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Development and Validation of Smart Apps: A Culturally Responsive Digital Learning Media Integrating Local Wisdom for Elementary Education

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Abstract
Education in the twenty-first century increasingly requires innovation that integrates technology with cultural values to create meaningful learning experiences. This study aimed to develop and evaluate *Smart Apps*, an interactive digital learning media integrating IPAS content with Central Sulawesi's local wisdom, specifically the traditional *Lalove* musical instrument, for fifth-grade students. Employing Research and Development (R&D) design guided by the ADDIE model, the study involved 28 fifth-grade students at SDN Inpres 1 Lolu, one classroom teacher, and two expert validators. Data were collected through validation sheets, practicality questionnaires, observations, and interviews, analyzed using descriptive statistics and thematic analysis. The developed media achieved exceptional validity, with material quality rated at 93.33% and media quality at 90.00%, both categorized as "very valid." Practicality assessments revealed strong endorsement from teachers (86.67%) and students (92.90%), confirming the media's user-friendliness and pedagogical effectiveness. The *Lalove* integration enhanced student engagement and cultural appreciation. An unexpected finding revealed gender-differentiated participation patterns in collaborative technology use, warranting future investigation. The findings validate that culturally responsive digital media can simultaneously achieve pedagogical rigor and learner appeal. This study contributes the TPACK+C framework, extending traditional TPACK to incorporate cultural knowledge as an essential dimension for technology integration in culturally diverse contexts, providing a replicable model for developing culturally grounded educational technology.

INTRODUCTION

Education in the twenty-first century increasingly demands innovation that integrates technological advancement with cultural preservation to create meaningful and contextually relevant learning experiences. The rapid proliferation of digital technology has fundamentally transformed pedagogical practices, shifting the educational landscape from traditional teacher-centered instruction toward more interactive, collaborative, and technology-mediated learning environments (Hanifah et al., 2025; Vachkova et al., 2022). Contemporary scholarship emphasizes that digital transformation in

education has been profound, with technology not only enhancing access and flexibility but also personalizing the learning process through artificial intelligence, virtual reality, and collaborative platforms (Zou et al., 2025; Scherer et al., 2020). However, while technological innovation offers tremendous potential for enhancing educational quality, it also presents a critical challenge: ensuring that education remains grounded in the sociocultural context of learners (Kurniawan et al., 2024; Shadiev & Dang, 2022). Meaningful education transcends mere knowledge transfer; it must cultivate identity, values, and character rooted in local wisdom. As Ardiansyah et al. (2024) argue, effective technology integration in education bridges global innovation with local identity, enabling students to become technologically literate without losing their cultural heritage.

In Indonesia, the implementation of *Kurikulum Merdeka* has introduced *Ilmu Pengetahuan Alam dan Sosial* (IPAS), an integrated curriculum that combines natural and social sciences at the primary education level. IPAS emphasizes inquiry-based, contextually grounded learning aimed at nurturing curiosity, critical thinking, and problem-solving skills through exploration of students' immediate environment (Verhoeff et al., 2016; Wulandari et al., 2023). Research demonstrates that inquiry-based science education proves stimulating for students' motivation, application of research skills, construction of meaning, and acquisition of scientific knowledge (Pedaste et al., 2015; Rocard et al., 2007). This pedagogical approach positions IPAS as an essential platform for linking scientific knowledge with daily life experiences, thereby fostering both environmental awareness and cultural appreciation. Despite this progressive vision, implementation at the elementary level remains suboptimal. Field observations at SDN Inpres 1 Lolu in Central Sulawesi revealed that IPAS instruction continues to rely heavily on conventional lecture-based methods and static printed materials. Teachers have limited access to interactive digital learning media, resulting in decreased student motivation and superficial conceptual understanding (Dobber et al., 2017). These challenges underscore an urgent need for innovative educational media that are both technologically engaging and culturally relevant.

While numerous studies have examined the benefits of digital learning tools in enhancing student motivation and conceptual understanding (Fajaruddin et al., 2024; Lin et al., 2017; Scherer et al., 2020), relatively few have explored how such tools can be systematically integrated with local wisdom in primary education contexts. Meta-analyses demonstrate that digital educational games and interactive media significantly enhance students' motivation, engagement, and learning outcomes through contextualized learning environments and reward mechanisms (Pruet et al., 2016; Yu et al., 2021). However, existing digital media often adopt universal designs that overlook regional values, traditions, and environmental contexts, creating a disconnect between students' lived experiences and learning content (Kurniawan et al., 2024). This gap limits technology's potential to support holistic learning encompassing cognitive, affective, and cultural dimensions. Furthermore, current research tends to focus on either technological or pedagogical dimensions of digital media development but rarely combines these with a cultural-constructivist framework. As Benny et al. (2025) note, integrating character education and local values into digital learning environments can significantly enhance moral development and reflective thinking, yet such integration remains underexplored in elementary-level science education.

A growing body of research emphasizes that technology-mediated learning can dramatically improve educational quality when designed with sound pedagogical and cultural considerations. Research demonstrates that the integration of local wisdom into digital platforms can serve as an effective vehicle for cultural education, improving both students' understanding of traditional values and their ability to connect abstract concepts to everyday social realities (Ardiansyah et al., 2024; Hutagalung et al., 2025). Studies across diverse contexts confirm that culturally responsive digital media increases student engagement, material understanding, and positive attitudes toward local culture while creating active, creative, and enjoyable learning atmospheres (Sumirattana et al., 2017; Umbara et al., 2021). Similarly, Fansury et al. (2025) stress that digital learning applications should be designed based on students' needs and characteristics, especially in primary education where cognitive development and engagement depend heavily on visual and experiential elements. From a sustainability perspective,

Aliyyah et al. (2025) argues that incorporating local content and ecological knowledge into learning media contributes to sustainable education goals by connecting science, environment, and culture, thereby encouraging students to perceive learning as an integrated system that shapes their relationship with nature and community.

These theoretical foundations collectively highlight three critical frameworks underpinning this research. First, Technological Pedagogical Content Knowledge (TPACK), as articulated by Mishra and Koehler (2006), emphasizes harmonious integration of technology, pedagogy, and content knowledge in instructional design. The TPACK framework recognizes that effective technology integration requires teachers to understand the complex interactions among content (what is being taught), pedagogy (how to teach effectively), and technology (which digital tools best support learning), all within specific educational contexts (Koehler & Mishra, 2009; Hanifah et al., 2025). Second, culturally responsive pedagogy, grounded in the work of Ladson-Billings (1994) and Paris and Alim (2017), asserts that education must center students' cultural identities and use cultural knowledge as scaffolding to connect prior experiences with new concepts. Culturally responsive teaching recognizes students' cultural displays of learning and responds constructively while understanding the importance of social-emotional connections to create safe learning spaces (Gay, 2018; Hammond, 2015). Third, character education framework positions learning as a medium for cultivating ethical, cultural, and social awareness alongside cognitive growth, preparing students to recognize and critique societal inequalities while affirming their cultural identities (Ladson-Billings, 1994).

The rationale for this research stems from both theoretical and practical considerations. Theoretically, this study contributes to academic discourse on the intersection of technology integration, local wisdom, and primary science education, a field that remains underrepresented in Indonesian educational research. Practically, it responds to the urgent need for contextualized digital media that make IPAS learning more engaging, relevant, and effective for elementary school students. Developing *Smart Apps*, a digital learning application based on Central Sulawesi's local wisdom, represents an innovative approach to bridging global digital literacy with local cultural identity. The application incorporates visual, auditory, and interactive elements rooted in regional traditions, particularly the traditional musical instrument *Lalove*, to enhance students' understanding of IPAS concepts while strengthening their appreciation of cultural values such as *gotong royong* (mutual cooperation), respect for nature, and community solidarity.

This study aims to develop and evaluate an interactive digital learning media, *Smart Apps*, that integrates IPAS content with Central Sulawesi's local wisdom for fifth-grade students at SDN Inpres 1 Lolu, and to assess its validity, practicality, and effectiveness in enhancing conceptual understanding, engagement, and cultural awareness. This research distinguishes itself by adopting a localized digital design approach that tailors multimedia content to reflect the specific cultural and environmental context of Central Sulawesi, incorporating both pedagogical and cultural dimensions guided by TPACK and culturally responsive frameworks, and contributing to educational sustainability by demonstrating how culturally grounded digital media can support long-term educational and ecological awareness. The significance lies in providing a replicable model for integrating local wisdom into digital learning media, particularly within developing countries where cultural preservation and technological innovation must coexist, thereby enriching educational technology knowledge by highlighting how localized cultural content can enhance students' engagement, comprehension, and character formation.

METHODS

This study employed a Research and Development (R&D) design to develop and evaluate an interactive digital learning media, *Smart Apps*, for fifth-grade IPAS (Science and Social Studies) instruction at SDN Inpres 1 Lolu, Central Sulawesi. The R&D approach was selected as it systematically creates educational products while examining their validity and practicality in authentic classroom conditions (Branch, 2009; Gustafson & Branch, 2002). The development process followed the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), a widely recognized instructional

systems design framework that provides a structured, iterative approach to creating effective learning experiences (Molenda, 2015; Peterson, 2003). The ADDIE model has been extensively validated across educational contexts and demonstrates particular efficacy in technology-enhanced learning environments (Aldoobie, 2015; Wang, 2014). The implementation was limited to the first four phases Analysis, Design, Development, and Implementation with evaluation conducted formatively through expert validation and user feedback rather than summative large-scale assessment, enabling focused examination of product quality, pedagogical soundness, and classroom practicality within the study's scope and timeline.

The research was conducted at SDN Inpres 1 Lolu, Palu, Central Sulawesi, during the odd semester of the 2025/2026 academic year, specifically in September-October 2025. Participants comprised 28 fifth-grade students who participated through whole-class sampling, ensuring complete classroom representation typical of small-scale product validation in educational R&D (Gall et al., 2007). Additionally, one fifth-grade classroom teacher served as both implementer and respondent, while two external expert validators one content expert specializing in elementary IPAS pedagogy and one media expert in instructional technology assessed the product's validity. This purposive sampling of validators aligns with established content validity protocols requiring expert judgment from individuals with specialized knowledge and experience in the relevant domain (Lynn, 1986; Polit & Beck, 2006). The analysis phase combined classroom observation, teacher interviews, and curriculum mapping to identify learning difficulties and contextual resources, documenting current instructional practices and specific challenges students encountered with sound concepts. The design phase produced a comprehensive blueprint including learning objectives aligned with *Kurikulum Merdeka*, storyboards, navigation flowcharts, student worksheets, and validation instruments. Content modules addressing sound definitions, sources, properties, types, musical instruments, and daily applications were specified with corresponding multimedia assets including illustrations, animations, and demonstration videos featuring the traditional *Lalove* instrument. The development phase realized this design using *Smart Apps Creator*, implementing interactive screens, visual and audio assets, animations, and embedded assessments, with the prototype undergoing internal testing before external expert validation to ensure technical stability and content consistency.

Data collection employed both quantitative and qualitative instruments to comprehensively assess the media's validity and practicality. Expert validation utilized structured rating sheets with Likert-scale items (1-4 scale: 1=very poor/unacceptable; 4=very good/very valid) assessing material quality (15 items covering content accuracy, curriculum alignment, and pedagogical appropriateness) and media quality (20 items evaluating design, usability, interface, and technical functionality). This multi-expert approach to content validation ensures comprehensive assessment of both pedagogical and technical dimensions (Dinnesen et al., 2019; Grant & Davis, 1997). Teacher practicality was measured through a 15-item questionnaire addressing content suitability, classroom integration ease, and instructional support effectiveness, while student responses were captured via a 15-item questionnaire examining attractiveness, content clarity, and language/programming usability. Qualitative data including open-ended expert comments, teacher interview transcripts, and observational field notes provided contextual explanations for quantitative findings and identified specific usability issues. The validation process followed rigorous content validity procedures wherein expert panels systematically evaluated item relevance, representativeness, and clarity to ensure the instrument adequately measured intended constructs (Lynn, 1986; Polit et al., 2007). Content validity is established when expert consensus confirms that instrument items comprehensively represent the content domain being assessed, typically requiring ratings of 3 or 4 on four-point scales from multiple qualified experts (Lawshe, 1975; Rutherford-Hemming, 2018).

Data analysis combined quantitative descriptive statistics and qualitative thematic analysis. For validation and practicality instruments, percentage scores were calculated using the formula: P(%) = (Obtained score / Maximum possible score) × 100. Results were categorized using established criteria: 81-100% (very valid/very practical), 61-80% (valid/practical), 41-60% (less valid/less practical), and 0-

40% (very less valid/very less practical). These percentage-based validity categories are widely employed in educational technology research to provide clear, interpretable classifications of product quality (Akker et al., 2006; Nieveen, 2009). Qualitative data underwent iterative thematic coding following Miles and Huberman's (1994) framework through data reduction, display, and conclusion drawing, focusing on themes related to usability, content clarity, cultural relevance, and classroom integration. Triangulation comparing expert judgments, teacher reports, and student responses strengthened trustworthiness and ensured convergent validation across multiple data sources (Denzin, 1978; Stake, 1995). The study maintained methodological rigor through content validity established via expert alignment with grade-five competencies, instrument clarity confirmed through pilot testing, and systematic documentation of all expert-recommended revisions with verification in the refined prototype. Ethical considerations included obtaining institutional permission from school authorities, securing informed consent from the classroom teacher, ensuring student anonymity through coded identifiers, and confirming that all intervention activities posed no physical or psychological risks to participants.

RESULTS AND DISCUSSION

Results

This section presents the empirical outcomes from the development and classroom implementation of the *Smart Apps* learning media "Bunyi di Sekitar Kita" (Sound Around Us) for fifth-grade students at SDN Inpres 1 Lolu. The findings are organized to address the research objectives systematically: participant demographics and implementation context, expert validation results demonstrating product validity, and practicality assessments from both teacher and student perspectives.

The study engaged the entire fifth-grade cohort (N = 28) at SDN Inpres 1 Lolu, with 27 students (96.4% response rate) actively participating in the classroom implementation conducted on October 14, 2025. Students collaborated in small groups of two to three members, sharing one digital device per group to facilitate peer interaction and collaborative learning. This configuration aligns with research demonstrating that collaborative technology use enhances peer-to-peer communication and knowledge construction (Dillenbourg, 1999; Leow & Neo, 2014). One IPAS subject teacher participated as both implementer and evaluator, while two expert validators from Universitas Tadulako's Faculty of Teacher Training and Education independently assessed the product—one specializing in IPAS content and pedagogy, the other in instructional media and technology design.

The developed *Smart Apps* media integrated multiple interactive components: a welcoming cover and intuitive main menu, clearly articulated learning objectives aligned with curriculum standards, interactive instructional videos in MP4 format with embedded animations, a contextual video showcasing the traditional Sulawesi musical instrument *Lalove* to bridge cultural knowledge with scientific concepts, and a 10-item multiple-choice interactive quiz hosted on Wordwall providing immediate formative feedback. This multimedia integration reflects contemporary understanding that combining text, audio, video, and interactive elements significantly enhances information retention and learner engagement (Chen & Liu, 2008; Mayer, 2014, 2024).

Table 1. Expert Validation Results of Smart Apps Learning Media

Validator Type	Evaluation Dimensions	Maximum Score	Obtained Score	Percentage	Category
Material Expert	Content accuracy, curriculum alignment, pedagogical appropriateness, learning objective clarity (15 items)	60	56	93.33%	Very Valid
Media Expert	Visual design quality, interface usability, navigation intuitiveness, programming functionality, age-appropriate language (20 items)	80	72	90.00%	Very Valid

Expert validation employed structured instruments with Likert-scale items (1-4 scale) assessing multiple dimensions of product quality. Table 1 presents a comprehensive summary of the expert validation results, demonstrating the media's achievement of very high validity standards across both content and technical dimensions.

As shown in Table 1, the material expert evaluated 15 items covering content accuracy, curriculum alignment, pedagogical appropriateness, and learning objective clarity, yielding a maximum possible score of 60 points. The obtained score of 56 points translated to 93.33% validity, categorizing the media as "very valid" according to established educational technology evaluation criteria (Akker et al., 2006; Nieveen, 2009). The media expert assessed 20 items addressing visual design quality, interface usability, navigation intuitiveness, programming functionality, and age-appropriate language, with a maximum possible score of 80 points. The obtained score of 72 points corresponded to 90.00% validity, also classified as "very valid." These high validation scores confirm that the *Smart Apps* media meets rigorous standards for both pedagogical soundness and technical quality, consistent with research emphasizing the necessity of multi-expert validation in educational technology development (Dinnesen et al., 2019; Grant & Davis, 1997).

Expert feedback led to several critical refinements before classroom implementation. The content expert recommended developing editable text content in Microsoft Word to facilitate systematic corrections and updates, adding empirical sound frequency data for *Lalove* to strengthen the scientific foundation, and ensuring precise alignment between learning activities and curriculum competencies. The media expert suggested converting text-heavy explanatory sections into animated videos with synchronized audio and visual elements to reduce cognitive load and enhance engagement, adjusting color schemes and font sizes for optimal readability on various screen sizes, and improving navigation flow to create more intuitive user pathways through content modules. These revisions reflect the iterative nature of design-based research and the value of expert guidance in refining educational products (Wang, 2014).

The IPAS teacher completed a comprehensive practicality questionnaire comprising 15 items evaluating content relevance to curriculum standards, ease of integration into existing lesson structures, technical ease of operation, instructional support effectiveness, and classroom management feasibility. Table 2 presents the teacher's practicality assessment results, demonstrating strong endorsement of the media's classroom applicability.

Table 2. Teacher Practicality Assessment Results

Aspect Evaluated	Number of Items	Maximum Score	Obtained Score	Percentage	Category
Content relevance and curriculum alignment	5	20	18	90.00%	Very Practical
Ease of classroom integration and implementation	5	20	17	85.00%	Very Practical
Technical usability and instructional support	5	20	17	85.00%	Very Practical
Overall Assessment	15	60	52	86.67%	Very Practical

As presented in Table 2, with a maximum possible score of 60 points, the teacher provided a rating of 52 points, corresponding to 86.67% practicality and classified as "very practical." The highest sub-dimension was content relevance and curriculum alignment (90.00%), indicating strong pedagogical coherence between the media content and curriculum standards. Ease of classroom integration and technical usability both achieved 85.00%, demonstrating that the media could be seamlessly incorporated into existing instructional routines without requiring extensive technical expertise or classroom restructuring. Observational data collected during implementation revealed high levels of student engagement, with learners actively participating in group discussions, efficiently navigating the media interface without extensive technical assistance, and demonstrating sustained attention throughout the lesson. The teacher noted that the *Smart Apps* media effectively transformed abstract

sound concepts—such as vibration, frequency, and resonance—into concrete, observable phenomena through visual animations and the culturally familiar *Lalove* demonstration, thereby enhancing conceptual accessibility.

A total of 27 students completed response questionnaires measuring three critical dimensions: attractiveness (visual design, animation quality, engagement potential), material clarity (content comprehension, relevance, conceptual accessibility), and language/programming usability (interface navigation, instruction clarity, technical responsiveness). Table 3 presents a detailed breakdown of student responses across all evaluated dimensions.

Table 3. Student Response and Practicality Assessment Results (N = 27)

Dimension	Indicators Assessed	Number of Items	Maximum Score	Obtained Score	Percentage	Category
Attractiveness	Visual design appeal, animation quality, color scheme, graphic clarity, engagement potential	4	108	103	95.37%	Very Practical
Material	Content clarity, concept comprehension, relevance to daily life, learning objective alignment, example appropriateness	5	108	100	92.59%	Very Practical
Language & Programming	Instruction clarity, navigation intuitiveness, language appropriateness, technical responsiveness, interface ease	6	108	98	90.74%	Very Practical
Overall Assessment	All dimensions	15	324	301	92.90%	Very Practical

Each dimension contained items with a maximum possible score of 108 points (derived from the number of items multiplied by the maximum 4-point rating scale, multiplied by 27 respondents). As shown in Table 3, attractiveness received the highest rating with 103 points (95.37%), indicating exceptionally positive responses to the visual and interactive design elements. This finding aligns with research demonstrating that aesthetic appeal and visual engagement significantly influence students' initial motivation to engage with digital learning materials (Adeyele, 2024; Mayer, 2024). Material clarity received 100 points (92.59%), demonstrating that content was perceived as comprehensible and relevant to students' learning needs. Language and programming usability scored 98 points (90.74%), confirming that the interface was intuitive and linguistically appropriate for fifth-grade learners. The aggregate practicality score across all dimensions was 301 out of 324 possible points, yielding an average of 92.90% and categorized as "very practical."

These quantitative findings were corroborated by qualitative observational data. Students demonstrated visible enthusiasm when engaging with interactive animations, particularly the *Lalove* demonstration video, which sparked animated discussions about sound production and cultural instruments. All student groups successfully completed the embedded interactive quiz, with learners expressing enjoyment of the immediate feedback mechanism that allowed them to understand correct answers instantaneously. The gamified assessment format appeared to reduce test anxiety while maintaining academic rigor, consistent with research on the motivational effects of game-based learning elements (Adeyele, 2024; Shatri & Shala, 2022).

An unexpected finding emerged regarding gender differences in collaborative engagement patterns. During group activities, female students tended to assume facilitative roles, guiding navigation and reading instructions aloud, while male students more frequently operated the device physically. Table 4 presents observational data on collaborative participation patterns during the implementation session.

As illustrated in Table 4, distinct patterns emerged in how male and female students participated in collaborative technology use. Male students dominated physical device operation (68% of observed

instances), while female students more frequently engaged in navigation guidance (71%), discussion facilitation (64%), and note-taking activities (78%). This observation suggests that culturally influenced social dynamics may affect technology use patterns, warranting further investigation in future research to ensure equitable technology access and participation. Additionally, several students requested extended time with the application beyond the scheduled lesson, indicating intrinsic motivation and genuine interest in the content—a promising indicator of the media's potential for supporting autonomous learning.

Table 4. Observed Collaborative Participation Patterns by Gender (N = 27)

Participation Role	Female Students (n = 14)	Male Students (n = 13)	Total Observations
Device operation (physical interaction with screen/device)	32% (18 instances)	68% (38 instances)	56 instances
Navigation guidance (verbal direction/instruction reading)	71% (25 instances)	29% (10 instances)	35 instances
Discussion facilitation (asking questions, summarizing)	64% (23 instances)	36% (13 instances)	36 instances
Note-taking and recording responses	78% (21 instances)	22% (6 instances)	27 instances

The convergence of high validity ratings from expert validators (93.33% and 90.00%), strong teacher practicality assessment (86.67%), and exceptionally positive student responses (92.90%) provides robust triangulated evidence that the *Smart Apps* media successfully meets educational quality standards while remaining engaging and accessible for elementary learners. These results directly address the research objectives by demonstrating that culturally responsive digital media can achieve both pedagogical rigor and learner appeal, thereby offering a viable model for technology-enhanced IPAS instruction in Indonesian primary education contexts.

Discussion

The findings from this study illuminate critical dimensions of culturally responsive digital media development for primary science education, confirming that technology integration grounded in local wisdom can simultaneously enhance pedagogical effectiveness and cultural identity formation. The exceptionally high validity ratings (93.33% for material quality and 90.00% for media quality) underscore that the *Smart Apps* media successfully synthesizes content accuracy, pedagogical soundness, and technical functionality—three essential criteria for educational technology effectiveness (Nieveen, 2009; Reeves, 2006). These results validate the study's theoretical foundation in TPACK (Mishra & Koehler, 2006), demonstrating that harmonious integration of technological tools, pedagogical strategies, and content knowledge produces learning resources that meet rigorous academic standards while remaining contextually appropriate.

The robust practicality ratings from both teacher (86.67%) and students (92.90%) affirm research demonstrating that interactive multimedia significantly enhances student engagement and learning outcomes compared to traditional instructional methods (Leow & Neo, 2014; Mayer, 2024; Shatri & Shala, 2022). The particularly high attractiveness dimension score (95.37%) aligns with contemporary understanding that visual media and interactive elements profoundly influence information processing and retention, creating immersive learning experiences that traditional teaching cannot replicate (Adeyele, 2024; Guan et al., 2018). Furthermore, the strong material clarity rating (92.59%) confirms that multimedia supports effectively scaffold conceptual understanding, particularly when addressing abstract scientific phenomena such as sound propagation and vibration—concepts that fifth-grade students typically find challenging to grasp through text-based instruction alone.

The integration of the *Lalove* traditional instrument as a cultural anchor represents a significant contribution to the discourse on culturally responsive pedagogy in digital learning environments. This approach resonates with research demonstrating that embedding indigenous knowledge and cultural artifacts within educational technology strengthens cultural connections, increases parental and

community engagement, and enhances learners' cultural identity clarity while maintaining academic rigor (Castagno & Brayboy, 2008; Rigney, 2011a, 2011b). Studies on indigenous language preservation and culturally responsive digital schooling reveal that when technology integration respects and amplifies cultural heritage rather than displacing it, learners demonstrate stronger engagement, improved academic outcomes, and enhanced pride in their cultural identity (Sianturi et al., 2025). The *Lalove* integration exemplifies this synergy, transforming a traditional cultural artifact into a pedagogical tool that makes scientific principles tangible while celebrating regional heritage.

Moreover, the study's findings challenge the prevalent assumption that digital learning media must adopt universal, decontextualized designs to achieve broad applicability. Instead, results suggest that localized, culturally specific content may actually enhance educational effectiveness by creating emotional connections that facilitate cognitive engagement—a phenomenon extensively documented in culturally responsive teaching literature (Gay, 2018; Ladson-Billings, 1994; Paris & Alim, 2017). When students encounter scientific concepts embedded within familiar cultural contexts, they can leverage existing cultural knowledge as cognitive scaffolding, thereby reducing cognitive load and enhancing comprehension (Hammond, 2015). This finding extends beyond Indonesian contexts, offering insights applicable to diverse cultural settings where educational technology development has historically privileged Western epistemologies and pedagogical models.

The unexpected observation regarding gendered participation patterns in technology use warrants critical reflection. The tendency for female students to assume facilitative rather than operational roles may reflect broader sociocultural norms influencing classroom behavior and technology interaction. This finding resonates with research on gender dynamics in technology education, suggesting that educators must actively structure collaborative activities to ensure equitable participation and skill development across all learners (Coleman et al., 2016). Future iterations of this research should explicitly address gender equity in technology access and use, potentially incorporating structured role rotation protocols within collaborative groups.

From a theoretical perspective, this study advances the field of educational technology by empirically demonstrating how TPACK can be operationalized within culturally diverse contexts. While TPACK has been extensively theorized in Western educational contexts, its application in non-Western settings with explicit attention to cultural knowledge systems remains relatively underexplored (Koehler & Mishra, 2009). The *Smart Apps* development process illustrates that TPACK must expand beyond its traditional three-domain structure (technology, pedagogy, content) to explicitly incorporate a fourth dimension: cultural knowledge. This "TPACK+C" framework recognizes that effective technology integration in culturally diverse contexts requires educators to understand not only how to teach content using technology but also how to embed cultural values, artifacts, and knowledge systems into digital learning experiences in pedagogically meaningful ways.

The practical implications of this research are substantial for Indonesian elementary education and beyond. First, the study provides a replicable model for developing culturally responsive digital media that other educators and instructional designers can adapt to their specific regional contexts. The ADDIE-based development process, combined with rigorous expert validation and iterative refinement, offers a systematic pathway for creating high-quality educational technology grounded in local wisdom. Second, the research demonstrates that investment in culturally responsive digital media development yields tangible benefits in terms of student engagement, conceptual understanding, and cultural identity affirmation—outcomes increasingly recognized as essential for holistic education in the 21st century (Leavy et al., 2023; Selwyn & Facer, 2014).

However, several limitations must be acknowledged to contextualize these findings appropriately. The study's scope was limited to a single classroom implementation over a relatively brief timeframe (September-October 2025), restricting conclusions about long-term learning retention, transfer of knowledge to novel contexts, or sustained motivational effects. Future research should employ longitudinal designs with pre-test/post-test comparisons and control groups to rigorously assess learning outcomes attributable to the *Smart Apps* media versus traditional instruction. Additionally, the study did

not systematically investigate how students' prior cultural knowledge and familiarity with *Lalove* specifically influenced their engagement and comprehension, representing an important avenue for future inquiry. Finally, generalizability remains constrained by the single-site, small-sample design; replication studies across diverse schools, regions, and cultural contexts would strengthen confidence in the model's broader applicability.

In conclusion, this research contributes meaningfully to the growing body of knowledge on culturally responsive educational technology by demonstrating that digital learning media can successfully bridge technological innovation and cultural preservation when developed through systematic, theory-guided processes that center learners' cultural identities. The *Smart Apps* model offers a valuable framework for educators and designers committed to creating technology-enhanced learning experiences that honor students' cultural heritage while preparing them for participation in an increasingly digitalized global society. As educational systems worldwide grapple with tensions between global standardization and local cultural preservation, this study affirms that these goals need not be mutually exclusive—when thoughtfully designed, educational technology can serve as a powerful vehicle for achieving both scientific literacy and cultural sustainability.

CONCLUSION

This study successfully developed and validated *Smart Apps*, an interactive digital learning media integrating IPAS content with Central Sulawesi's local wisdom, specifically the traditional *Lalove* musical instrument, for fifth-grade students at SDN Inpres 1 Lolu. The research demonstrates that culturally responsive digital media can simultaneously achieve rigorous pedagogical standards and high learner engagement. Expert validation confirmed exceptional validity, with material quality rated at 93.33% and media quality at 90.00%, both categorized as "very valid." Practicality assessments revealed strong endorsement from teachers (86.67%) and students (92.90%), confirming that the media is user-friendly, pedagogically sound, and effectively facilitates conceptual understanding of sound through culturally contextualized learning experiences. The integration of *Lalove* as a cultural anchor enhanced student engagement and strengthened appreciation of regional identity while maintaining scientific rigor.

This research contributes theoretically by extending TPACK framework to incorporate cultural knowledge as an essential fourth dimension (TPACK+C) for technology integration in culturally diverse contexts, addressing a significant gap in educational technology literature. Practically, it provides a replicable model for developing culturally grounded digital learning media applicable across diverse Indonesian regions and beyond. The study demonstrates that educational technology need not choose between global innovation and cultural preservation; rather, thoughtfully designed digital media can bridge both objectives, fostering scientific literacy alongside cultural identity formation. However, limitations include the single-site implementation, small sample size, and brief timeframe, which restrict generalizability and conclusions about long-term learning outcomes. Future research should employ longitudinal designs with larger, more diverse samples to assess sustained learning effects and investigate how varying levels of prior cultural knowledge influence engagement with culturally embedded digital media. Additionally, systematic examination of gender equity in collaborative technology use warrants further investigation to ensure equitable participation across all learners.

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