Smart Boards in Steam Learning: Unveiling Challenges and Benefits in Elementary Schools

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ABSTRACT:
This study examined elementary school teachers' experiences of using smart boards in STEAM learning, focusing on their pedagogical uses, perceived affordances, and implementation constraints. Using a qualitative descriptive case study approach, this study involved ten public elementary school teachers in Central Java, Indonesia, selected through purposive sampling. Data were collected using a triangulation technique comprising semi-structured in-depth interviews, direct classroom observations, and documentation, specifically lesson plans and students' digital work. Data analysis was conducted thematically, following Braun and Clarke's (2006) six-stage model. The findings indicate that, in terms of benefits, the use of smart boards fosters student curiosity, facilitates the visualization of abstract concepts, and boosts students' enthusiasm for learning. Conversely, the primary challenges identified include a lack of regular professional training, operational technical issues, slow curriculum adaptation, and high demands on teachers' creativity in designing interactive content. Maximizing the utility of these tools requires synergy among three parties: feature developers, policymakers, and teachers.

Keywords: Smart Boards, STEAM Learning, Teachers' Perspective, Challenges, Benefits

1. Introduction

The STEAM framework is globally recognized for fostering critical thinking, creativity, and technological literacy from an early age. At the primary school level, children transition from the concrete to the formal operational phase, requiring dynamic visual representations and direct object manipulation. However, teachers frequently struggle to represent abstract concepts and facilitate shared digital manipulation in whole-class settings (Perignat & Katz-Buonincontro, 2019). Passive environments relying solely on printed textbooks contribute to low scientific literacy and mathematical reasoning (Pacheco-Velazquez et al., 2024). Consequently, the STEAM approach aims to break rigid disciplinary boundaries through contextual, project-based activities to ensure students remain globally competitive (Diego-Mantecon et al., 2021; Land, 2013).

Amid widespread educational digitalization, Smart Boards or Interactive Whiteboards (IWBs)

have evolved into the focal point of classroom interactivity. Governments worldwide are spearheading national initiatives to modernize primary schools through Interactive Flat Panels powered by 4K UHD and cloud computing. For instance, Indonesia mandated a comprehensive school smart board rollout beginning in 2025 through Presidential Instruction Number 7 of 2025. These devices integrate a computer, projector, and conventional whiteboard into a single multi-touch platform (Hew & Cheung, 2014; Higgins et al., 2012). In STEAM instruction, smart boards serve as influential multimedia intermediaries that display virtual labs, 3D visualizations, and block programming. Aligning with cognitive load theory, this multi-sensory integration reduces conceptual barriers, extends attention spans, and transforms students into active participants (Balalle, 2024).

Studies confirm numerous multidimensional benefits of integrating smart boards into primary education. Pedagogically, they facilitate differentiated instruction, allowing teachers to instantly adjust pacing and present content accommodating visual, auditory, or kinesthetic learning styles (Hew & Cheung, 2014; Higgins et al., 2012). Socially, multi-touch capabilities and QR codes enable collaborative problem-solving and digital art creation. Surveys reveal that over 90% of students find that interactive visualizations make math and science concepts more concrete and meaningful. Furthermore, the technology saves lesson preparation time through cloud-based digital templates, allowing teachers to dedicate more instructional time to specialized student interventions (Park et al., 2021).

Despite this technical potential, real-world implementation faces severe structural and operational obstacles. The most fundamental challenge is the low level of digital-pedagogical competence among primary school teachers. Without ongoing training, the smart board's functionality is often reduced to a static projector screen, risking a decline in STEAM education quality (Hew & Cheung, 2014; Bati et al., 2018; Mishra & Koehler, 2009; Scherer et al., 2020). Additionally, roughly 70.6% of teachers frequently encounter technical issues like software malfunctions, calibration errors, and unstable connectivity, which disrupt instruction and trigger tech anxiety. High initial hardware costs and long-term maintenance burdens also threaten to widen the digital divide between schools (Higgins et al., 2012). This clear gap between policy and classroom reality highlights the scarcity of holistic dual-analysis research (Ertmer et al., 2012; Bati et al., 2018; Mishra & Koehler, 2009). Therefore, the study "Smart Board in STEAM Education: Unveiling Challenges and Benefits in Elementary School" is crucial to identify root obstacles, analyze interactive achievements, and formulate strategic recommendations for an effective educational transformation.

2. Materials and Methods

This study employs a qualitative, descriptive case study design to analyze the challenges and benefits of smart board integration in elementary school STEAM education from the perspectives of 10 teachers selected through purposive sampling. To ensure credibility, data were collected over four weeks using data triangulation, combining in-depth interviews, classroom observations, and lesson plan analysis.

The collected data underwent a cyclical, six-phase thematic analysis based on the Braun and Clarke (2006) model to examine pedagogical, technical, and practical classroom outcomes. This rigorous approach allowed for an objective, in-depth understanding of technology implementation without manipulating participant behavior.

3. Result

The data analysis followed the Braun and Clarke (2006) model, comprising data familiarization, initial coding, theme searching, theme review, theme definition and naming, and final report writing. The first step, data familiarization, involved the researcher repeatedly reading the transcripts of responses from Informants 1 through 10, who teach Grades I, III, IV, V, and VI. Preliminary notes indicated that teachers observed increased student curiosity through the use of visual media; however, effectiveness was hindered by internet infrastructure issues and challenges in synchronizing content with the

Merdeka Curriculum.

The second result involved initial coding, systematically labeling recurring features within the interview data. The coding categories were as follows: KOD-01 (positive effects), resulting in increased student curiosity, realistic visualization of learning materials, simulations, and improved learning outcomes; KOD-02 (features utilized), resulting in educational games, educational quizzes, and instructional videos; KOD-03 (issues), resulting in content misalignment with the latest curriculum, unstable internet connections, and limited availability of smart boards; and KOD-04 (suggestions and solutions), resulting in aligning smart board content with the Merdeka Curriculum, enabling offline access to features, providing one smart board per classroom, and implementing continuous training.

The third result involves identifying themes. The initial codes mentioned above were organized into four major themes: students' cognitive and affective impacts; patterns of interactive feature usage; challenges regarding infrastructure and content synchronization; and stakeholder synergy for maximizing smart board utilization.

The fifth result involves the definition and naming of themes. Each theme is assigned a clear conceptual definition, as follows: Strengthening Motivation & Conceptual Understanding; Preference for Gamification & Audio-Visual Media; School Digital Ecosystem Gap; Sustainable Capacity/Infrastructure & Competence. The sixth result consists of the final report, which is summarized in the following table.

Table 1. Analysis of Smart Board Utilization in STEAM Learning

Analysis Dimension	Component / Sub-aspect	Key Findings and Course of Action
Benefits of Learning	Instructional Quality	Provides interactive visualizations and simulations to facilitate the understanding of concepts.
	Psychological Impact	Sparks curiosity, positive academic anxiety, and student enthusiasm for learning.
Utilization Pattern	Basic Features	Didominasi oleh penggunaan media interaktif dasar seperti gim edukasi, kuis, dan video.
	Complex Features	Alat peraga virtual, laboratorium digital, dan desain 3D masih belum dioptimalkan oleh guru.
Strategic Recommendations	App Developers	Alignment of content with the Merdeka Curriculum and provision of offline access features.
	Government	Meeting classroom device ratios, providing internet connectivity, and conducting periodic training.
	Educators (Teachers)	Enhancement of operational competence through peer collaboration and the design of innovative scenarios.

4. Discussion

This discussion explores the integration of Smart Boards into STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning through four key themes: cognitive-affective reinforcement, the dichotomy between gamification and complex features, digital ecosystem barriers, and recommendations for multi-stakeholder synergy

4.1 Strengthening Motivation and Conceptual Understanding Through Cognitive Visualization

Findings indicate that the use of smartboards significantly enhances instructional quality through interactive visualizations and simulations that render abstract material concrete. Theoretically, this aligns with the Cognitive Theory of Multimedia Learning developed by Mayer (2014), wherein the simultaneous operation of visual and auditory channels on smartboards helps reduce students' cognitive load when processing complex STEAM material.

Dynamic visualizations enable students to construct more robust mental models compared to static textual media (Higgins et al., 2012; Neo et al., 2023). In the context of science and mathematics, the smartboard's ability to directly demonstrate micro or macro phenomena has been shown to accelerate the conceptual transition from the abstract to the concrete (Mercer et al., 2010). The process of manipulating digital objects on an interactive screen facilitates kinesthetic-visual learning, which is crucial for students' spatial understanding in basic engineering projects (Park et al., 2021).

Regarding the dimension of psychological impact, the finding reported by 100% of the informants of a surge in students' curiosity and learning enthusiasm confirms the validity of Self-Determination Theory (SDT) within the digital classroom environment (Sailer et al., 2017). Curiosity sparked by interactive interfaces stimulates students' intrinsic motivation. When students experience a sense of autonomy while interacting with smartboards, their affective engagement increases dramatically (Zheng et al., 2024). This boost in intrinsic motivation is not merely a fleeting emotional reaction but a psychological stimulant that fosters what is termed "positive academic anxiety", a form of curiosity that drives students to solve problems without the fear of making mistakes (Kim et al., 2015). This positive affective construct contributes directly to long-term memory retention and superior learning outcomes (Honey & Kanter, 2013; Anito & Morales, 2022).

4.2 The Dichotomy of Feature Utilization: Gamification Preferences versus the Marginalization of Complex STEAM Tools

While students' affective aspects showed significant development, research findings revealed a stark gap in the utilization of smart board features. Educators' use of the technology remains polarized around basic adoption levels centered on simple gamification media (Li & Wong, 2021). Educational games (70%) and educational quizzes (40%) recorded the highest usage rates, followed by instructional videos at 30%. This strong preference for basic gamification suggests that teachers utilize smart boards primarily as classroom management tools to control student dynamics and attention, rather than as instruments to foster the Higher-Order Thinking Skills (HOTS) essential to STEAM education (Hew & Cheung, 2014).

Conversely, the finding that complex features such as virtual laboratories, virtual manipulatives, and Tinkercad (3D design) showed 0% utilization indicates a failure to transition from the "substitution" function to the "redefinition" function within the SAMR (Substitution, Augmentation, Modification, Redefinition) framework (Chen & Tsai, 2021). These unused features are, in fact, the heart of authentic STEAM learning; without 3D design and virtual laboratories, the engineering and technology components of STEAM are effectively eliminated (Nguyen et al., 2024).

This phenomenon can be explained through Mishra and Koehler's (2009) TPACK (Technological Pedagogical Content Knowledge) framework. The teachers in this study appear to possess basic Technological Knowledge (TK) but have yet to integrate it with STEAM-specific Pedagogical Content Knowledge (PCK) (Ertmer et al., 2012; Nguyen et al., 2024). Consequently, they remain in a technology-use comfort zone that merely replicates conventional methods, such as replacing chalkboards with simple digital quizzes, while avoiding complex design software that demands intensive curricular preparation (Bati et al., 2018; Nguyen et al., 2024). Teachers' admissions that they prefer basic technology

because they are still in the early stages of learning highlight the need for a structured bridge to digital literacy.

4.3 Structural Barriers and the School Digital Ecosystem Gap

Teachers' inability to explore the complex features of smart boards does not stem from a single cause but is influenced by external obstacles or "second-order barriers" within Ertmer's technology integration theory (Ertmer et al., 2012). The theme of the "School Digital Ecosystem Gap" reflects how the advanced hardware (smart boards) adopted by schools suffers from dysfunction due to a lack of supporting infrastructure. Unstable and slow internet connectivity poses a major problem, crippling cloud-based tools such as Tinkercad or interactive virtual laboratories. When the internet connection fails, the smart board functions merely as an expensive projector, which in turn diminishes teachers' self-efficacy regarding the adoption of digital innovations in the classroom (Teo et al., 2022).

Beyond network constraints, a lack of local content aligned with the Merdeka Curriculum serves as a significant barrier. Many applications built into international smart boards are produced overseas based on Western curricular standards that have not been adapted to the cultural context and local learning outcomes of Indonesia (Juuti et al., 2024). Limitations regarding device availability—where teachers must queue to use the smart boards—result in a fragmented learning experience for students (Chai et al., 2020). STEAM education requires continuous experimentation; if access to tools is restricted by internal school scheduling bureaucracy, STEAM integration will never achieve the expected level of conceptual depth.

4.4 Multi-Stakeholder Synergy for Sustainable Capacity

To break this cycle of technology adoption dysfunction, research data necessitate a strategic blueprint involving three key actors within the education ecosystem (Darling-Hammond et al., 2017). This tripartite collaboration is crucial because providing digital infrastructure without pedagogical alignment and technical support will merely result in inefficiencies in the education budget (Haleem et al., 2022).

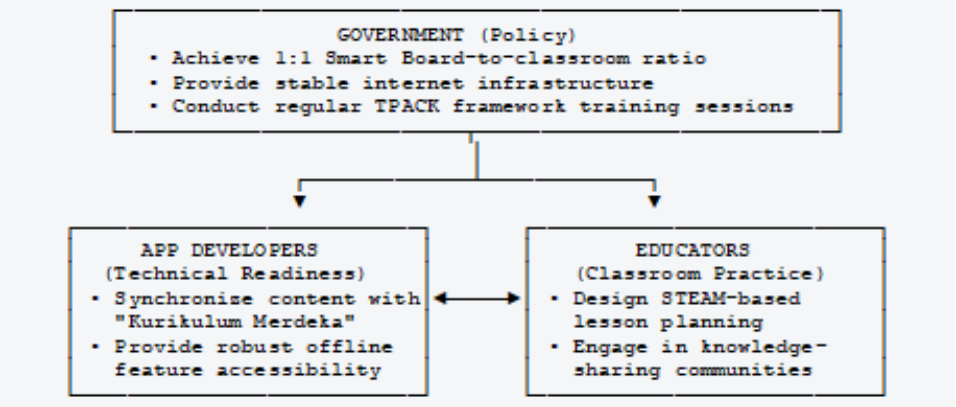

Figure 1. Multi-stakeholder synergy chart for sustainable capacity.

Software developers must shift away from high-tech egocentrism toward a contextual Universal Design for Learning (UDL) approach. A concrete recommendation is to restructure the application architecture to enable offline functionality. This feature is crucial for mitigating network latency in areas with marginal internet infrastructure (Sarker et al., 2023). Furthermore, developers must collaborate with national curriculum experts to map virtual laboratory content and teaching aids directly to the Learning Outcomes (CP) structure of the Merdeka Curriculum (Suyanto et al., 2025), ensuring teachers perceive these tools as a means to

alleviate, rather than increase, their administrative burden (Sokal et al., 2020).

Government intervention must not stop at piecemeal logistical procurement (Warschauer et al., 2014). The ideal policy target is achieving a ratio of one smart board per classroom to eliminate time lost searching for equipment or waiting in queues to use it. However, this physical investment must be accompanied by the provision of adequate internet bandwidth at the school level (Warschauer et al., 2014). Regarding human resource development, the government must design continuous outreach and training programs that focus not merely on mechanical skills (e.g., turning on the device and using the touchscreen) but on integrative pedagogy (e.g., designing STEAM-based lessons using smart boards) (Chai et al., 2020; Darling-Hammond et al., 2017). Periodic post-training evaluations must also be institutionalized to ensure the sustainability of such large-scale technology investments (Instefjord & Munthe, 2020).

On the front lines, teachers are required to enhance their professional agency (Kao et al., 2022; Kayi-Aydin, 2026). Competence enhancement occurs most effectively through Professional Learning Communities (PLCs) or peer collaboration within the school (peer knowledge sharing). Through these communities, teachers with higher levels of technological knowledge can mentor novice teachers in designing smartboard-based learning scenarios (Kao et al., 2022). Teachers must also shift from being mere consumers of media (downloading ready-made games) to becoming designers of innovative scenarios who actively and progressively integrate the complex features of smartboards to realize the true essence of STEAM learning (Ertmer et al., 2012; Mishra & Koehler, 2009).

5. Conclusion

The use of smart boards has been proven to significantly enhance the quality of learning and boost students' intrinsic motivation by up to 100% in STEAM education. However, teacher utilization remains limited to basic interactive features, such as gamification. It has yet to extend to complex capabilities like virtual laboratories or 3D design, largely due to initial competency constraints. Maximizing the technology's potential requires synergy among three parties: feature developers, policymakers, and teachers. Developers can create offline application access and ensure synchronization with the Merdeka Curriculum. Policymakers can facilitate an ideal device-to-user ratio, stable internet connectivity, and structured pedagogical training. Meanwhile, educators are expected to enhance their professional agency through active peer learning communities.

6. Author Declaration

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies, have been completely observed by the authors.

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