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Development of Interactive Learning Media Based on Open Technology

Siti Nur Aisyah Rahman [1]*, Ahmad Fauzi Pratama [2]
[1] Universitas Muhammadiyah Yogyakarta, Indonesia, sitinur.aisyah.rahman@gmail.com
[2] Universitas Lampung, Indonesia, ahmad.fauzi.pratama@gmail.com

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Abstract:*This study developed an interactive learning media based on open technology that is pedagogically effective, increasing motivation, engagement, and accessibility for diverse learners in Indonesia. Using a quasi-experimental approach and statistical analysis, it was found that this media significantly improves learning outcomes with a large effect size (d=1.35) and strengthens mastery of higher-order cognitive skills. The use of open source platforms such as Moodle and H5P allows customization to suit local contexts and reduces development costs by up to 70%. Evaluation results show high levels of satisfaction, sustained engagement, and increased learner motivation. These findings support the role of open technology in realizing inclusive and equitable education and provide important implications for education policy related to the development of open source-based digital media. This study contributes to the literature on educational innovation and offers a scalable and sustainable media development model in Indonesia.*
Keywords: Interactive Learning Media, Open Technology, Learning Outcomes, Educational Innovation.

INTRODUCTION

The development of information and communication technology has brought about a major transformation in education, particularly in the development of innovative and interactive learning media. Open technology-based learning media is a strategic solution for improving the quality of learning in the digital era. Open source technology offers flexibility, accessibility, and high cost-efficiency for educational institutions in developing media tailored to students' needs. This concept allows educators to freely adapt, modify, and distribute content without expensive proprietary licensing fees. This is particularly relevant in

Indonesia, which faces budgetary and technological infrastructure constraints. The implementation of open technology-based interactive learning media not only increases student engagement but also facilitates personalized and adaptive learning. Research shows that this media can significantly improve learning motivation, conceptual understanding, and learning outcomes (Wijaya & Saputra, 2023).

The learning paradigm is now shifting from teacher-centered to student-centered learning, demanding active student participation. Interactive learning media based on open technology supports this shift by providing a dynamic and responsive learning environment. Platforms such as Moodle, H5P, Articulate, and other open-source LMSs have proven effective in creating engaging and meaningful learning experiences. The advantage of open technology is its ability to be customized to the context, student characteristics, and learning objectives. Research shows that this media improves competency achievement, including critical thinking, collaboration, and problem-solving skills. Furthermore, open technology facilitates educator collaboration in collectively sharing educational resources and innovations (Rahmat & Hidayat, 2023).

The characteristics of effective interactive learning media encompass several important aspects. First, interactivity enables learners to actively participate through simulations, quizzes, educational games, and online discussions. Second, multimedia combines text, images, audio, video, and animation to support various learning styles. Third, personalization adapts content and learning paths to suit learners' abilities and progress. Fourth, direct and constructive feedback helps learners improve their understanding. Fifth, accessibility ensures the media is accessible to all learners, including those with special needs. The integration of these five aspects in the development of open technology-based media produces quality products and effectively improves learning outcomes (Susanti et al., 2023).

Open technology in education refers to software, hardware, and content that can be freely accessed, used, modified, and distributed. In line with UNESCO's OER principles, platforms such as Moodle, WordPress, Jitsi, BigBlueButton, and H5P have been widely used by global educational institutions. The main advantage of open technology is its transparent source code, allowing developers to customize and enhance functionality as needed. Unlike proprietary technology with a paid license, open technology is highly relevant in Indonesia due to budget constraints and the need for scalability in many schools. Research shows that

institutions that adopt open technology can achieve up to 70% cost savings compared to proprietary technology (Kurniawan & Lestari, 2023).

The process of developing interactive learning media must be systematic, combining principles of instructional design, user experience, and software engineering. Common models such as ADDIE, Dick and Carey, and ASSURE have distinct advantages. The analysis phase involves identifying the needs and characteristics of participants. Design encompasses the design of content, interfaces, and interactions. Development is the production process using selected open technologies. Implementation involves launch and user training. Evaluation is conducted both formatively and summarily to assess effectiveness and improve the media. An iterative approach and user-centered design principles ensure the media meets user needs and preferences (Pratama & Nugroho, 2023).

Pedagogical aspects are the primary foundation for developing effective interactive learning media, based on learning theory and evidence-based practices. Constructivism theory emphasizes active learning through interaction and reflection. Cognitive load theory guides design to avoid overloading participants' cognitive capacities. Mayer's multimedia learning theory effectively integrates text, images, audio, and video. Active approaches such as problem-based, project-based, and inquiry-based learning can be implemented through interactive media based on open technology. Universal design for learning (UDL) principles ensure that media accommodates diverse learner characteristics. Research shows that media based on pedagogical foundations produces better learning outcomes than a focus solely on technology (Sari & Wibowo, 2023).

Learning motivation is crucial for improving student engagement and outcomes. Interactive media based on open technology can enhance intrinsic and extrinsic motivation through gamification, immediate feedback, and personalization. Gamification uses elements such as points, badges, leaderboards, challenges, and narratives to enhance engaging learning. Self-determination theory suggests that motivation arises when psychological needs are met: autonomy, competence, and relatedness. Interactive media supports this by providing choice, level-appropriate challenges, and social collaboration features. Research shows that gamification increases engagement by up to 60% and completion rates by up to 40%, but care must be taken to avoid the over-justification effect, which reduces intrinsic motivation (Firmansyah & Azizah, 2023).

Evaluating the effectiveness of interactive learning media requires a multidimensional approach that measures learning outcomes, user experience, and technical performance. Kirkpatrick's model, with four levels (reaction, learning, behavior, and outcomes), can be

adapted for comprehensive evaluation. The first level assesses satisfaction through surveys and interviews. The second level measures learning through pre-tests, post-tests, and learning analytics. The third level assesses transfer to real-world practice through observations and portfolios. The fourth level measures the long-term impact on goal achievement. Usability evaluations such as ease of use, efficiency, effectiveness, and satisfaction are also important. Analytics data from open technology-based media, such as activity logs and interaction patterns, provide objective insights into learner engagement (Hidayat & Marlina, 2023).

The implementation of open technology-based interactive learning media faces challenges such as infrastructure readiness (internet, hardware, technical support), limited digital literacy and TPACK (Comprehensive Assessment of Learning) skills among educators, resistance to change, sustainability in content maintenance and updates, and high quality assurance. To address these challenges, strategies such as educator capacity development, infrastructure improvement, effective change management, and a quality assurance system are needed. Research shows that institutional success in implementing interactive media depends on leadership commitment, a clear vision, and a systematic approach to change management (Putra & Anggraini, 2023).

Collaboration and community building are crucial in developing interactive learning media based on open technologies. Open source communities such as GitHub, GitLab, and SourceForge facilitate the sharing of knowledge, resources, and best practices among global educators and developers. Communities of practice enable learning from each other's experiences, troubleshooting support, and collaboration on content development. The concept of co-creation engages students as co-creators, increasing ownership and ensuring the media meets their needs. Professional learning networks (PLNs) through online and offline platforms support the continuous development of educator competencies. Research shows that educators active in communities have higher technological competencies and innovative practices (Wulandari & Setiawan, 2023).

Personalization and adaptive learning are key trends in the development of interactive learning media that adapt to the diverse characteristics, needs, and progress of learners. Adaptive learning systems use algorithms to analyze learner interactions and automatically adjust the difficulty level, pathway, and content presented. AI and machine learning technologies enable increasingly sophisticated systems to understand individual learning patterns and preferences. Personalization can be applied to learning pace, content modality,

complexity level, assessment format, and scaffolding. Learning analytics dashboards help educators monitor progress and provide timely interventions. However, implementation must consider data privacy, AI ethics, and algorithm bias. Research shows that adaptive learning increases learning efficiency by up to 50% and retention by up to 30% (Nurhadi & Kusuma, 2023).

Mobile learning (m-learning) is a significant evolution in the delivery of interactive learning media that utilizes mobile devices such as smartphones and tablets. The high smartphone penetration rate in Indonesia, exceeding 70%, opens up significant opportunities for integrating this technology into education. Mobile-friendly learning media enables learning anytime and anywhere, supporting seamless learning that combines formal and informal learning. Responsive design ensures content adapts to various screen sizes and device orientations. Special features such as push notifications, offline access, location-based learning, and augmented reality create immersive and contextual learning experiences. Open-source mobile apps (PWAs), based on open technology, offer a cost-effective solution with features similar to native apps. Research shows that m-learning increases flexibility and accessibility, especially in remote areas or for learners with limited time (Safitri & Hartono, 2023).

The integration of authentic and formative assessments in open technology-based learning media enables more comprehensive and meaningful learning measurement. Authentic assessments assess students' ability to apply knowledge through real-world tasks such as projects and simulations. Formative assessments provide continuous feedback for monitoring and adjusting learning strategies. Technology supports automated scoring, instant feedback, and in-depth analytics. Adaptive assessments adjust the difficulty level of questions based on student responses, providing more accurate measurement. Collaborative assessments through peer review and group projects foster critical thinking and communication skills. However, assessment design must align with learning objectives and measure higher-order skills such as analysis, evaluation, and creativity. Research shows that this integration of assessments enhances deep learning and knowledge transfer (Riyanto & Permata, 2023).

Sustainability and scalability are crucial in developing open technology-based learning media for long-term impact and broad reach. Sustainability encompasses financial aspects, infrastructure, content relevance, and community engagement. Scalability enables deployment from pilot to large-scale without increasing costs and complexity. Open source and cloud technologies support scalability and elastic scaling. Comprehensive documentation, training, and support systems are essential for widespread adoption. Community development

and institutional policies contribute to long-term sustainability. A holistic approach that considers technical, pedagogical, organizational, and cultural aspects is key to success (Mahmud & Indrawati, 2023).

METHOD

The ADDIE (Analysis, Design, Development, Implementation, Evaluation) model was chosen for the development of open technology-based interactive learning media due to its systematic and iterative nature. The analysis phase involved a needs assessment through a survey of 150 educators and 500 students from 15 institutions in Indonesia, as well as a literature review of 75 journal articles in databases such as Scopus, Google Scholar, and Garuda. Data collection instruments included a Likert questionnaire, semi-structured interviews, and an observation checklist. Quantitative data were analyzed using SPSS 26, and qualitative data through thematic analysis using NVivo 12. The results of this analysis served as an important basis for the subsequent media design and development stages.

The Design and Development phase was carried out iteratively by a multidisciplinary team consisting of instructional designers, subject matter experts, user experience designers, and developers. The design integrated the principles of multimedia learning, user-centeredness, and universal design for learning for effectiveness and usability. Storyboards and prototypes were created using open source tools such as Moodle, H5P, and Inkscape. Using an agile methodology with two-week sprints, this process enabled rapid prototyping and continuous feedback. The results of each sprint were tested through usability testing using the think-aloud and SUS methods. Expert review by five learning experts and five educational technology experts ensured content, pedagogy, and technical quality. Revisions were made until a SUS score of ≥70 and expert validation of ≥80% were achieved.

The implementation phase was conducted through a pilot testing with a quasi-experimental design involving 240 students, divided into an experimental group using open technology-based interactive media and a control group using conventional methods. Purposive sampling with criteria of internet access, devices, basic digital literacy, and volunteerism. The pilot lasted 8 weeks, with 3 sessions per week, each 90 minutes long. Learning outcomes were measured through a reliable pre-test and post-test (Cronbach's alpha 0.87). Data on engagement, motivation, and satisfaction were collected via online surveys every 2 weeks. Automatic analytics data from the system were analyzed using descriptive and

inferential statistics. Monitoring was carried out through observation checklists and feedback to ensure consistent implementation according to the design.

The evaluation phase was conducted formatively during development and summatively after implementation to assess the effectiveness, efficiency, and appeal of the learning media. Formative evaluation included one-to-one (10 participants), small group (30 participants), and field trials (100 participants) to identify issues and improve. Summative evaluation used a mixed-methods approach, combining quantitative data from test scores, surveys, and learning analytics, as well as qualitative data from interviews and group discussions. Effectiveness analysis compared learning outcomes between groups using t-tests and ANCOVA, and calculated Cohen's d. Usability measures included SUS, NASA TLX, and UEQ. Data triangulation enhanced validity. Evaluation results provided evidence of effectiveness and recommendations for further improvement and development.

RESEARCH RESULT

The needs analysis results show that 87% of educators strongly support the need for interactive media to increase engagement, while 92% of students prefer more interactive, technology-based learning. Demographic data shows that 78% of students have access to smartphones and 65% have access to laptops, indicating technological readiness. The gap analysis revealed that 73% of institutions still use conventional methods, limited by technology due to budget constraints and a lack of knowledge about open technologies. The educator survey showed that 68% have basic to intermediate digital literacy, but only 34% are familiar with open technologies and 23% have experience developing digital media. Diverse learning characteristics demand a multimedia approach. These findings emphasize the importance of a comprehensive needs analysis as a foundation for successful instructional design.

The interactive learning media prototype consisted of 12 modules with 48 pieces of content, including videos, simulations, adaptive quizzes, educational games, and virtual labs. Each module followed a consistent structure containing learning objectives, pre-assessments, main content, exercises, formative assessments, and summaries. The multimedia composition included 35% videos, 25% interactive activities, 20% text and graphics, 15% assessments, and 5% collaboration tools. Usability testing with 10 participants identified 23 issues, categorized as 8 critical, 10 serious, and 5 minor, primarily related to navigation and instructions. Iterative improvements reduced the issues to 3 minor issues. Expert validation averaged a score of 4.3–4.5, and the SUS increased from 62 to 78, underscoring the

importance of iterative development and user-centered design to ensure the quality of the learning media.

The implementation of pilot testing with a quasi-experimental design showed positive results on learning outcomes. The pre-test showed no significant difference between the experimental group (M=58.4, SD=12.3) and the control group (M=57.8, SD=11.9). The post-test showed the experimental group outperforming (M=82.6, SD=9.7) the control group (M=68.3, SD=11.2), with $p<0.001$ and Cohen's d=1.35, indicating a large effect. ANCOVA confirmed effectiveness with $F(1,237)=94.32$, $p<0.001$, $\eta^2=0.28$. The score gain reached 24.2 points for the experimental group and 10.5 for the control group. Maintenance of the results over 4 weeks showed the experimental group maintained 89% of the gain, better than the control group. High performance was seen across all cognitive levels, including higher-order skills.

Engagement and motivation analysis demonstrated the positive impact of open technology-based interactive learning media. Analytics data showed the experimental group logged in more frequently (4.8 times/week) than the control group (1.2). The average time per session was 87 minutes for the experimental group and 45 minutes for the traditional activity. The activity completion rate reached 94% in the experimental group, higher than 76%. The average interaction per session was 142 times, indicating high engagement. The IMMS survey showed higher scores across all dimensions: attention, relevance, confidence, and satisfaction. Interviews revealed themes of "fun learning," "self-directed learning," and "immediate feedback." 78% of experimental participants reported experiencing flow, indicating optimal engagement.

User satisfaction and usability evaluations showed a positive response to the open-source interactive learning platform. The SUS score of 240 participants averaged 78.5 (SD=8.3), categorized as "good" and above the industry average of 68. The UEQ positively assessed all dimensions: attractiveness, clarity, efficiency, dependability, stimulation, and innovation. NASA-TLX demonstrated a moderate workload (mean 42 out of 100), while 89% of participants would recommend the platform, 85% preferred interactive learning, and 82% felt more confident. Only 12% experienced technical issues, mostly related to internet connection. The platform complies with WCAG 2.1 Level AA. Favorite features include interactive simulations, immediate feedback, and multimedia content. Overall, the platform meets quality standards and is well-received by users.

DISCUSSION

A. Pedagogical Effectiveness of Interactive Learning Media

This study confirms the pedagogical effectiveness of open technology-based interactive learning media in improving student learning outcomes, with an effect size of 1.35 indicating a significant practical impact. Based on the cognitive theory of multimedia learning, learning is more effective when information is presented through multimodality that activates verbal and visual processes. This media integrates text, graphics, animation, narrative, and interactive elements to reduce cognitive load and enhance meaning. Interactivity enables active knowledge construction and reflection, while adaptive features adjust the level of difficulty to achieve an optimal challenge zone ("flow"). These results align with meta-analyses showing that interactive multimedia improves learning by 30-50% compared to traditional methods (Wijaya & Saputra, 2023).

In-depth analysis shows that interactive learning media is highly effective in developing higher-order thinking skills (HOTS) such as applying, analyzing, and evaluating. Unlike traditional instruction that focuses on lower-order skills, interactive simulations and scenario-based learning force participants to apply concepts, analyze complex problems, and evaluate solutions. Virtual laboratories and problem-based modules support critical thinking and real-world problem-solving. Collaborative features and incremental scaffolding enhance self-directed learning and the social construction of knowledge. These results reinforce the literature that open technology can effectively support HOTS development, countering concerns that technology only encourages superficial learning (Rahmat & Hidayat, 2023).

Superior learning retention in the experimental group four weeks post-intervention indicates that learning through interactive media is more durable and difficult to forget. The forgetting curve theory explains that without repetition and meaningful processing, information is quickly lost. Interactive learning experiences encourage in-depth processing through active engagement, response, and connections to prior knowledge, creating stronger memory traces. Distributed practice and repeated testing strengthen memory consolidation, while multimedia presentations provide numerous recall cues. The emotional engagement of game elements enhances memory encoding through the amygdala. Transfer of learning demonstrates real understanding, not just memorization (Susanti et al., 2023).

The integration of authentic assessment into learning media significantly improves pedagogical effectiveness by providing opportunities to demonstrate competency in real-world contexts. Traditional assessments often fail to capture the full range of learning

outcomes, particularly practical and application skills. Portfolios, projects, and simulations measure not only knowledge but also the ability to apply, create, and evaluate. Technology supports automated assessments, adaptive questioning, and immediate feedback that refine understanding. Learning analytics provide in-depth data on the learning process. Integrated formative assessments and clear rubrics enhance measurement validity and enhance real-world readiness (Kurniawan & Lestari, 2023).

The effectiveness of learning media varies based on learner characteristics, indicating the need for personalization and limitations of intervention effectiveness. Learners with low prior knowledge benefit most from structured guidance and scaffolding, while those with high prior knowledge value the flexibility of non-linear exploration. Visual learners appreciate graphical representations and animations, while kinesthetic learners are more engaged through interactive simulations. Learners with strong self-regulation skills benefit from self-paced learning features, while those with weak skills require additional support. UDL principles help reach diverse learners, but they require complementary human support. A hybrid model combining interactive media and teacher guidance is optimal (Pratama & Nugroho, 2023).

Sustained pedagogical effectiveness requires regular content updates, maintenance of technical functionality, and evolution based on educational needs. Open source technology-based learning media offers long-term benefits because they are not dependent on proprietary vendors that can discontinue products or increase costs. Open licensing allows community contributions that can enrich content. Institutional support, teacher training, and quality assurance processes are essential for sustainability. Change management strategies and communities of practice support the integration of innovation into learning practices. Regular evaluation and gathering evidence of success are essential to demonstrate continued value to stakeholders (Sari & Wibowo, 2023).

B. Impact on Learning Motivation and Engagement

The significant increase in motivation and engagement in this study can be explained through the Self-Determination Theory (SDT) framework, which identifies three psychological needs essential for intrinsic motivation: autonomy, competence, and relatedness. Interactive learning media fulfills the need for autonomy through choice in learning paths, pace, and representation formats, giving participants control over their

learning experience. The need for competence is met through balanced challenges, supported by scaffolding and immediate feedback, as well as visual progress indicators and achievement badges. Relatedness is built through collaborative features, discussion forums, and peer interaction. Gamification elements such as points, leaderboards, and challenges enhance extrinsic motivation, but are balanced to avoid diminishing intrinsic motivation (Firmansyah & Azizah, 2023).

Learning analytics data provides objective evidence of sustained engagement through metrics such as login frequency, time per session, and completion rate. The average login frequency of 4.8 times per week far exceeds typical engagement, indicating that the learning medium is central to learning activities. The 87-minute session time with no attendance requirement demonstrates voluntary engagement driven by interest and value. The 94% completion rate far exceeds the average for online courses, which is often below 15%. Engagement patterns remain stable, indicating sustained interest. Active interaction and exploration of selected materials signal deep engagement, and access outside of school hours demonstrates flexibility. These patterns align with self-directed learning and differ from the engagement that simply follows the rules of a traditional classroom (Hidayat & Setiawan, 2023).

Flow theory provides a useful framework for understanding the optimal engagement experience reported by most learners. Flow, characterized by a sense of total immersion, clear goals, immediate feedback, and a balance between challenge and ability, is the pinnacle of engagement and enjoyment. Interactive learning media create conditions conducive to flow through clear learning goals, immediate feedback, adjustments to difficulty levels, and an immersive interactive environment. Learners experiencing flow cite "losing track of time," "complete focus," and "enjoyment in the learning process" as key indicators. The results suggest that well-designed interactive media can support immersive and enjoyable learning experiences, although the propensity to flow varies among individuals (Nurhadi & Kusuma, 2023).

The process of social comparison through leaderboards and public displays of achievement has complex effects on motivation, varying across learners. For some, social comparison is motivating, providing benchmarks and encouraging competition to improve performance. They monitor their position and increase their effort when falling behind. Conversely, for struggling learners, public comparison creates anxiety and decreases motivation, especially when upward comparisons highlight their shortcomings. Strategies to mitigate these negative effects include private mode, emphasizing personal progress,

diversifying leaderboards, and competitions as collaborative challenges. Self-comparison features that highlight individual growth are universally motivating without negative social effects. A personalized approach to motivational features can enhance the effectiveness of gamification based on learner characteristics (Wulandari & Setiawan, 2023).

Attribution patterns for success and failure are influenced by the characteristics of feedback, which have significant implications for motivation and persistence. Interactive learning media provide direct, specific, and constructive feedback that helps learners attribute outcomes to controllable factors such as effort and strategy, rather than ability. Feedback explains errors and provides guidance, supporting a growth mindset that abilities can be developed through effort. Unlike traditional assessments that only provide right/wrong answers, this feedback reinforces the belief that effort leads to progress. However, some learners exhibit an entity mindset that is resistant to attributional change, indicating the need for explicit metacognitive instruction (Putra & Anggraini, 2023).

The long-term sustainability of motivational effects remains an important question for future research. The novelty effect, a decline in initial enthusiasm for new technology as the novelty wears off, has been documented. Although engagement metrics remained stable during the 8-week intervention, longer-term studies are needed to ensure motivation persists over months or years. Strategies for maintaining long-term engagement include regular content updates, gradually unlocking features, evolving challenges, and community-generated content. Activity variety, integration into the curriculum, and intrinsic interest are also important. Teacher enthusiasm and positive usage models are significant. Research shows short- to medium-term motivational benefits, but longitudinal studies are needed to determine sustained effects (Mahmud & Indrawati, 2023).

C. The Role of Open Technology in Educational Accessibility and Equity

Open technology plays a crucial role in democratizing access to quality educational resources and tools, addressing the gap in equity in learning opportunities. Cost is often a major barrier to technology adoption, as proprietary software licensing fees are often prohibitively expensive. Open source technology reduces or eliminates these costs, making advanced educational tools accessible to schools and students regardless of economic status. Beyond initial costs, this technology also reduces ongoing licensing costs and forced upgrades. Savings can be allocated to teacher training, infrastructure improvements, or

support services. Open source code allows for local adaptation as needed. Studies have shown that effective interactive learning media can be developed using open technology, challenging the assumption that quality technology requires expensive solutions (Dewi & Saputra, 2023).

Accessibility features in open technology-based learning media ensure the inclusion of learners with diverse abilities and needs. WCAG compliance is achieved through the use of semantic HTML, proper heading structure, alternative text for images, captions for videos, keyboard navigation, and sufficient color contrast. Open-source accessibility testing tools and platforms facilitate evaluation and improvement at no additional cost. Compatibility with screen readers allows learners with visual disabilities to access content. Adjustable text size, high-contrast modes, and captions support learners who are deaf. Universal Design for Learning principles ensure content is understandable and usable by all. While challenges remain, training content creators and contributions from the open source community are essential for continuous improvement (Pratama et al., 2023).

Geographical disparities are addressed through the distribution of web-based learning media accessible anywhere with an internet connection, reducing distance and location barriers. Learners in previously disadvantaged rural and remote areas can access the same high-quality interactive learning experiences as those in cities. Responsive design ensures access via smartphones, which are more common in underserved areas. Offline features through Progressive Web App (PWA) architecture enable content downloads for use in low-connection environments. Despite this, the digital divide remains a challenge, with varying levels of internet access and device availability. Strategies such as community access points, device lending programs, offline distribution, and hybrid models can help bridge this gap (Kurniawan & Lestari, 2023).

The linguistic diversity and localization capabilities of open technologies support linguistic equity in education. Many proprietary educational technologies are only available in dominant languages like English, hindering minority-speaking communities. Open-source platforms enable community-driven translation and localization efforts, creating learning resources in hundreds of languages, including minority languages. Volunteer collaboration accelerates this process, and cultural adaptations are made to reflect local experiences. Studies have shown successful implementation in Indonesian, but open architecture allows for expansion to regional languages. Translation quality needs to be moderated by the community, and technical infrastructure must be well-prepared. Multilingual support aligns with UNESCO's goals of language preservation and mother tongue education (Hidayat & Setiawan, 2023).

Community ownership and governance of open educational technology supports a participatory development model that empowers local stakeholders, rather than simply passive users of external solutions. Traditional proprietary models empower vendors, who determine product features, pricing, and direction without user input. Open source governance models enable community participation in decision-making, feature prioritization, and development, creating a sense of shared ownership. This builds local technical capacity and reduces dependence on external vendors. However, effective community governance requires adequate structures and processes. Sustainability relies on voluntary contributions, and institutional support is essential for this model to remain sustainable (Sari & Wibowo, 2023).

Equity concerns not only access but also the quality of educational experiences and outcomes. Providing technology access alone is insufficient if the learning experience is inadequate or does not effectively support learning. This study shows that open source technology-based learning media achieve comparable or better results than commercial alternatives, challenging negative perceptions about open source quality. However, quality depends on resources for development, design expertise, and ongoing maintenance. Institutions with limited resources may struggle to implement and adapt open technology, creating new inequalities. Training, technical support, and inter-institutional collaboration can help address these gaps (Firmansyah & Azizah, 2023).

D. Implications for Educational Policy and Practice

The results of this study have important implications for policy development at the institutional, regional, and national levels regarding educational technology integration. The effectiveness and cost-efficiency of open source educational technology should be considered in procurement, which currently often favors proprietary solutions due to vendor relationships and quality assumptions. Policies that mandate the evaluation of open source alternatives could save costs that could be allocated to other priorities. Open licensing policies for publicly funded educational resources ensure investments produce public goods accessible to all. Accessibility, interoperability, and data privacy standards should be incorporated into educational technology development. Community-driven development models can also accelerate innovation (Nurhadi & Kusuma, 2023).

Teacher preparation and professional development programs need to be rethought to equip educators with the competencies to utilize interactive learning technologies. Traditional

approaches focus on pedagogical methods for face-to-face learning with minimal technology integration. Professional development should adopt the TPACK framework, which coherently integrates knowledge of technology, pedagogy, and content. Pre-service teachers need hands-on experience in designing, implementing, and evaluating technology-based learning. Ongoing training for active teachers should go beyond basic workshops on technology use and support communities of practice and specialized training on open-source technologies and learning analytics. Policies that provide free time and incentives are essential to support professional participation (Wulandari & Setiawan, 2023).

Curriculum design implications include the need to reimagine the scope, sequence, and structure of learning experiences to harness the potential of interactive technologies. Traditional linear, textbook-based curricula are not optimal for interactive digital technologies. Modular and flexible curriculum designs enable personalized learning pathways and competency-based models supported by technology-based mastery assessments. Authentic and applied learning experiences are more easily integrated through simulations and virtual environments. Barriers include the pressure of standardized testing, textbook adoption cycles, and traditional teacher training. Systematic curriculum reviews and piloting competency-based models can support innovation, with collaboration between educators, designers, and technologists (Putra & Anggraini, 2023).

Assessment policies and practices must evolve to adapt to technology-based learning environments and measure a variety of competencies. Paper-based standardized tests are ineffective at assessing digital skills and technology-based learning. Authentic and performance-based assessments, such as portfolios and digital projects, should be used to replace or complement traditional tests. Learning analytics provide objective data that complements traditional assessments. Barriers include accountability and infrastructure pressures. The gradual integration of technology-based assessments, starting with formative assessments, can ease the transition. Professional development is essential for educators to design and implement innovative assessments, with open-source tools supporting adoption. Studies demonstrate the benefits and feasibility of integrated assessments (Mahmud & Indrawati, 2023).

Infrastructure investment policies must prioritize digital infrastructure as a critical educational infrastructure, on a par with buildings and facilities. Fast internet connections, adequate devices, technical support, and professional development are key infrastructure for technology-based education. In resource-constrained contexts, these investments compete with other pressing needs. Evidence of the benefits of investment through improved learning

outcomes, efficiency, and equity strengthens this argument. Public-private partnerships and open technology lower costs, enabling more affordable infrastructure. A phased approach that provides universal basic access and incremental capacity increases is necessary. Infrastructure plans must consider the total cost of ownership, including maintenance and upgrades (Dewi & Saputra, 2023).

Policy implications of this research include the need for longitudinal and rigorous studies to examine the long-term effects, scalability, and variation in technology-based learning contexts. A single study is insufficient for major policy decisions; replication studies across multiple contexts are essential to strengthen the evidence base. Longitudinal research and comparisons of technological and pedagogical approaches are needed to identify best practices. A focus should also be on cost analysis and implementation factors that determine success. Funding support should advance this agenda, including open science practices and research-practitioner partnerships. Funding constraints and the need for investment in research infrastructure are recognized. Recommendations include collaborative priority-setting and the development of mechanisms for implementing research findings into policy (Pratama et al., 2023).

CONCLUSION

This research successfully developed an interactive learning media based on open technology that is pedagogically effective, increases motivation and engagement, and is accessible to a diverse range of learners. The quasi-experimental study demonstrated significant learning outcomes with a large effect size (d=1.35), reflecting significant practical impact. This media enhances both lower and higher cognitive skills, such as applying, analyzing, and evaluating, essential for 21st-century competencies. Better learning retention was evident four weeks post-intervention, indicating deep and lasting understanding. Engagement metrics and motivation data demonstrated a fun and personally meaningful learning experience, supporting sustained intrinsic motivation.

Open technologies have proven viable and profitable for the development of high-quality educational technology, challenging the notion that expensive, high-quality educational technology requires proprietary solutions. Open source platforms like Moodle, H5P, and other web technologies provide a solid foundation for creating sophisticated, interactive learning experiences without high licensing costs. The flexibility to customize and

adapt technology to contextual needs is also a key advantage over proprietary systems. Community-driven development models facilitate knowledge sharing, collaboration, and continuous improvement. Accessibility features can be effectively implemented using open standards and tools, supporting the inclusion of diverse learners. Cost savings can be allocated to other educational needs, but require institutional commitment to training and technical support.

Educational policies and practices require systemic changes, including open-source evaluation in technology procurement, development of teachers' TPACK competencies, and technology-based curriculum design for personalized learning. Assessment systems must be able to measure diverse competencies through authentic digital assessments. Digital infrastructure must be prioritized as the foundation of modern education. Research limitations, such as short duration and focus on a single area, can be addressed through longitudinal studies, replications, and large randomized trials. Continued research is essential to support evidence-based policies and technological innovations such as AI and VR.

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