase analytical process, encompassing categorization, content analysis, and conceptual synthesis, was employed. In our coding process, we systematically categorized the included studies into thematic clusters for various types of digital tools, pedagogical applications, learner outcomes, and technological integrations using the SAMR model as the principal structuring model. Within content analysis, significant themes, repeated patterns, and emergent ideas were systematically uncovered as ways in which digital tools facilitate conceptual understanding, exploratory learning, and the development of the 4Cs—for example, through facilitating collaborative engagement and critical evaluation of mathematical models. Finally, by conceptual synthesis, these results were integrated and mapped across the TPACK, SAMR, and 4Cs frameworks to reveal and draw attention to convergences, divergences, and the importance of the mediating role of TPACK. This methodical analysis produced aggregated conclusions on the pedagogical benefits of digital mathematics resources, facilitating the development of an integrated instructional design philosophy in support of 21st-century mathematics education. The methodological process adopted in this study for the ILR is illustrated in Figure 1.

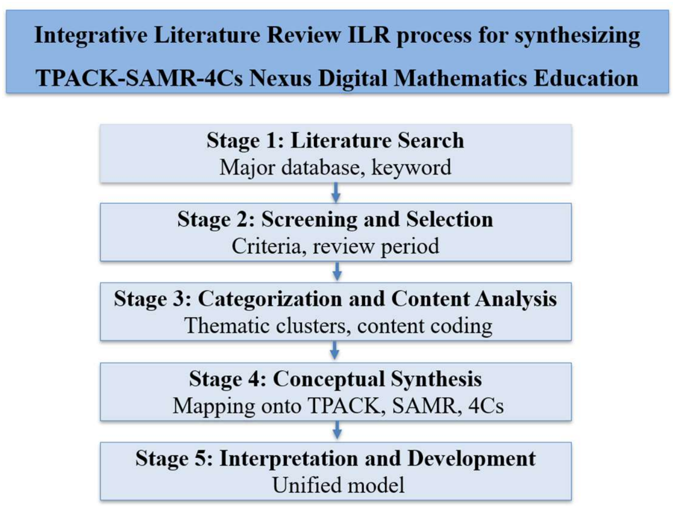

Figure 1: Graphical framework illustrating the Integrative Literature Review (ILR) process for synthesizing the TPACK–SAMR–4Cs nexus in digital mathematics education.

IV. RESULTS

For methodological transparency and analytic rigor, findings are presented in accordance with the systematic review procedures outlined in the methodology. A total of 23 reviewed studies (2010–present) that met all inclusion criteria were analyzed using a three-stage coding structure corresponding to: (a) the level of technology integration (SAMR), (b) the degree of teacher technological–pedagogical expertise (TPACK), and (c) the extent to which learning outcomes targeted 21st-century skills (4Cs). This coding framework provided a consistent foundation for identifying meaningful cross-study patterns.

This comprehensive investigation produced two key conclusions, which are shown separately in Tables 1 and 2. While Table 2 summarizes research showing that teachers' integrated TPACK is the crucial mediator enabling transformational (M/R-level) technology use, Table 1 illustrates how levels of technology integration within the SAMR model serve as strong indicators of 4Cs development.

4.1 Finding 1: SAMR as an indicator of 4Cs development

To present the first major finding clearly and systematically, the evidence related to the relationship between SAMR levels and 4Cs development was synthesized and organized into thematic categories. Table 1 provides a structured summary of these patterns, showing how different levels of technological integration contribute to varying degrees of higher-order skill development.

Table 1: Summary of systematic findings for SAMR to 4Cs development

SAMR Level	Key Findings from Systematic Review	Implications for 4Cs Development
Beyond Augmentation (A → M/R)	Substantial evidence shows that 4Cs development increases when technology integration surpasses the Augmentation level (Hamilton et al., 2016, pp. 433-441; Drugova et al., 2021, pp. 4923–4948)	Higher SAMR levels enable deeper engagement, inquiry, and reasoning.
Modification (M)	Use of Dynamic Mathematics Software (GeoGebra, Desmos) supports hypothesis testing, model evaluation, and critical questioning of mathematical relationships (Hoyles, 2018, pp. 209-228; Juandi et al., 2021, pp. 1-8).	Strong effect on Critical Thinking and Conceptual Understanding.
Redefinition (R)	Tasks that enable previously impossible learning experiences show the highest levels of Collaboration and Creativity, often supported by collaborative digital platforms (Ke, 2014, pp. 26-39)	Strong effect on Collaboration and Creativity; shifts focus from procedure → innovation.
Meta-analytic Evidence	Model-based learning, exploration, and simulations consistently improve achievement and conceptual reasoning (Cheung & Slavin, 2013, pp. 88-113; Steenbergen-Hu & Cooper, 2013, pp. 970-987)	Reinforces the need for exploratory problem-solving environments to build 4Cs holistically.

Content analysis confirmed that the development of 21st-century skills is related to the Task Transformation level (Drugova et al., 2021, pp. 4923–4948). Generalizable learning gains were found across studies when digital technologies were introduced beyond the Augmentation level, the level where a particular level of functional improvement does not drastically impact the core mathematical problem (Hamilton et al., 2016, pp. 433-441).

At the Modification (M) level, Dynamic Mathematics Software (DMS), such as GeoGebra, provides a platform for hypothesis testing, model evaluation, and exploration of complex mathematical relationships. The resulting environments moved student engagement away from procedural computation and toward analytical reasoning and conceptual inquiry (Hoyles, 2018, pp. 209-228; Juandi et al., 2021, pp. 1-8). Meta-analytic evidence also confirms that exploration and model-based tasks produce significant improvements in conceptual understanding and achievement (Cheung & Slavin, 2013, pp. 88-113; Steenbergen-Hu & Cooper, 2013, pp. 970-987).

At the Redefinition (R) stage, learning activities enhanced by technology enable possibilities that would otherwise be unattainable. Students worked well together and showed creative thinking. Using digital platforms, they were able to discuss, share ideas, and solve math problems together. Open-ended modeling tasks encouraged them to find new ways to represent and solve problems (Ke, 2014, pp. 26-39).

4.2 Finding 2: TPACK as a critical mediator for High-Level integration

The second main finding concerns how teachers' technological and pedagogical skills enable them to use digital tools in new ways. The studies reviewed indicate that TPACK is the main factor affecting SAMR-level outcomes. Table 2 shows how different parts of TPACK shape the depth and quality of technology use.

Table 2: Summary of systematic findings for TPACK to high-Level SAMR integration

TPACK Dimension	Key Findings from Systematic Review	Implications for SAMR & Pedagogical Practice
Integrated TPACK	Teachers with strong integrated TPACK (especially TPK + PCK) are the only ones capable of designing and implementing M/R-level tasks (Drijvers et al., 2010, pp. 213-234; Tondeur et al., 2017, pp. 555-575).	TPACK directly enables High-Level SAMR, leading to stronger 4Cs outcomes.
TPACK Deficit → S/A Levels	Limited TPACK results in technology being used only for substitution or minor enhancement, yielding low cognitive impact (Abbitt, 2011, pp. 281-300; Muslimin et al., 2023, pp. 1-15).	Explains why many classrooms remain stuck at S/A levels, even with abundant technology.
Content-Specific TPACK PD	The most effective professional development integrates technology with mathematical content and pedagogy rather than teaching tools in isolation (Polly & Orrill, 2012, pp. 1-32; Theodorio et al., 2024, pp. 1-18).	Professional development must target mathematics-specific TPACK, not tool training.
TPACK → SAMR → 4Cs Pathway	Evidence confirms a mediating chain: strong TPACK → M/R-Level tasks → 4Cs outcomes.	Supports the creation of Unified Instructional Design Principles for digital mathematics education.

A review of TPACK-related studies shows that when teachers combine technological, pedagogical, and content knowledge, this combination plays a key role in whether technology use reaches the transformative Modification (M) or Redefinition (R) stages of the SAMR model. Teachers with strong TPACK—especially those exhibiting well-developed Technological Pedagogical Knowledge (TPK)—designed pedagogically sound, technology-enhanced tasks that aligned with higher-order learning objectives (Drijvers et al., 2010, pp. 213-234; Tondeur et al., 2017, pp. 555-575).

However, limited TPACK consistently led to technology use at only the substitution or augmentation levels, with minimal improvement in cognitive benefits (Abbitt, 2011, pp. 281-300; Muslimin et al., 2023, pp. 1-15). These trends suggest that the implementation gap is not due to the availability of digital tools but rather to a lack of integrated technological–pedagogical reasoning. Consequently, content-driven professional development—where technology and pedagogy are fully embedded within mathematical content—is essential (Polly & Orrill, 2012, pp. 1-32; Theodorio et al., 2024, pp. 1-18).

4.3 Conceptual synthesis: Unified instructional design principles

Integrating findings across the TPACK, SAMR, and 4Cs frameworks led to the proposal of four unified instructional design principles for optimizing digital mathematics education. These principles explicitly align advanced technology use with the cultivation of 21st-century competencies, as shown in Table 3.

Table 3: Unified instructional design principles for digital mathematics education: a synthesis of TPACK, SAMR, and 21st-century skills (4Cs)

Principle	Framework Synthesis	Rationale and Supporting Evidence
1. Design for Transformation (M/R Target)	SAMR serves as the design goal, requiring learning tasks to reach Modification or Redefinition levels	Tasks must be sufficiently complex to necessitate the 4Cs, fostering higher-order reasoning beyond procedural fluency (Harskamp, 2014, pp. 383-392).
2. Prioritize Integrated TPACK Development	TPACK represents the teacher's essential capacity to implement technology effectively	Without integrated TPACK, technology use defaults to the less impactful A level, limiting opportunities for 4Cs development (Abar & Almeida, 2025, pp.1-8; Muslimin et al., 2023, pp. 1-15).
3. Foster Digital Authenticity	TPACK represents the teacher's essential capacity to implement technology effectively.	Digital tools should support open-ended modeling and problem-solving, enabling students to create and critically evaluate their own representations (Hoyles, 2018, pp. 209-228).
4. Structure for Digital Discourse	Directly targets Collaboration and Communication within shared digital environments	Learning tasks should require interactive digital workspaces where students articulate reasoning and negotiate collective solutions (Drijvers et al., 2010, pp. 213-234).

This systematic synthesis confirms that the transformative potential of digital tools in fostering 21st-century skills is directly proportional to the teacher's integrated TPACK and their intentional pedagogical design of learning experiences at the Modification and Redefinition levels of the SAMR model.

V. CONCLUSION AND DISCUSSION

This Integrative Literature Review (ILR) clarifies how the TPACK framework, the SAMR model, and 21st-century skills (4Cs) are interconnected in digital mathematics education. The synthesis of studies from 2015 to 2025 shows that simply having access to technology does not automatically develop the 4Cs. Instead, these skills grow when teachers use thoughtful teaching methods based on their professional expertise. In particular, the transformative potential of digital tools is most consistently realized when teachers enact robust, integrated TPACK to design and implement learning tasks at the Modification (M) and Redefinition (R) levels of SAMR. By integrating evidence across the reviewed literature, this study offers a coherent framework that helps bridge the gap between digital access and meaningful pedagogical transformation.

The study offers two primary contributions to the field. First, it establishes a unified, three-lens analytic model (TPACK–SAMR–4Cs) that provides a theoretical explanation for why transformational outcomes are most prevalent at the M/R levels. Second, it translates this theoretical synthesis into practical design principles that guide classroom practice, teacher professional development, and policy-level decisions. Several key insights emerge from this study. First, the implementation gap—particularly in contexts such as Thailand—stems from a TPACK deficit rather than a mere lack of digital infrastructure. Evidence suggests that many educators remain at the Substitution and Augmentation levels, often due to limited Technological Pedagogical Knowledge (TPK) rather than a scarcity of resources (OEC, 2023). Addressing this requires professional development that is not only content-based but also intentionally utilizes the SAMR model to help teachers align technology with mathematical reasoning. Second, the Unified Instructional Design Principles provide actionable implications for policy, emphasizing M/R-level task design to encourage collaboration, creativity, and authentic problem-solving. Finally, as an ILR, this study is limited by its reliance on secondary data. Future research should employ longitudinal and experimental designs to empirically validate these Unified Principles and track the trajectory of teachers' TPACK–SAMR competencies and their subsequent impact on student outcomes. Such evidence will further strengthen the conceptual foundation provided here, driving the evolution of innovative, evidence-informed digital pedagogy in mathematics.

SUGGESTION

The established interplay between TPACK, SAMR, and the 4Cs, therefore, recommends two crucial steps for advancing digital mathematics education. First, policymakers in education need to redefine teacher professional development (PD) to more explicitly transition from basic tool training to content-specific, integrated TPACK development. This PD needs to be focused on the Unified Instructional Design Principles—specifically, developing learning tasks to intentionally target the Modification (M) and Redefinition (R) levels of the SAMR model—as an essential skill of all mathematics educators. Second, curriculum designers and school administrators must prioritize tasks that integrate Digital Discourse and Digital Authenticity. This is about moving away from substitution-level digital worksheets toward structured, open-ended modeling and collaborative problem-solving activities that require higher-order Critical Thinking and Communication skills. It is possible to successfully close the ongoing gap between technological access and real pedagogical change in the classroom by carefully incorporating these ideas into both practice and policy.

REFERENCES

Abar, C. A. A. P., & Almeida, M. V. D. (2025). Integration of TPACK and SAMR Models: Theoretical-Methodological articulations for the use of technologies in mathematics teaching. *Journal of Technologies Information and Communication, 5*(1), 1-8. https://doi.org/10.55267/rtic/1666.

Abbitt, J. T. (2011). Measuring technological pedagogical content knowledge in preservice teacher education: A review of current methods and instruments. *Journal of Research on Technology in Education*, *43*(4), 281-300. https://doi.org/10.1080/15391523.2011.10782573.

Aldosemani, T. (2019). In-service teachers' perceptions of a professional development plan based on SAMR model: A case study. *Turkish Online Journal of Educational Technology – TOJET, 18*(3), 46-53. https://eric.ed.gov/?id=EJ1223786.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and Teaching of 21st Century Skills* (pp.17-66). Springer. https://doi.org/10.1007/978-94-007-2324-5_2.

Chai, C. S., Koh, J. H. L., & Tsai, C. C. (2013). A review of technological pedagogical content knowledge. *Journal of Educational Technology & Society, 16*(2), 31-51. https://eric.ed.gov/?id=EJ1016563.

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis. *Educational Research Review, 9*, 88-113. https://doi.org/10.1016/j.edurev.2013.01.001.

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher's role in whole-class discussions with an interactive whiteboard in a mathematics classroom. *Educational Studies in Mathematics, 75*(3), 213-234.

Drugova, N., Cernostana, A., Lapina, O., & Romanova, I. (2021). Toward a model of learning innovation integration: TPACK–SAMR based analysis of the introduction of a digital learning environment. *Education and Information Technologies*, 26, 4923–4948. https://doi.org/10.1007/s10639-021-10529-6.

Hamilton, E. R., Rosenberg, J. M., & Akcaoglu, M. (2016). Examining the Substitution Augmentation Modification Redefinition (SAMR) model for technology integration. *Tech Trends*, 60, 433-441. http://dx.doi.org/ 10.1007/s11528-016-0091-y.

Harskamp, E. G. (2014). The effects of computer technology on primary school students' mathematics achievement: A meta-analysis. In S. Chinn (Ed.), *The Routledge International Handbook of Dyscalculia and Mathematical Learning Difficulties*. Abingdon (pp.383-392). UK: Routledge.

Hoyles, C. (2018). Transforming the mathematical practices of learners and teachers through digital technology. *Research in Mathematics Education, 20*(3), 209-228. https://discovery.ucl.ac.uk/id/eprint/10050688/1/Hoyles_Final%20revisedApril%2018rev2018-05-27.pdf.

Juandi, D., Kusumah, Y. S., Tamur, M., Perbowo, K. S., & Wijaya, T. T. (2021). A meta-analysis of GeoGebra software decade of assisted mathematics learning: What to learn and where to go? *Heliyon, 7*(5), 1-8. https://doi.org/10.1016/j.heliyon.2021.e06953.

Ke, F. (2014). An implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing. *Computers & Education, 73*, 26–39. https://doi.org/10.1016/j.compedu.2013.12.010.

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education, 193*(3), 13-19. https://www.bu.edu/journalofeducation/files/2014/02/BUJoE.193.3.Koehleretal.pdf.

Muslimin, A. I., Mukminatien, N., & Ivone, F. M. (2023). TPACK-SAMR digital literacy competence, technostress, and teaching performance: Correlational study among EFL lecturers. *Contemporary Educational Technology, 15*(2), 1-15. https://doi.org/10.30935/cedtech/12921.

Office of the Education Council (OEC). (2023). *Education in Thailand 2022 Report*. Ministry of Education.

Polly, D., & Orrill, C. H. (2012). Developing technological pedagogical and content knowledge (TPACK) through professional development focused on technology-rich mathematics tasks. *Meridian*, 15, 1–32. https://www.researchgate.net/publication/280134624.

Scott, C. L. (2015). The Futures of Learning 3: What kind of pedagogies for the 21st Century?. *UNESCO*. https://unesdoc.unesco.org/ark:/48223/pf0000243126.

Steenbergen-Hu, S., & Cooper, H. (2013). A meta-analysis of the effectiveness of intelligent tutoring systems on K–12 students' mathematical learning. *Journal of Educational Psychology, 105*(4), 970-987. https://doi.org/10.1037/a0032447.

Theodorio, A. O., Waghid, Z., & Wambua, A. (2024). Technology integration in teacher education: Challenges and adaptations in the post- pandemic era. *Discover Education*, 3, 1-18.https://doi.org/10.1007/s44217-024-00341-1.

Tishkovskaya, S., & Lancaster, G. A. (2012). Statistical Education in the 21st Century: a Review of Challenges, Teaching Innovations and Strategies for Reform. *Journal of Statistics Education, 20*(2), 1-56.

Tondeur, J., van Braak, J., Ertmer, P. A., & Ottenbreit-Leftwich, A. (2017). Understanding the relationship between teachers' pedagogical beliefs and technology use in education: A systematic review of qualitative evidence. *Educational Technology Research and Development, 65*(3), 555–575. https://doi.org/10.1007/s11423-016-9481-2.

Voogt, J., & Pareja Roblin, N. (2012). A comparative analysis of international frameworks for 21st century skills. *Journal of Curriculum Studies, 44*(3), 299-321.

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