JME - Dwi Egi_Article.docx

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Submission date: 17-Jun-2025 06:50AM (UTC+0300)
Submission ID: 2590848397
File name: JME_-_Dwi_Egi_Article.docx (2.56M)
Word count: 9861
Character count: 64284

Journal on Mathematics Education
Volume xx, No. x, xxxx, pp. xx-xx

Designing a STEM-Based Digital Learning Space to Foster Creative Mathematical Thinking and Autonomous Learning in Secondary Education

Abstract

This study aims to develop and evaluate the effectiveness of a STEM-Based Digital Learning Space (DLS) designed to enhance junior high school students' creative mathematical thinking skills and autonomous learning. The DLS was developed in response to the limited interdisciplinary integration of science, technology, engineering, and mathematics in teaching, as well as the lack of access to contextualized and personalized digital learning environments. The development process followed the 4D model (Define, Design, Develop, Disseminate), accompanied by expert validation and multi-stage field testing. Expert validation results indicated that the DLS was highly feasible, while student practicality testing categorized the system as very practical. Effectiveness testing demonstrated a significant improvement in students' creative mathematical thinking abilities (N-Gain = 0.554, moderate category) and strengthened their autonomous learning. The DLS was designed as an ecosystem integrating both a Personal Learning Environment (PLE) and a Personal Teaching Environment (PTE), equipped with interactive features such as simulations, adaptive quizzes, digital worksheets, and collaborative forums. This innovation holds strong potential to support the transformation of digital mathematics learning at the secondary school level, aligning with the Deep Learning Curriculum and national digital literacy enhancement programs, particularly in regions with limited technological infrastructure.

Keywords: Autonomous Learning, Creative Mathematical Thinking, Digital Learning Space, Secondary Education, STEM-Based Learning.

In the era of the Industrial Revolution 4.0 and the post-COVID-19 period, educational challenges can no longer be addressed merely through partial technological adoption (González-Pérez & Ramírez-Montoya, 2022). A comprehensive pedagogical transformation is required to prepare a generation capable of adapting to the complexities of the digital age (Røe et al., 2022). In this context, creative mathematical thinking emerges as a critical 21st-century competency, particularly in response to automation and the explosion of data (Yulianto et al., 2024; Szabo et al., 2020). Unfortunately, digitalization in Indonesian education continues to face disparities in access and digital literacy (Samane-Cutipa et al., 2022; Li & Yu, 2022; Rawal, 2024). These gaps are exacerbated by procedural teaching systems that fail to sufficiently promote creativity and idea exploration (Yulianto et al., 2024), as reflected in the OECD (2023) report that ranks Indonesian students low in mathematical literacy, particularly on non-routine problems requiring flexible thinking.

Creative mathematical thinking, which involves the formulation, transformation, and flexible application of ideas in complex situations, serves as the foundation of 21st-century numeracy skills (Dilekçi & Karatay, 2023). This activity encompasses logical reasoning (Shuib et al., 2021) as well as the capacity to generate original and effective solutions (Rosengren et al., 2020). In mathematics education, creativity manifests through novel ideas, effective strategies, and interconnected solutions for solving non-routine problems (Joklitschke et al., 2022). However, Indonesian students' performance in this domain remains low (Tanujaya et al., 2021), largely due to an instructional culture that limits contextual exploration (Prahmana et al., 2020). Therefore, STEM-based curricula and learning media are urgently needed to foster students' autonomy and creative exploration in addressing real-world problems (Yuliardi et al., 2024; Nurintya & Agoestanto, 2022).

http://doi.org/10.22342/jme.v13i1.xxxx

The core dimensions of creative thinking fluency, flexibility, originality, and elaboration are widely recognized through the Torrance Test of Creative Thinking (TTCT) framework, which has been adapted across various disciplines, including mathematics (Alabbasi et al., 2022; Suherman & Vidákovich, 2022). However, conventional approaches to assessing mathematical creativity remain generic and fail to reflect the discipline's specific demands for precision, logical structure, and multi-strategic exploration (Hjelte et al., 2020). Therefore, this study adapts the TTCT indicators within the context of probability learning: fluency as the ability to generate diverse experimental procedures and representations; flexibility as the formulation of alternative strategies based on probability data; originality in designing unconventional solutions; and elaboration through the development and justification of solutions using statistical arguments. These adjustments aim to capture the complexity of heuristic processes in solving mathematical probability problems (Yulianto et al., 2024).

Developing creative thinking skills requires a learning environment that fosters exploration, reflection, and the reconstruction of conceptual meaning (Zhou et al., 2024; Junaedi et al., 2021). In this context, the STEM approach offers an integrative framework that combines science, technology, engineering, and mathematics to address authentic problem-solving tasks (Purwaningsih et al., 2020; Setiawati & Agoestanto, 2023). STEM not only enhances cognitive flexibility through multimodal representations (Hallström & Ankiewicz, 2023) but also fosters originality via digital design and experimentation (Nugraha et al., 2023). Studies by Yuliardi et al. (2024) and Stoyanov et al. (2022) have demonstrated that integrating a Digital Learning Space (DLS) within STEM education significantly improves students' autonomy, collaboration, and creativity.

Based on these findings, the development of a STEM-Based Digital Learning Space in this study was designed as a pedagogical intervention to cultivate students' creative thinking, autonomous learning, and critical reflection in solving data-driven mathematical problems (Yuliardi et al., 2024). This strategy is intended to contribute to the transformation of Indonesia's education system towards a more adaptive, innovative, and globally competitive model (Cheng, 2022; Akhmetova et al., 2025). In the digital disruption and automation era, STEM serves not merely as an interdisciplinary field but as an epistemic framework integrating conceptual knowledge with practical application through project-based learning, collaboration, and authentic problem-solving (Nguyen et al., 2020; Conde et al., 2021). Countries such as Finland, the United States, Taiwan, and Malaysia have implemented national STEM policies that emphasize cross-disciplinary creativity, computational reasoning, and strategic reflection (Ha et al., 2020). At the global level, several universities have developed Self-Access Learning Centers (SALCs) such as those at Kanda University, ASLLC (EdUHK), and ELSAC (University of Auckland) to enhance academic autonomy. However, adoption in Indonesia remains limited (de Vink et al., 2023; Martín-Páez et al., 2019), hindered by low digital literacy, conventional instructional cultures, and inadequate STEM learning infrastructure. Yet, integrated STEM approaches inherently promote cross-disciplinary exploration and authentic problem-solving (Tramonti et al., 2024).

In Indonesia, although the "Merdeka Curriculum" and "Sekolah Penggerak" programs rhetorically advocate STEM-based education policies, their implementation in practice has not fully reflected this transformative approach (Jasiah et al., 2024). Learning models remain largely procedural and teacher-centered (Cheon et al., 2020), further constrained by low digital literacy among teachers, insufficient interdisciplinary training, and the scarcity of adaptive DLS platforms (Samane-Cutipa et al., 2022; Li & Yu, 2022; Rawal, 2024). Without systemic solutions, this gap risks widening the global competence divide faced by Indonesian students in meeting 21st-century demands. Therefore, STEM education in Indonesia must be reconceptualized as a pedagogical foundation that nurtures autonomy, cognitive flexibility, and creativity in authentic problem-solving. This strategy should include cross-subject integration, the enhancement of reflective pedagogical capacities among teachers (McGuire & Lay, 2019; Romijn et al., 2021), and the development of STEM-based DLS platforms that empower students as solution designers (Hughes & Morrison, 2020). Through this approach, STEM education is expected to foster adaptive, self-directed learners capable of driving meaningful change (Yuliardi et al., 2024).

In the context of 21st-century education, autonomous learning has been recognized as a fundamental foundation for shaping resilient, reflective, and adaptive learners (González-Pérez & Ramírez-Montoya, 2022). Unlike traditional teacher-centered models, autonomous learning positions students as the primary agents in managing learning strategies, reflecting on achievements, and conducting self-assessment (Yuliardi et al., 2024). Technologies such as LMSs are expected to facilitate transformative self-directed learning, not merely serve as administrative tools (Athaya et al., 2021; Clark et al., 2021; OECD, 2023). Therefore, the design of digital pedagogy must shift towards STEM-based Digital Learning Spaces (DLS) that are open, contextual, and foster student agency (Aini et al., 2022; Nguyen et al., 2020; Conde et al., 2021). However, its realization is still hindered by systemic factors such as rigid curricula, limited teacher digital competence, and unequal access to technology (Yulianto et al., 2024). Without comprehensive intervention, the synergistic potential of STEM, autonomous learning, and DLS risks becoming mere jargon without meaningful transformational impact in educational practice.

Digital Learning Spaces (DLS) are developed based on the principles of Networked Learning, emphasizing connectivity, collaborative knowledge construction, and active collaboration (NLEC, 2021). DLS serves as infrastructure for both synchronous and asynchronous learning, aligned with the self-regulated learning framework that supports flexible access, goal setting, and learner autonomy (Dignath & Veenman, 2020; Sun et al., 2023). The DLS design also integrates the concepts of Personal Learning Environments (PLE) and Personal Teaching Environments (PTE), allowing for personalization and adaptive instructional design (Cenka et al., 2022; Tur et al., 2022). Collaborative forums and formative assessments within the DLS enhance students' cognitive presence (Maranna et al., 2022). However, the widely claimed accessibility and low-cost benefits of DLS require critical evaluation, especially in developing countries facing infrastructure, device, and digital literacy gaps (Gumbi et al., 2023). These disparities risk widening educational inequality, particularly among marginalized student groups. The effectiveness of DLS as a medium for flipped classrooms and inquiry-based learning also heavily depends on teacher professional development, supportive policies, and equitable digital infrastructure (Al-Said et al., 2023; Sosa Díaz et al., 2021; NLEC, 2021).

Research on DLS in the STEM context should transcend mere access issues by fostering digital learning environments that encourage exploration, experimentation, and authentic problem-solving (Purwaningsih et al., 2020; Setiawati & Agoestanto, 2023). The integration of STEM within DLS should not only deliver digital content but also create creative learning spaces that strengthen contextual mathematical reasoning and active participation (Wan et al., 2020; Johnston et al., 2022). Specifically, this study responds to the need for a digital learning environment that promotes creative mathematical thinking within local contexts. The STEM-Based Digital Learning Space (DLS) developed in this study is integrated with a problem-solving approach based on pedagogically and culturally adapted TIMSS-PISA content. This model addresses a gap in the literature concerning the integration of content design, local culture, and learner autonomy within digital platforms. The DLS is designed with a culturally responsive pedagogy that incorporates ethnomathematics and local wisdom into assessments, materials, and digital discussions. Interactive features such as adaptive feedback, open-ended simulations, and collaborative spaces support the activation of self-regulated learning (SRL), divergent thinking, and conceptual generalization in authentic situations.

Unlike previous studies, this model offers a transformative approach that not only stimulates creative mathematical thinking but also builds contextual, independent, and inclusive digital literacy. Based on this background, the present study aims to answer two main research questions: (1) What are the characteristics of a valid and practical STEM-based DLS design that supports autonomous digital mathematics learning? (2) How does the DLS influence students' creative mathematical thinking skills in the context of self-directed learning?

METHODS

This study employed a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, Disseminate) by Roman (2022) to develop a STEM-Based Digital Learning Space (DLS) integrated into both synchronous and asynchronous learning environments. This model was selected for its systematic, flexible, and iterative nature, allowing multi-stage validation and expert involvement from the early stages of development, crucial for producing a digital product that is valid, practical, and effective within the STEM education context. The final product consists of a web-based digital learning system equipped with interactive modules, probability simulations, discussion forums, and digital worksheets (LKPD) designed to enhance students' scientific literacy and creative mathematical thinking skills. The DLS design integrates two main functions: (1) Pedagogical and Technological Enhancement (PTE), emphasizing instructional management by teachers (account setup, multimedia integration, task management, and rubric-based evaluation), and (2) Personalized Learning Environment (PLE), promoting active student engagement through independent and collaborative activities, quizzes, reflection, and peer assessment based on task performance.

In the Define stage, a front-end analysis was conducted to map STEM learning needs in partner schools, along with a learner analysis to identify student characteristics, challenges, and learning requirements. The Design stage involved the development of evaluation instruments based on Torrance's (1974) indicators for creative mathematical thinking tests (fluency, flexibility, elaboration, originality, and connection-making) and Fisher et al.'s (2001) framework for the autonomous learning questionnaire (self-regulation, motivation control, initiative). Lightweight digital media were selected, and instructional materials were developed, integrating STEM content with technology. During the development stage, validation by content experts, media specialists, and initial user teachers was conducted using Aiken's V, with all items exceeding a value of 0.80. The trials followed a design-based research principle, encompassing a small-scale trial (7 students from Grade VIII at SMP Latansa 2), an expanded trial (60 students from SMP Latansa 2 and SMP Kun Karimma), and field testing (120 students from SMP Daar El Qolam 2 and 3, and SMP Latansa 1), purposively selected based on theoretical and contextual considerations.

Inclusion criteria included: (1) availability of adequate ICT infrastructure (computer labs and stable internet connections); (2) active involvement of mathematics teachers in technology-based learning; and (3) representation of school diversity based on accreditation status (A) and geographical location to evaluate practicality, engagement, and product effectiveness. Each stage was accompanied by teacher training and observations conducted by a trained evaluation team. At the Disseminate stage, the developed product was distributed through accredited scientific publications, national teacher training workshops, and intellectual property rights (IPR) applications to strengthen the product's legitimacy. These efforts aimed to build a sustainable digital learning ecosystem through teacher learning communities and integration with the Merdeka Mengajar platform. Through this design, the STEM-DLS is expected to promote contextual, adaptive, and reflective learning while supporting the Merdeka Belajar policy and the national digital education transformation agenda.

Instruments and Validity

Students' creative mathematical thinking skills were assessed using pre-test and post-test instruments based on five core indicators: fluency, flexibility, elaboration, originality, and connection-making, as proposed by Torrance (1974). The test consisted of five open-ended essay questions, validated by three mathematics education experts, yielding an Aiken's V coefficient of 0.85, indicating high content validity. Internal reliability was confirmed with Cronbach's alpha ($\alpha = 0.81$), demonstrating good consistency. Students' autonomous learning was measured using a 30-item questionnaire based on the Self-Directed Learning Readiness model (Fisher et al., 2001), encompassing learning initiative, self-regulation, and metacognitive awareness. Responses were rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), with an internal reliability coefficient of $\alpha = 0.873$. Construct validity was verified through exploratory factor analysis (KMO > 0.8), supporting the appropriateness of the three-factor model. In addition to these measurement instruments, the content validity and practicality of the STEM-Based Digital Learning Space (DLS) platform were evaluated by subject matter experts, digital media specialists, and STEM education experts using a standardized evaluation rubric and a student practicality questionnaire.

Data Collection and Analysis

Data were collected using a mixed-methods approach (Creswell & Plano Clark, 2018) to evaluate the effectiveness and user experience of the STEM-DLS. Qualitative data, in the form of multimodal documentation transcripts (photos, videos, audio recordings), were analyzed thematically (Braun & Clarke, 2006) to explore students' mathematical reasoning during the assembly, experimentation, and presentation phases. Quantitative analysis included content validity testing (Aiken's V), practicality evaluation (descriptive statistics), and effectiveness assessment (N-Gain, paired and independent t-tests, one-way ANOVA), as well as MANOVA to examine the effectiveness of the STEM-DLS across multiple variables. The STEM-DLS product was validated by three experts: an educational technology specialist, a mathematics expert, and a mathematics teacher as a pedagogical evaluator. Validation was conducted using a 5-point Likert scale covering content substance, alignment with core competencies, STEM integration, instructional design quality, assessment, and collaborative features. The mean validation scores determined the product's feasibility, categorized as invalid, less valid, fairly valid, valid, and highly valid. The product was deemed feasible if it achieved at least the "valid" or "highly valid" category; otherwise, revisions were made accordingly. In terms of practicality, students evaluated the DLS based on usability, clarity, readability, and time adequacy. A mean score of ≥70% indicated practicality; scores below this threshold required improvements based on user feedback.

RESULTS AND DISCUSSION

Results

In the Define stage, participatory front-end and learner analyses were conducted at SMP Latansa Mashiro to map students' pedagogical needs and characteristics. The analysis revealed that learning in the school remained compartmentalized across disciplines (Science, Mathematics, ICT), technology use was limited to passive presentation media, and students' digital literacy was low, with most unfamiliar with LMS platforms or exploratory applications (see Table 1).

Table 1. Summary of Front-End and Learner Analysis Findings

Aspect	Key Findings	Implications for Solution Design
STEM Integration	Learning remains sectoral; no explicit integration across disciplines (Science, Mathematics, Technology).	Design project-based learning scenarios that integrate concepts from multiple disciplines.
Technology Utilization	Teachers rarely use supporting applications other than PowerPoint; no interactive digital media or simulations are employed.	Develop a Digital Learning Space that emphasizes exploratory and interactive visualization.
Student Digital Literacy	72.2% of students are only proficient with basic applications (WhatsApp, YouTube); unfamiliar with LMS platforms, GeoGebra, or other exploratory tools.	Provide gradual, adaptive digital media training tailored to students' initial skill levels.
Learning Autonomy	61.1% of students struggle with independent learning; they require intensive teacher guidance.	Integrate scaffolding into the digital task design to enable progressive student autonomy.
Technical Constraints	58.3% of students lack stable internet access at home; 25% own only low-spec smartphones.	Design lightweight learning media accessible offline or semi-offline (e.g., interactive HTML, locally stored videos).
Student Creative Potential	Only 16.7% of students exhibit tendencies towards creative thinking (e.g., asking critical questions, offering alternative solutions).	Apply strategies to stimulate creative thinking through real-world problem contexts and provide open exploration spaces.

At the Design stage, an initial prototype of the STEM-Based Digital Learning Space (STEM-DLS) was developed based on the framework of the Personal Teaching Environment (PTE) and Personal Learning Environment (PLE) (Figure 1). Four main components were designed: (1) Assessment instruments, consisting of a mathematical creative thinking test based on the indicators of fluency, flexibility, elaboration, originality, and connection-making (Torrance, 1974), along with an autonomous learning questionnaire referring to the dimensions of self-regulation, initiative, and metacognitive awareness (Fisher et al., 2001; Gu et al., 2023); (2) Digital media, using lightweight HTML and locally produced videos to support exploratory STEM principles and accommodate students' limited device access; (3) Integrated teaching materials, connecting science, mathematics, and ICT in a project-based learning scenario; and (4) The DLS design, which distinguishes between teachers' roles (PTE) and students' independent and collaborative activities (PLE). Key platform features include discussion forums, assignment reflection spaces, interactive quizzes, and peer assessment, all of which promote learner autonomy. The entire design was validated by two instructional design experts and one STEM content expert, who confirmed its feasibility for further implementation. The STEM-DLS platform prototype is accessible at https://kalana.my.id, as illustrated in Figure 1.

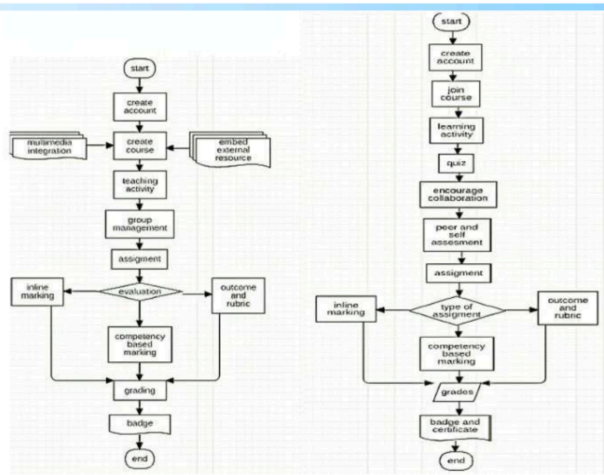

Figure 1. Flow diagram of PTE and PLE (Yuliardi et al., 2024)

The development phase of the STEM-DLS aimed to ensure content validity, pedagogical suitability, and practical applicability within a digital learning context. Validation was conducted by two experts in educational technology and mathematics, as well as a mathematics teacher serving as a pedagogical evaluator. The validation instrument consisted of 20 items covering content substance, relevance to core competencies, and the integration of STEM components. The entire validation process was supported by a panel discussion using a triangulated consensus approach to align perspectives between academic experts and field practitioners. Therefore, the developed DLS product meets both substantive and technical feasibility criteria for implementation in digital STEM learning (see Tables 2 and 3).

Table 2. Expert Validation Results – Content

Assessed Aspect	Description	AV	Validity Category
Content Quality and Objectives	Alignment with learning objectives and student competencies	3.90	Valid
Instructional Design	Structure, delivery strategy, and material sequencing	4.00	Valid
Learning Design	Activity planning, student engagement, and scenario development	4.05	Valid
Evaluation and Feedback	Clarity of assessment instruments and effectiveness of feedback	3.86	Valid
Discussion and Collaboration Features	Ease of information sharing and online discussion facilities	3.95	Valid
Average Validity	Overall mean score from content experts	4.35	Practical

Table 3. Expert Validation Results – Media

Assessed Aspect	Description	AV	Validity Category
DLS Web Appearance	Layout clarity, visual aesthetics, readability, and user interface navigation	4.20	Good

Assessed Aspect	Description	AV	Validity Category
DLS Menu Design	Menu structure, icons, ease of access, and completeness of digital navigation	3.80	Good
Audio-Visual Clarity and Interactivity	Media sound/image quality, system response to user interaction, and user engagement	4.25	Good
Programming Appropriateness and Functionality	Technical performance, cross-device compatibility, and system reliability in practice	4.20	Good
Average Validity	Aggregate score from all media validation aspects	4.11	Practical

Development Results of STEM-DLS Features

The development of the STEM-DLS was carried out through collaboration among the academic team, web developers, teachers, and students to ensure both pedagogical relevance and contextual suitability for partner schools. The design of the DLS integrates international best practices, such as Project-Based Learning and TIMSS/PISA frameworks, while being adapted to local constraints, including low-specification devices, visual preferences, and limited digital literacy. Therefore, the platform was designed to be modular, lightweight, and supportive of asynchronous access to enhance inclusivity. The STEM-DLS features include interactive simulations, a progress dashboard, digital student worksheets, and a Collaborative Learning Hub, all aimed at fostering 4C skills (Creativity, Critical Thinking, Communication, Collaboration) as well as self-directed learning through a self-regulated learning approach. In addition to STEM-based content, the DLS is equipped with automated formative assessments, adaptive feedback, and performance tracking via learning analytics, enabling teachers to conduct real-time, data-driven assessments.

Table 4. Summary of Key Features of the STEM-DLS

Feature	Main Function	Benefits for Teachers/Students
Learning Dashboard	Provides learning guidance, content navigation, and student progress tracking.	Supports independent learning management; helps teachers monitor students' progress efficiently.
Interactive Simulations & Videos	Presents STEM concepts visually and multimodally.	Enhances contextual and applied understanding of abstract concepts.
Digital Student Worksheets & Project Upload	Serves as a medium for task completion and student project documentation.	Encourages project-based learning and the development of digital portfolios.
Automated Formative Assessment	Offers interactive quizzes with feedback and alternative solutions.	Delivers instant feedback; provides teachers with performance-based assessment data.
Collaborative Learning Hub	Acts as a discussion forum and a space for sharing learning outcomes.	Facilitates collaboration, reflection, and idea exchange among users.
Resource Center (STEM Gallery)	Hosts a gallery of projects, videos, and context-based assignments.	Enhances knowledge transfer and inspiration from real learning environments.

These features were developed following the principles of connected learning to support contextual education in the digital era. Formative validation and limited student trials were conducted iteratively to refine the design and functionality. As part of the STEM-DLS, seven units of digital Student Worksheets were designed and validated by content experts. The content validation was carried out by two university lecturers specializing in educational technology and mathematics, as well as a mathematics teacher who served as a pedagogical evaluator, assessing the format, language, content, and illustrations. The results indicated that all assessed aspects achieved the "Very Valid" category, with an average score of 95.07% (see Table 5). In terms of practicality, the DLS was evaluated by students using a practicality questionnaire covering ease of access, clarity of presentation, readability of information, and appropriateness of time allocation. All aspects scored above 70%, with an average of 89.38%, classified as "Very Practical" (Table 6).

Table 5. Results of Student Worksheet Validation Analysis

Validator Rating Average	Face Validity	Content Validity	Construct Validity	Validation Average
Student Worksheet – 1	96.35%	93.06%	96.21%	95.21%
Student Worksheet – 2	95.83%	92.36%	96.21%	94.80%
Student Worksheet – 3	95.83%	92.36%	95.45%	94.55%
Student Worksheet – 4	95.83%	93.75%	96.21%	95.26%
Student Worksheet – 5	96.88%	93.06%	94.70%	94.88%
Student Worksheet – 6	96.35%	93.75%	97.73%	95.94%
Student Worksheet – 7	95.31%	93.06%	96.21%	94.86%
Average	96.05%	93.06%	96.10%	95.07%
Category	**Very Valid**	**Very Valid**	**Very Valid**	**Very Valid**

Table 6. Practicality of STEM-Based DLS Based on Student Assessment

Practicality Aspects	1	2	3	4	5	6	7	Average	Category
Ease of Access and Navigation	92.78	95.00	90.83	92.78	90.83	90.83	89.17	91.75	Very Practical
Clarity of Information and STEM Content Presentation	91.67	90.67	88.67	87.67	87.67	85.00	87.00	88.34	Very Practical
Readability of Text and Digital Visualization	88.33	89.00	89.33	90.00	90.67	91.33	88.33	89.57	Very Practical
Appropriateness of Feature Usage Time Allocation	88.33	89.17	87.50	87.50	86.67	87.50	88.33	87.86	Very Practical
Overall Practicality Average	90.28	90.96	89.08	89.49	88.96	88.67	88.21	89.38	Very Practical

STEM Task Description

This program aims to enhance secondary school students' creative mathematical thinking through STEM learning rooted in the local culture of the Baduy community. Preliminary observations revealed that many students struggle with data interpretation, constructing numerical arguments, and applying concepts of probability and ratio in real-life contexts. To address these challenges, a series of thematic activities was developed, integrating mathematical concepts (data, scale, probability), science (weather observation, energy), technology (basic LMS, simulations), and engineering (designing simple tools). These activities are organized into seven main topics, each reflecting elements of Baduy daily life, such as traditional games, weaving patterns, house structures, and local natural resources. Every task incorporates Torrance's dimensions of creativity fluency, flexibility, originality, and elaboration through open-ended problem-solving exercises.

Table 7. STEM Learning Plan Based on Baduy Local Culture

Mathematics Topic	Creative Thinking Indicators	STEM Components	Digital Learning Media
Patterns and Sequences in Baduy Weaving Motifs	Fluency, Elaboration	M, A, T	Weaving motif images, pattern exploration videos, and interactive pattern simulations in LMS
Ratios and Scale: Baduy Traditional Village Map	Flexibility, Originality	M, T, E	Digital village maps, drone videos, digital measurement apps, and building scale simulations
Data and Statistics: Traditional Energy Survey of Baduy Houses	Fluency, Flexibility, Elaboration	M, S, T	Digital questionnaires, interactive graphs, LMS for survey data input and visualization
Probability: Traditional Baduy Games Experiment	Fluency, Originality, Elaboration	M, S, T	Experiment videos, simple spin wheel simulations, data-based experiment dashboards
Plane and Solid Figures: Baduy Traditional House Architecture	Originality, Elaboration	M, A, T	3D house models, area and volume simulations, local architectural animations
Cartesian Coordinates: Locating Baduy Natural Resources	Flexibility, Elaboration	M, S, T	Interactive coordinate maps, position and distance exercises, and digital mapping tools
Final Project: Designing a Simple Traditional Weather Monitoring Tool	Elaboration, Originality, Flexibility	S, T, E, M	Digital weather tool simulations, local rainfall observation videos, and an LMS for experiment documentation

Note: M = Mathematics (concepts and calculations); T = Technology (digital tools, calculators, LMS, simulations); S = Science (observation and real experiments); E = Engineering (design of simple technological solutions).

To strengthen the integration of mathematical concepts and STEM principles in real-world contexts, the final project was designed to address the needs of the local community, specifically farmers in the Baduy region who face difficulties in predicting weather patterns for subsistence farming. This project challenges students to design and implement a simple weather data collection tool using an engineering-for-social-context approach, fully incorporating Science, Technology, Engineering, and Mathematics (STEM) components. Unlike conventional experiment-based methods, this project emphasizes problem-based learning, focusing on designing practical solutions for local environmental issues. The project follows six structured stages (see Table 7) aimed at fostering creative thinking skills, elaboration, originality, flexibility, fluency, as well as developing students' social responsibility by designing solutions aligned with community needs. Learning activities are conducted both synchronously and asynchronously using an open-source LMS, supported by videos, simulations, and digital collaboration. Students are encouraged to design, build, and test prototypes of mini weather monitoring tools, present data through graphs, and provide interpretations relevant to local agricultural practices. This project not only integrates subjects such as Science, Mathematics, and ICT but also embodies the values of *Merdeka Belajar* and the *Pancasila Student Profile* by promoting exploration, independence, and social contribution. The detailed project stages are presented in Table 7.

Table 7. Final STEM Project Design: Simple Weather Data Collection Tool

STEM Phase	Task Description	Explanation	Guidelines	Duration
Asking Essential Questions	Identifying community problems and formulating research questions	Students explore farmers' needs (e.g., difficulties in predicting weather changes) and formulate a research question: "How can we measure and predict weather simply?"	Use local farmer interview videos, LMS discussion forums, and inquiry guides based on community needs.	2 lessons @ 50 minutes (synchronous)
Designing a Prototype Tool	Designing a simple weather monitoring tool	Students discuss and design a tool by selecting the type of weather data to collect (temperature, humidity, rainfall) and determining methods for data visualization and documentation.	Provide sensor tutorial videos, weather instrument simulations, and digital design templates via LMS. Emphasize measurement principles and interdisciplinary STEM connections.	3 lessons @ 50 minutes (synchronous & asynchronous)
Scheduling and Task Division	Project management within teams	Students create a project work plan, assign roles (designer, data recorder, analyst), and establish activity flow and data collection schedules.	Utilize LMS planner templates, teamwork rubrics, and collaborative forum discussions. Encourage accountability among team members.	1 lesson @ 50 minutes (synchronous)
Building and Testing the Tool	Construction and testing of a mini weather monitoring tool	Students build a simple tool (e.g., a manual ombrometer), record daily data for five days, and compare their results with simulation or digital weather forecasts.	Use data recording sheets, simple data loggers, and LMS platforms to compare actual data with simulations (e.g., online BMKG forecasts).	4 lessons @ 50 minutes (asynchronous)
Analyzing and Presenting Data	Data interpretation and visualization	Collected data is analyzed using graphs and narratives. Students connect findings to local agricultural phenomena and practical implications.	Provide digital table templates, Google Sheets spreadsheets, and trend analysis rubrics. Encourage discussions linking data insights to real-life farming challenges.	2 lessons @ 50 minutes (synchronous)
Reflection and Presentation	Delivering project outcomes and self-evaluation	Students prepare reports, create digital presentations, and reflect on their learning experience and encountered technical challenges.	Use LMS video recorders for documentation, presentation rubrics, and Zoom/Google Meet for project exposure sessions with classmates and mentors.	2 lessons @ 50 minutes (synchronous)

Phase 1: Facilitating Meaningful Questions in a Local STEM Context

This phase aims to foster students' scientific curiosity and divergent thinking through a community-based problem-based learning approach centered on real issues faced by Baduy farmers, such as planting season uncertainty and extreme weather conditions. Students are encouraged to explore these problems through contextual videos and guided discussions, with the teacher acting as a learning coach who connects scientific concepts with local wisdom. Through this process, students formulate exploratory questions to design simple, locally sourced weather prediction tools. The success of this phase is evaluated using an exploratory question rubric that assesses relevance to applied science, originality, and the feasibility of tool development, in order to build cross-disciplinary understanding rooted in the local context. Examples of the exploratory questions formulated by students include: "How can we create a simple yet accurate tool for predicting weather for farmers?" and "Is it possible to build a temperature and humidity measuring device using local materials?"

Figure 2. Learning Coach

Figure 3. Students Conducting Literature Review

Phase 2. Designing the Prototype

In this phase, students, teachers, and local farmer groups collaboratively designed a simple climate monitoring prototype based on the Internet of Things (IoT) to assist Baduy farmers in adapting to shifting planting patterns caused by climate change. The students developed a data logger using temperature (DHT11), humidity, and rainfall (rain gauge) sensors integrated with Arduino, which was tested for seven days to record environmental data. The prototype was then upgraded into a Raspberry Pi-based system, enabling real-time weather data monitoring and visualization through a Python GUI interface, with data stored in CSV format on a local server without requiring an internet connection (see Figure 4).

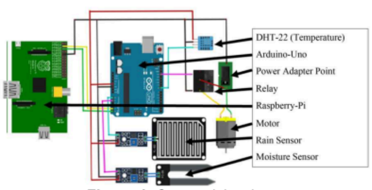

Figure 4. Connectivity view.

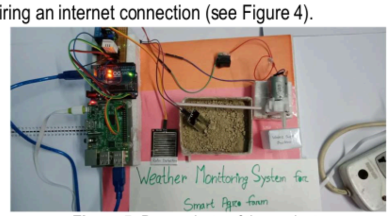

Figure 5. Demo photo of the project

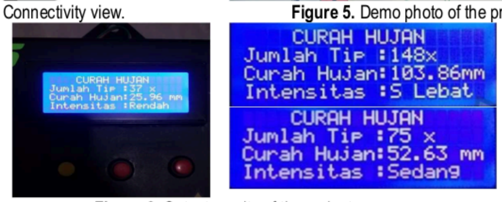

Figure 6. Output results of the project

Stage 3: Project Scheduling

In a 50-minute synchronous learning session, students are guided to develop a structured project work plan and distribute roles based on each team member's competencies and interests. They utilize digital tools such as the local LMS, Google Calendar (for structured physical scheduling), and online discussion platforms like WhatsApp or LMS forums. The success of this stage is evaluated using three main instruments: (1) a Project Planning Rubric developed based on indicators of time management effectiveness and role distribution; (2) an Activity Log Tracker that automatically monitors individual digital contributions via the LMS; and (3) a Team Reflection Sheet, designed following the Pancasila Student Profile reflection guidelines issued by the Indonesian Ministry of Education and Culture. System Usage Procedure by Indigenous Farmers: 1) The system automatically activates at 5:00 AM and 4:00 PM to collect data; 2) Sensors detect temperature, humidity, and rainfall levels; 3) Raspberry Pi stores and processes data into daily graphical visualizations (simple icons: hot, humid, heavy rain); 4) Farmers read a small LCD screen displaying weather status and simple warnings ("Planting delayed," "Heavy rain alert"); and 5) Training is provided by students and teachers to explain how to interpret weather patterns and their impact on the local rice cultivation cycle.

Stage 4: Project Monitoring and Evaluation

This stage ensures the technical quality and learning impact of the student-constructed weather monitoring device. Teachers and students serve as evaluators using rubrics based on design originality, measurement accuracy, scientific validity, and local contextual relevance. A five-day field test compares the device's readings with official data from the Meteorology, Climatology, and Geophysics Agency (BMKG) to assess validity and reliability. Evaluation results are then used as the basis for design improvement, facilitated by mentors.

Stage 5: Data Analysis and Dissemination

After five days of weather data collection, students process the observations using spreadsheets to visualize trends in temperature, humidity, and rainfall. This activity enhances data literacy and contextual understanding through a STEM-based scientific inquiry approach. Students formulate simple hypotheses on the impact of weather conditions on agriculture and engage in reflective discussions under teacher guidance. This phase contributes to strengthening community scientific literacy and adaptive resilience to local climate change. A key activity is stimulating students to develop and test hypotheses regarding the effects of weather patterns on planting cycles, soil fertility, and crop yields. Teachers facilitate reflective discussions using analytical questions such as: "How can this data help farmers make planting decisions?" or "What are the limitations of this data for short-term predictions?" The processed data is presented in simple infographics designed to be easily understood by community members with limited educational backgrounds. These infographics are then presented by students in small video forums uploaded to the LMS.

Effectiveness of STEM-DLS

After completing all stages of development and implementation, the next step was to evaluate the effectiveness of the STEM-DLS using a quasi-experimental design at the field level. Based on the results of the independent sample t-test presented in Table 8, a significant difference was found in creative thinking abilities between students in the experimental and control groups, indicating a moderate to large practical effect. These findings confirm that the STEM-DLS learning model is demonstrably more effective than conventional approaches in stimulating creative thinking, particularly through the integration of visual exploration, contextual projects, and digital scaffolding.

Table 8. Autonomy Levels and Creative Thinking Before and After in the Control Class.

Autonomy Level	Indicators	Boys			Girls		
	Autonomy	Before	After	$t_{emp.}$	Before	After	$t_{emp.}$
High	Self-initiation	4.111	4.455	2.533	4.022	4.388	2.402
	Goal orientation	4.233	4.600	2.642	4.100	4.478	2.318
	Persistence	3.988	4.300	2.200	3.877	4.188	2.011
	Responsibility	4.211	4.622	2.881	4.078	4.500	2.540
	Decision-making	4.089	4.500	2.700	3.955	4.388	2.380
Moderate	Self-initiation	3.788	4.100	2.200	3.689	4.022	2.089
	Goal orientation	3.955	4.344	2.478	3.822	4.256	2.204
	Persistence	3.700	4.044	2.100	3.566	3.900	1.922
	Responsibility	3.800	4.222	2.820	3.755	4.211	2.322
	Decision-making	3.789	4.178	2.511	3.688	4.089	2.144
Low	Self-initiation	3.411	3.800	2.000	3.388	3.700	1.901
	Goal orientation	3.544	3.900	2.211	3.422	3.833	2.100
	Persistence	3.422	3.700	1.889	3.311	3.600	1.800
	Responsibility	3.655	3.978	2.000	3.588	3.911	2.045
	Decision-making	3.611	3.944	2.022	3.489	3.822	2.033
Creative Thinking Level	**Indicators Thinking Level**	**Boys**			**Girls**		
		Before	**After**	$t_{emp.}$	**Before**	**After**	$t_{emp.}$
High	Fluency	1.322	1.544	2.111	1.200	1.422	2.015
	Flexibility	0.722	0.933	2.066	0.855	1.066	2.100
	Originality	2.100	2.400	2.220	2.566	2.822	1.966
	Elaboration	1.366	1.622	2.144	2.200	2.466	2.111
	Connection-making	1.533	1.789	2.089	1.644	1.922	2.022
Moderate	Fluency	1.078	1.300	2.010	0.988	1.200	1.885
	Flexibility	0.633	0.844	2.033	0.744	0.955	2.044
	Originality	1.855	2.122	2.150	2.422	2.655	1.933
	Elaboration	1.200	1.456	2.244	2.100	2.356	2.088
	Connection-making	1.444	1.678	2.033	1.522	1.744	2.011
Low	Fluency	0.889	1.066	2.089	0.855	1.044	2.012
	Flexibility	0.422	0.633	2.066	0.622	0.811	2.000
	Originality	1.433	1.678	2.033	2.211	2.433	1.889
	Elaboration	1.000	1.211	2.011	1.944	2.177	2.022
	Connection-making	1.233	1.455	2.077	1.311	1.522	1.955

Table 9. Autonomy Levels and Creative Thinking Before and After in the Experimental Class.

Autonomy Level	Indicators	Boys			Girls		
	Autonomy	Before	After	$t_{emp.}$	Before	After	$t_{emp.}$
High	Self-initiation	4.133	4.722	3.122	4.089	4.678	3.055
	Goal orientation	4.200	4.789	3.300	4.122	4.733	3.188
	Persistence	4.011	4.611	3.122	3.911	4.500	3.044
	Responsibility	4.255	4.855	3.233	4.144	4.755	3.211
	Decision-making	4.144	4.800	3.344	4.022	4.688	3.278
Moderate	Self-initiation	3.822	4.444	3.144	3.722	4.366	3.100
	Goal orientation	3.977	4.600	3.266	3.855	4.544	3.189
	Persistence	3.755	4.333	3.000	3.622	4.255	2.944
	Responsibility	3.866	4.522	3.144	3.811	4.466	3.111
	Decision-making	3.833	4.478	3.188	3.755	4.400	3.077
Low	Self-initiation	3.433	4.011	2.933	3.400	3.977	2.855
	Goal orientation	3.577	4.144	2.988	3.444	4.111	2.911
	Persistence	3.433	4.000	2.800	3.322	3.911	2.733

Autonomy Level	Indicators Autonomy	Boys Before	After	$t_{emp.}$	Girls Before	After	$t_{emp.}$
	Responsibility	3.688	4.244	2.944	3.622	4.200	2.866
	Decision-making	3.633	4.222	3.022	3.511	4.122	2.900
Creative Thinking Level	**Indicators Thinking Level**	**Boys Before**	**After**	$t_{emp.}$	**Girls Before**	**After**	$t_{emp.}$
High	Fluency	1.344	1.700	2.455	1.244	1.644	2.333
	Flexibility	0.755	1.144	2.566	0.900	1.300	2.488
	Originality	2.188	2.722	2.611	2.633	3.044	2.444
	Elaboration	1.411	1.877	2.488	2.255	2.733	2.600
	Connection-making	1.577	2.033	2.533	1.677	2.100	2.511
Moderate	Fluency	1.100	1.544	2.366	1.000	1.466	2.233
	Flexibility	0.655	1.044	2.500	0.766	1.144	2.411
	Originality	1.900	2.433	2.577	2.466	2.977	2.388
	Elaboration	1.222	1.700	2.611	2.144	2.677	2.544
	Connection-making	1.488	1.933	2.544	1.555	2.000	2.466
Low	Fluency	0.911	1.366	2.433	0.877	1.322	2.355
	Flexibility	0.444	0.877	2.488	0.655	1.044	2.344
	Originality	1.477	2.011	2.611	2.233	2.744	2.477
	Elaboration	1.033	1.511	2.555	2.000	2.511	2.500
	Connection-making	1.266	1.755	2.500	1.344	1.833	2.455

The results indicate that the STEM-DLS intervention contributed positively to enhancing students' learning autonomy and creative thinking skills compared to the control class. To assess the extent of this learning model's impact on students' cognitive achievements, a comparative analysis of pretest, posttest, and N-Gain scores in mathematical creative thinking was conducted, as presented in Table 10.

Table 10. Mean Scores of Pretest, Posttest, and N-Gain in Mathematical Creative Thinking Ability

Group	N	Pretest Mean	Posttest Mean	N-Gain (⟨g⟩)	Effectiveness Interpretation
Experimental (STEM-DLS)	60	53.12	75.46	0.554	Moderate (Effective)
Control (Conventional)	60	52.78	63.29	0.223	Low (Less Effective)
Difference	—	—	+12.17	+0.331	—

The difference in N-Gain scores between the experimental and control groups indicates that the implementation of STEM-DLS was more effective in improving students' mathematical creative thinking abilities. To further examine the interaction effect between the learning model and students' autonomy levels, a Two-Way ANOVA was conducted, with the results shown in Table 11.

Table 11. Two-Way ANOVA (Autonomy Level × Learning Model)

Source	Sum of Squares	df	Mean Square	F	Significance
Corrected Model	2.450	5	0.490	37.690	0.000
Intercept	40.320	1	40.320	3102.31	0.000
Autonomy Level	1.750	2	0.875	67.310	0.000
Learning Model	0.580	1	0.580	44.620	0.000
Autonomy Level * Learning Model	0.120	2	0.060	4.620	0.012
Error	1.500	114	0.013		
Total	44.270	120			
Corrected Total	3.950	119			

The Two-Way ANOVA results reveal a significant interaction between students' autonomy levels and the learning model on their autonomy scores. To identify which groups differed significantly, a post hoc Tukey HSD test was performed, as presented in Table 12.

Table 12. Tukey HSD Test – Learning Autonomy Level

(I) Autonomy Level	(J) Autonomy Level	Mean Difference (I-J)	Std. Error	Sig. (p)	Academic Interpretation
Low	Moderate	-0.348*	0.033	0.000	Significant: Low < Moderate
Low	High	-0.601*	0.033	0.000	Significant: Low < High
Moderate	High	-0.253*	0.033	0.000	Significant: Moderate < High

The Tukey HSD test confirms that higher levels of learning autonomy correspond to higher learning achievements, particularly when applying the STEM-DLS model. These findings highlight the critical role of students' autonomy readiness in maximizing the effectiveness of STEM-based instruction. To complement these findings, the next analysis focuses on the interaction between creative thinking ability levels and the learning model (see Table 13).

Table 13. Two-Way ANOVA (Creative Thinking Level × Learning Model)

Source	Sum of Squares	df	Mean Square	F	Significance
Corrected Model	2.750	5	0.550	26.190	0.000
Intercept	51.200	1	51.200	2438.10	0.000
Creative Thinking Level	2.100	2	1.050	50.000	0.000
Learning Model	0.460	1	0.460	21.905	0.000
Creative Thinking × Learning Model	0.190	2	0.095	4.524	0.013
Error	2.400	114	0.021		
Total	56.350	120			
Corrected Total	5.150	119			

The results of the Two-Way ANOVA test revealed a significant interaction between students' levels of creative thinking ability and the learning model employed. These findings indicate that the impact of the STEM-DLS model varies across different categories of students' creative thinking skills. To determine the specific differences between groups, a post-hoc Tukey HSD test was conducted, as presented in Table 14.

Table 14. Tukey HSD Test on Creative Thinking

(I) Creative Thinking Level	(J) Creative Thinking Level	Mean Difference (I-J)	Standard Error	Sign. (p)	Academic Interpretation
Low	Moderate	-0.175	0.028	0.000	Significant: Low < Moderate
	High	-0.279	0.028	0.000	Significant: Low < High
Moderate	Low	0.175	0.028	0.000	Significant: Moderate > Low
	High	-0.104	0.028	0.001	Significant: Moderate < High
High	Low	0.279	0.028	0.000	Significant: High > Low
	Moderate	0.104	0.028	0.001	Significant: High > Moderate

The results of the Tukey HSD test confirmed significant differences in creative thinking abilities among the three levels of creativity. Students in the high creativity group demonstrated substantially higher performance compared to those in the moderate and low creativity groups. These findings provide a critical basis for supporting the dissemination and broader replication of the STEM-DLS model as outlined in the subsequent phase. The fourth phase of this study focused on a structured dissemination strategy to expand the impact of the STEM-DLS innovation adaptively and sustainably. This strategy encompassed four main pillars: academic legitimacy, independent replication, intellectual property rights legalization, and the activation of learning communities. First, scientific articles related to the conceptual framework and design of STEM-DLS were submitted as a means of academic validation and outreach.

Second, a national training program involving 42 teachers from various regions of Lebak and Pandeglang resulted in a replication readiness rate of 78.6%, with two non-research schools beginning to implement portions of the modules. The effectiveness of dissemination was evaluated through three key indicators: (1) adoption by six non-research subject teachers, supported by lesson plans and video documentation; (2) the establishment of an independent Teacher Learning Community with a monthly reflection agenda; and (3) transformation of instructional practices as evidenced by project portfolios and increased use of interdisciplinary interactive digital media. These findings suggest that an adaptive, data-driven dissemination strategy can lay the groundwork for a participatory, contextual, and potentially nationwide replicable digital learning ecosystem.

Discussion

The development of the STEM-Based Digital Learning Space (DLS) successfully addressed the limitations of conventional LMS platforms in partner schools, particularly in terms of flexibility, visualization, and student empowerment. Figure 7 illustrates one of the STEM-DLS products, which was designed based on local needs through a participatory front-end analysis involving teachers and students, in line with the concept of a collaborative digital ecosystem.

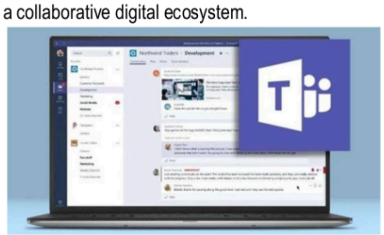

Figure 7 presents the online STEM-DLS platform, which can be accessed at https://kalana.my.id.

The project-based STEM learning stages were applied to foster students' creative mathematical thinking skills, starting from the *Essential Question* phase, which enhances fluency and flexibility, to the *Design a Plan* phase, which develops originality and elaboration, and the *Schedule & Monitor* phase, which promotes autonomous learning and independent project management. In the *Assess the Outcome* phase, students sharpen their data literacy skills through experimental result analysis and theoretical reflection. Initial implementation demonstrated a significant increase in student participation and improvement in creative mathematical thinking skills, as measured by various TTCT indicators. These findings align with the main objective of this study, which was to develop an effective STEM-DLS model for enhancing students' mathematical creativity and autonomous learning.

The STEM-DLS innovation developed in this study successfully addressed the shortcomings of conventional LMS platforms in supporting contextual and collaborative learning (Nurintya & Agoestanto, 2022). The DLS features innovative elements such as STEM project videos, a shared practice space, and interactive discussions, enabling teachers and students from various regions to access and replicate this learning model. Validation results in terms of practicality, validity, and effectiveness indicate that the DLS significantly enhances learning quality, student engagement, and teacher creativity. Its key strengths include easy web access, a user-friendly interface, contextual STEM content integration, and interactive quizzes with automated feedback. These findings are consistent with those of Lin et al. (2017) and Yuliardi et al. (2024), who emphasized the effectiveness of DLS in promoting interaction and learning outcomes. However, as noted by Saputro & Tri. (2019), the success of DLS also depends on teacher readiness, the enhancement of digital literacy, and the reinforcement of interactive pedagogy. Therefore, the DLS implementation was accompanied by intensive training and the development of teacher communities of practice to ensure sustainable, transformative impact.

This study reinforces the theoretical framework of STEM integration through digital technology by developing an adaptive and contextual Digital Learning Space (DLS) model. This DLS innovation broadens the STEM learning framework by emphasizing the integration of science, technology, creativity development, digital literacy, and autonomous learning. The DLS prototype is flexible and can be replicated by teachers through a co-design approach to support project-based learning models. Practically, the DLS provides tangible benefits for teachers by offering an open, modular, and collaborative digital learning platform, supported by teacher training and learning communities for broader regional replication. For policymakers, these findings serve as a valuable reference for accelerating digital transformation in education, aligned with the Merdeka Belajar policy and SDG Goal 4 on quality education. The study's limitations lie in the relatively small sample size (N = 120) and limited geographical representation, restricting the generalizability of the findings. Future research is recommended to involve more diverse samples across educational levels and regions and to test the effectiveness of the DLS model in various STEM project contexts. Infrastructure limitations and unequal internet access also present challenges that require policy support in the form of minimum technology provision in schools and teacher training to optimize the use of DLS as a sustainable digital learning ecosystem.

CONCLUSION

The development of the STEM-Based Digital Learning Space (STEM-DLS) using the 4D model has successfully addressed the need for adaptive digital learning media to overcome the limitations of conventional LMS platforms in fostering student autonomy and creative learning. The DLS has been proven valid, practical, and effective in enhancing students' self-directed learning and creative mathematical thinking through the integration of contextual learning principles, STEM syntax, and interactive digital features. Effectiveness testing revealed that the DLS promotes active student engagement, strengthens digital literacy, and facilitates collaboration among educational stakeholders. With its accessibility and flexibility, the DLS holds strong potential for widespread adoption to support the development of an inclusive and sustainable digital learning ecosystem, aligned with the 'Merdeka Belajar' educational policy.

Acknowledgments

This research was funded by the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the Beginner Lecturer Research Grant (Hibah Penelitian Dosen Pemula), fiscal year 2025, under contract number 8031/LL4/PG/2025, 29/E-5/UNILAM/2025. The authors gratefully acknowledge this support. The authors also extend their sincere appreciation to the school principals, mathematics teachers, and students in Kabupaten Lebak, Banten, for their enthusiastic participation and invaluable contributions during the implementation of the STEM-based Digital Learning Space. Special thanks are due to the academic advisors and technical team for their constructive feedback throughout the development and trial phases of this study.

Declarations

Author Contribution : DYA: Conceptualization, Writing - Original Draft, Editing, Visualization, and Methodology; EAJ: Writing - Review & Editing, Formal analysis, and Supervision.

Funding Statement : This research was funded by the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia.

Conflict of Interest : The authors declare no conflict of interest.

Additional Information : Additional information is available for this paper.

REFERENCES

Aini, I. N., Zulkardi, Putri, R. I. I., & Yaniawati, P. (2022). Developing PISA-like math problems in the content of space and shape through the context of historical buildings. *Journal on Mathematics Education*, *13*(4), 723–738. https://doi.org/10.22342/jme.v13i4.pp723-738

Akhmetova, A. I., Sovetkanova, D. M., Komekbayeva, L. K., Abdrakhmanov, A. E., Yessenuly, D., & Serikova, O. S. (2025). A systematic review of artificial intelligence in high school STEM education research. *Eurasia Journal of Mathematics, Science and Technology Education, 21*(4), em2623. https://doi.org/10.29333/ejmste/16222

Alabbasi, A. M. A., Paek, S. H., Kim, D., & Cramond, B. (2022). What do educators need to know about the Torrance Tests of Creative Thinking: A comprehensive review. *Frontiers in Psychology, 13*, 1000385. https://doi.org/10.3389/fpsyg.2022.1000385

Al-Said, K., Krapotkina, I., Gazizova, F. *et al.* (2023). Distance learning: studying the efficiency of implementing flipped classroom technology in the educational system. *Educ Inf Technol* **28**, 13689–13712. https://doi.org/10.1007/s10639-023-11711-x

Athaya, H., Nadir, R. D. A., Sensuse, D. I., Kautsarina, K., & Suryono, R. R. (2021). Moodle Implementation for E-Learning: A Systematic Review. In *Proceedings of 2021 International Conference on Sustainable Information Engineering and Technology, SIET 2021* (pp. 106-112). (ACM International Conference Proceeding Series). Association for Computing Machinery. https://doi.org/10.1145/3479645.3479646

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cenka, B. A., Santoso, H. B., & Junus, K. (2022). Personal learning environment toward lifelong learning: an ontology-driven conceptual model. *Interactive Learning Environments*, *31*(10), 6445–6461. https://doi.org/10.1080/10494820.2022.2039947

Cheng, M.M.H. (2022). An Overview of STEM Education in Asia. In: Cheng, M.M.H., Buntting, C., Jones, A. (eds) Concepts and Practices of STEM Education in Asia. Springer, Singapore. https://doi.org/10.1007/978-981-19-2596-2_1

Cheon, S. H., Reeve, J., & Vansteenkiste, M. (2020). When teachers learn how to provide classroom structure in an autonomy-supportive way: Benefits to teachers and their students. *Teaching and Teacher Education, 90*, 103004. https://doi.org/10.1016/j.tate.2019.103004

Clark, A. E., Nong, H., Zhu, H., & Zhu, R. (2021). Compensating for academic loss: Online learning and student performance during the COVID-19 pandemic. *China Economic Review, 68*, 101629. https://doi.org/10.1016/j.chieco.2021.101629

Conde, M. Á., Rodríguez-Sedano, F. J., Fernández-Llamas, C., Gonçalves, J., Lima, J., & García-Peñalvo, F. J. (2021). Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review. *Computer Applications in Engineering Education, 29*(1), 46–65. https://doi.org/10.1002/cae.22354

Creswell, J.W. & Plano Clark, V.L. (2018). Designing and conducting mixed methods research. 3rd Edition. SAGE Publications, Inc.

de Vink, I. C., Willemsen, R. H., Keijzer, R., Lazonder, A. W., & Kroesbergen, E. H. (2023). Supporting creative problem solving in primary geometry education. *Thinking Skills and Creativity, 48*, 101307. https://doi.org/10.1016/j.tsc.2023.101307

Dignath, C., Veenman, M.V.J. (2021). The Role of Direct Strategy Instruction and Indirect Activation of Self-Regulated Learning: Evidence from Classroom Observation Studies. *Educ Psychol Rev* **33**, 489–533. https://doi.org/10.1007/s10648-020-09534-0

Dilekçi, A., & Karatay, H. (2023). The effects of the 21st-century skills curriculum on the development of students' creative thinking skills. *Thinking Skills and Creativity, 47*, 101229. https://doi.org/10.1016/j.tsc.2022.101229

Fisher, M., King, J., & Tague, G. (2001). Development of a self-directed learning readiness scale for nursing education. *Nurse education today*, *21*(7), 516–525. https://doi.org/10.1054/nedt.2001.0589

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st Century Skills Frameworks: Systematic Review. *Sustainability*, *14*(3), 1493. https://doi.org/10.3390/su14031493

Gu, X., Tong, D., Shi, P., Zou, Y., Yuan, H., Chen, C., & Zhao, G. (2023). Incorporating STEAM activities into creativity training in higher education. *Thinking Skills and Creativity, 50*, 101395. https://doi.org/10.1016/j.tsc.2023.101395

Gumbi, N., Gumbi, L., & Twinomurinzi, H. (2023). Towards Sustainable Digital Agriculture for Smallholder Farmers: A Systematic Literature Review. *Sustainability*, *15*(16), 12530. https://doi.org/10.3390/su151612530

Ha, C. T., Thao, T. T. P., Trung, N. T., Huong, L. T. T., Dinh, N. V., & Trung, T. (2020). A Bibliometric Review of Research on STEM Education in ASEAN: Science Mapping the Literature in Scopus Database, 2000 to 2019. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(10), em1889. https://doi.org/10.29333/ejmste/8500

Hallström, J., & Ankiewicz, P. (2023). Design as the basis for integrated STEM education: A philosophical framework. *Frontiers in Education, 8*, Article 1078313. https://doi.org/10.3389/feduc.2023.1078313

Hjelte, A., Schindler, M., & Nilsson, P. (2020). Kinds of Mathematical Reasoning Addressed in Empirical Research in Mathematics Education: A Systematic Review. *Education Sciences*, *10*(10), 289. https://doi.org/10.3390/educsci10100289

Hughes, J. M., & Morrison, L. J. (2020). Innovative learning spaces in the making. *Frontiers in Education, 5*, Article 89. https://doi.org/10.3389/feduc.2020.00089

Jasiah, J., Mazrur, M., Hartati, Z., Rahman, A., Kibtiyah, M., Liadi, F., & Fahmi, F. (2024). Islamic teachers' implementation of the Merdeka Curriculum in senior high schools: A systematic review.

International Journal of Learning, Teaching and Educational Research, 23(4), 375–392. https://doi.org/10.26803/ijlter.23.4.21

Johnston, K., Kervin, L., & Wyeth, P. (2022). STEM, STEAM and Makerspaces in Early Childhood: A Scoping Review. *Sustainability*, *14*(20), 13533. https://doi.org/10.3390/su142013533

Joklitschke, J., Rott, B. & Schindler, M. (2022). Notions of Creativity in Mathematics Education Research: a Systematic Literature Review. *Int J of Sci and Math Educ* **20**, 1161–1181. https://doi.org/10.1007/s10763-021-10192-z

Junaedi, Y., Wahyudin, & Juandi, D. (2021). Mathematical creative thinking ability of junior high school students on polyhedron. *Journal of Physics: Conference Series, 1806*, 012069. https://doi.org/10.1088/1742-6596/1806/1/012069

Li, M., & Yu, Z. (2022). Teachers' Satisfaction, Role, and Digital Literacy during the COVID-19 Pandemic. *Sustainability*, *14*(3), 1121. https://doi.org/10.3390/su14031121

Lin, M.-H., Chen, H.-C., & Liu, K.-S. (2017). A Study of the Effects of Digital Learning on Learning Motivation and Learning Outcome. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(7), 3553-3564. https://doi.org/10.12973/eurasia.2017.00744a

Maranna, S., Willison, J., Joksimovic, S., Parange, N., & Costabile, M. (2022). Factors that influence cognitive presence: A scoping review. *Australasian Journal of Educational Technology*, *38*(4), 95–111. https://doi.org/10.14742/ajet.7878

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799–822. https://doi.org/10.1002/sce.21522

McGuire, L. E., & Lay, K. A. (2019). Reflective Pedagogy for Social Work Education: Integrating Classroom and Field for Competency-Based Education. *Journal of Social Work Education*, *56*(3), 519–532. https://doi.org/10.1080/10437797.2019.1661898

Networked Learning Editorial Collective (NLEC)., Gourlay, L., Rodríguez-Illera, J.L. *et al.* (2021). Networked Learning in 2021: A Community Definition. *Postdigit Sci Educ* **3**, 326–369. https://doi.org/10.1007/s42438-021-00222-y

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM Education in Secondary Schools: Teachers' Perspective towards Sustainable Development. *Sustainability*, *12*(21), 8865. https://doi.org/10.3390/su12218865

Nugraha, M. G., Kidman, G., & Tan, H. (2023). Pre-service teacher in STEM education: An integrative review and mapping of the Indonesian research literature. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(5), em2262. https://doi.org/10.29333/ejmste/13155

Nurintya, F., & Agoestanto, A. (2022). Development of STEM-Based Learning Tools to Increase Students' Mathematical Creative Thinking Ability through Inquiry Learning. *Unnes Journal of Mathematics Education*, *11*(1), 21-30. https://doi.org/10.15294/ujme.v11i1.55842

OECD. (2023). *PISA 2022 Results (Volume I): The State of Learning and Equity in Education.* OECD Publishing. https://doi.org/10.1787/53f23881-en

Prahmana, R. C. I., Sagita, L., Hidayat, W., & Utami, N. W. (2020). Two decades of realistic mathematics education research in Indonesia: A survey. *Infinity*, *9*(2), 223–246. https://doi.org/10.22460/infinity.v9i2.p223-246

Purwaningsih, E., Sari, A. M., Yuliati, L., Masjkur, K., Kurniawan, B. R., & Zahiri, M. A. (2020). Improving the problem-solving skills through the development of teaching materials with STEM-PjBL (science, technology, engineering, and mathematics-project-based learning) model integrated with

TPACK (technological pedagogical content knowledge). *Journal of Physics: Conference Series, 1481*(1), 012133. https://doi.org/10.1088/1742-

Rawal, D. M. (2024). Mapping of school teachers' digital competency in the context of digital infrastructure: A systematic review and empirical study of India. *Journal of Professional Capital and Community, 9*(3), 173–195. https://doi.org/10.1108/JPCC-01-2024-0016

Røe, Y., Wojniusz, S., & Bjerke, A. H. (2022). The digital transformation of higher education teaching: Four pedagogical prescriptions to move active learning pedagogy forward. *Frontiers in Education, 6*, 784701. https://doi.org/10.3389/feduc.2021.784701

Roman, T.A. (2022). Review of *Merging the Instructional Design Process with Learner-Centered Theory: The Holistic 4D Model* by Charles M. Reigeluth and Yunjo An. *TechTrends* **66**, 560–562. https://doi.org/10.1007/s11528-022-00723-y

Romijn, B. R., Slot, P. L., & Leseman, P. P. M. (2021). Increasing teachers' intercultural competences in teacher preparation programs and through professional development: A review. *Teaching and Teacher Education, 98*, 103236. https://doi.org/10.1016/j.tate.2020.103236

Rosengren, S., Eisend, M., Koslow, S., & Dahlen, M. (2020). A Meta-Analysis of When and How Advertising Creativity Works. *Journal of Marketing*, *84*(6), 39-56. https://doi.org/10.1177/0022242920929288 (Original work published 2020)

Samane-Cutipa, V. A., Quispe-Quispe, A. M., Talavera-Mendoza, F., & Limaymanta, C. H. (2022). Digital gaps influencing the online learning of rural students in secondary education: A systematic review. *International Journal of Information and Education Technology, 12*(7), 685–690. https://doi.org/10.18178/ijiet.2022.12.7.1671

Saputro, B., & Tri Susilowati, A. (2019). Effectiveness of Learning Management System (LMS) On In-Network Learning System (SPADA) Based on Scientific. Journal for the Education of Gifted Young Scientists, 7(3), 481-498. https://doi.org/10.17478/jegys.606029

Setiawati, E. P., & Agoestanto, A. (2023). Development of Problem-Based Learning Mathematical Module with STEM Approach to Improve Problem-Solving Ability and Self-Efficacy. *Unnes Journal of Mathematics Education*, *12*(1), 60-71. https://doi.org/10.15294/ujme.v12i1.68716

Shuib, T. R., Husin, M. R., Ghazali, N. H. C. M., & Othman, M. S. (2021). The effect of logical thinking on students' higher-order thinking skills. *International Journal of Academic Research in Business and Social Sciences, 10*(2), 1044–1050. https://doi.org/10.6007/IJARPED/v10-i2/10594

Sosa Díaz, M. J., Guerra Antequera, J., & Cerezo Pizarro, M. (2021). Flipped Classroom in the Context of Higher Education: Learning, Satisfaction and Interaction. *Education Sciences*, *11*(8), 416. https://doi.org/10.3390/educsci11080416

Stoyanov, S., Glushkova, T., Tabakova-Komsalova, V., Stoyanova-Doycheva, A., Ivanova, V., & Doukovska, L. (2022). Integration of STEM Centers in a Virtual Education Space. *Mathematics*, *10*(5), 744. https://doi.org/10.3390/math10050744

Suherman, S., & Vidákovich, T. (2022). Assessment of mathematical creative thinking: A systematic review. *Thinking Skills and Creativity, 44*, 101019. https://doi.org/10.1016/j.tsc.2022.101019

Sun, J. C.-Y., Liu, Y., Lin, X., & Hu, X. (2023). Temporal learning analytics to explore traces of self-regulated learning behaviors and their associations with learning performance, cognitive load, and student engagement in an asynchronous online course. *Frontiers in Psychology, 13*, 1096337. https://doi.org/10.3389/fpsyg.2022.1096337

Szabo, Z. K., Körtesi, P., Guncaga, J., Szabo, D., & Neag, R. (2020). Examples of Problem-Solving Strategies in Mathematics Education Supporting the Sustainability of 21st-Century Skills. *Sustainability*, *12*(23), 10113. https://doi.org/10.3390/su122310113

Tanujaya, B., Prahmana, R. C. I., & Mumu, J. (2021). Mathematics instruction to promote mathematics higher-order thinking skills of students in Indonesia: Moving forward. *TEM Journal*, *10*(4), 1945–1954. https://doi.org/10.18421/TEM104-60

Torrance, E. P. (1974). *The Torrance Tests of Creative Thinking: Norms-Technical Manual.* Princeton, NJ: Personal Press.

Tramonti, M., Dochshanov, A. M., Fiadotau, M., Grönlund, M., Callaghan, P., Ailincai, A., Marini, B., Joenvaara, S., Maurer, L., & Delle Donne, E. (2024). Game on for Climate Action: Big Game Delivers Engaging STEM Learning. *Education Sciences*, *14*(8), 893. https://doi.org/10.3390/educsci14080893

Tur, G., Castañeda, L., Torres-Kompen, R., & Carpenter, J. P. (2022). A literature review on self-regulated learning and personal learning environments: features of a close relationship. *Interactive Learning Environments*, *32*(4), 1402–1421. https://doi.org/10.1080/10494820.2022.2121726

Wan, Z. H., Jiang, Y., & Zhan, Y. (2020). STEM Education in Early Childhood: A Review of Empirical Studies. *Early Education and Development*, *32*(7), 940–962. https://doi.org/10.1080/10409289.2020.1814986

Yulianto, D., Umami, M. R., Anwar, S., Juniawan, E. A., & Junaedi, Y. (2024). The influence of project-based mathematics learning on 21st century skills (4Cs) considering students' learning styles and teachers' instructional methods. *AXIOM : Jurnal Pendidikan Dan Matematika*, *13*(2), 153. https://doi.org/10.30821/axiom.v13i2.19787

Yulianto, D., Umami, M., Junaedi, Y., & Anwar, S. (2024). Analysis of Mathematical Literacy among Junior High School Students in Lebak-Banten Regency: A Case Study of PISA-Type Questions Considering Accreditation, School Status, Skill Levels, and Gender. *PAKAR Pendidikan*, *22*(1), 203-232. https://doi.org/10.24036/pakar.v22i1.509

Yuliardi, R., Kusumah, Y. S., Nurjanah, Juandi, D., & Suparman (2024). Development of a STEM-based digital learning space platform to enhance students' mathematical creativity in future learning classrooms. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(12), em2545. https://doi.org/10.29333/ejmste/15665

Zhou, Y., Ning, Y., Chen, J., Zhang, W., & Wijaya, T. T. (2024). Development and validation of the Mathematical Higher-Order Thinking Scale for high school students. *Psychology in the Schools, 61*(8), 31603192. https://doi.org/10.1002/pits.23213

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