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MathSTEAM Space: A Design-Based Digital Learning Ecosystem Bridging Contextual Mathematics and STEAM Pedagogy in Junior Secondary Education

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Abstract. Despite growing calls for contextual mathematics learning and the integration of science, technology, engineering, arts and mathematics (STEAM) into mathematics learning, few digital platforms integrate contextual problem framing, project-based activity, formative feedback, and progress monitoring within a single pedagogically coherent environment. This gap is particularly acute in resource-constrained junior secondary settings. This study reports the design-based development of MathSTEAM Space, a web-based digital learning ecosystem that integrates contextual mathematics learning and STEAM pedagogy in Indonesian junior secondary education. The study was guided by a design-based research framework operationalized through an analysis, design, development, implementation, and evaluation (ADDIE) development cycle. Evidence was drawn from a needs analysis of 26 in-service mathematics teachers (analyzed via reflective thematic analysis of 104 open-response units and a Likert-type questionnaire), platform development documentation, and a proof-of-concept classroom trial with 80 seventh-grade students. Teachers identified digital worksheets, contextual project exemplars, scaffolded feedback, and learning-progress monitoring as priority needs. These needs were translated into a Laravel-MySQL ecosystem organized around the six-stage MathSTEAM cycle,

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which includes context, concept, conceptualize, create, confirm, and communicate. The system features role-based access, contextual modules, project submission, formative feedback, and comprehensive tracking for learning and activity progress. Teacher evaluations were consistently positive, with construct means ranging from 4.27 to 4.43 out of 5 and positive-response rates between 96.2% and 100%. In the classroom trial, 74 of 80 students (92.5%) logged in without major difficulty and 73 (91.2%) independently uploaded their mini projects. These findings suggest that MathSTEAM Space may function as a pedagogically structured ecosystem instead of a conventional content-delivery learning management system, thereby supporting contextual and project-based STEAM mathematics. The study contributes transferable, resource-aware design principles derived from the first design-based research cycle. These guidelines may support the development of similar pedagogically coherent ecosystems in other resource-constrained junior secondary contexts, although broader longitudinal studies are warranted to examine learning effectiveness and scalability at scale.

Keywords: Contextual mathematics learning; steam education; design-based research; ADDIE model; digital learning ecosystem; Indonesia; education quality; educational environment

1. Introduction

Mathematics education is increasingly expected to help students interpret, model, and solve problems embedded in complex social, technological, and environmental contexts. However, in many junior secondary classrooms, mathematics is still experienced as a sequence of abstract procedures rather than as a meaningful way of reasoning about real-world phenomena. Contextual mathematics learning has consequently emerged as an important orientation, because it connects mathematical concepts with situations that are familiar, useful, and cognitively meaningful for learners. A growing body of evidence indicates that contextual teaching and learning supports students' interest, conceptual understanding, mathematical literacy, and capacity to solve authentic problems (Afni & Hartono, 2020; Hendriyanto et al., 2023; Kolar & Hodnik, 2021; Muhaimin, Dasari, et al., 2025; Velani & Retnawati, 2020). A recent systematic review further confirms that contextual approaches improve mathematical achievement when they are implemented coherently, rather than as superficial real-world contextualization (Kusnirova et al., 2026).

In parallel, STEAM pedagogy has gained traction as a way to organize learning across science, technology, engineering, arts, and mathematics. STEAM is not merely a combination of subject labels; it requires students to explore problems, generate ideas, create products or representations, communicate solutions, and reflect on the usefulness of disciplinary knowledge. Systematic reviews and classroom studies emphasize that STEAM-oriented learning is promising for developing creativity, problem solving, collaboration, transferable skills, and engagement, particularly when it is supported by project-based and interdisciplinary tasks (Bertrand & Namukasa, 2020; Fitriana et al., 2023; García-Vandewalle García et al., 2023; Martín-Cudero et al., 2024; White & Delaney, 2021).

Despite this potential, integrating mathematics into STEAM remains difficult for teachers. The challenge is not simply to add technology or projects to a lesson, but to design a coherent learning sequence that maintains mathematical rigor while allowing students to investigate authentic problems. A particular challenge is that interdisciplinary STEAM projects can become predominately craft-like, or artistic activities that, while engaging, become detached from formal mathematical concepts and targeted learning objectives; in such cases, the mathematical content risks being treated as incidental, rather than central, to the inquiry, undermining the very purpose of embedding mathematics within contextual and creative tasks.

Teachers frequently require realistic project exemplars, structured learning activities, assessment support, and confidence in using digital tools. Studies of teachers' technology use in mathematics and STEAM education show that teachers' beliefs, digital self-efficacy, and access to relevant pedagogical support strongly shape the quality of technology integration (Hendriyanto et al., 2026; Lavicza et al., 2022; Muhaimin, Vrapı, et al., 2025; Pahmi & Supriyadi, 2026). A recent systematic review of digital technology in mathematics teaching design similarly concludes that technology yields learning value only when it is embedded in deliberate pedagogical design, rather than adopted as an isolated tool (Fitriana et al., 2025; Muhaimin et al., 2023).

Digital learning ecosystems offer one promising response to these challenges. Unlike a conventional learning management system (LMS) that mainly distributes content, a digital learning ecosystem connects learners, teachers, content, projects, assessment, analytics, and community interaction within a single, pedagogically designed environment. In mathematics and STEAM education, such ecosystems have been associated with open resources, interactive learning communities, gamification, project-based tasks, and learning-progress data that support both student autonomy and teacher decision-making (Azrai et al., 2025; Kummanee et al., 2020; Sahara et al., 2024; Wahyuni et al., 2025).

Nevertheless, the literature reveals a persistent and unresolved design gap. Many digital tools support mathematics practice, multimedia explanation, assessment or communication separately, but comparatively few systems intentionally integrate contextual mathematics learning, STEAM pedagogy, project-based activity, and progress monitoring into a single coherent ecosystem. As Table 1 illustrates, widely used platforms tend to optimize one or two pedagogical functions while leaving the integration of contextual problem framing, interdisciplinary project scaffolding, and formative progress monitoring to the individual teacher.

This gap is especially consequential in resource-constrained settings, where teachers need practical support for designing feasible projects, guiding student work, and documenting learning progress. The absence of an integrated, locally responsive design is precisely what motivated the present study. This design gap is especially acute in the Indonesian junior secondary educational context. Indonesian students' mathematics performance has consistently highlighted the need for more contextually meaningful learning; the Programme for International

Student Assessment (PISA) 2022 data show that Indonesian 15-year-olds scored well below the Organization of Economic Co-Operation and Development (OECD) average in mathematical reasoning, with difficulty in applying mathematics to unfamiliar situations being a recurring concern (OECD, 2023).

The national curriculum policy has responded through Kurikulum Merdeka, which is a framework that mandates contextualized, project-based, and interdisciplinary approaches across subject areas, including mathematics. This framework has also positioned digital tools as key enablers of this transformation. However, the realities of Indonesian junior secondary classrooms impose specific resource constraints that shape what a usable design must accommodate. Not all students have personal devices, making shared school laboratory or classroom arrangements common; internet connectivity is frequently intermittent or constrained by limited school bandwidth; teacher preparation time for designing project-based materials is scarce due to substantial teaching loads; and project materials must remain affordable for families.

These conditions collectively define what this study means by a “resource-aware” or “resource-constrained” setting: a design that is functional on shared devices and under limited bandwidth, feasible within realistic teacher preparation workloads, and supportable by low-cost, locally sourceable project materials. It is precisely within these constraints that the absence of an integrated, pedagogically coherent digital ecosystem for contextual STEAM mathematics becomes most consequential.

To address this gap, this study designed and developed MathSTEAM Space, a web-based digital learning ecosystem that integrates contextual mathematics learning and STEAM pedagogy in Indonesian junior secondary education. The contribution of the study is threefold. First, it advances a single pedagogical architecture known as the MathSTEAM cycle, which moves students through six deliberate stages. These stages include ‘context’ for framing a real-world problem; ‘concept’ for identifying the relevant mathematical concepts; ‘conceptualize’ for planning a solution approach; ‘create’ for constructing the project artifact; ‘confirm’ for receiving structured feedback and refining the work; and ‘communicate’ for presenting and reflecting on the learning process.

This six-stage architecture operationalizes the full progression from a real-world problem to a mathematical concept to project creation, iterative refinement, and public communication, thereby integrating STEAM throughout the mathematics learning process, rather than treating it as a supplementary activity after mathematics instruction. Second, it grounds the design in authentic, locally generated teacher and classroom evidence, yielding transferable design principles for similar resource-aware contexts. Third, it embeds formative learning- progress and activity-progress monitoring as an intrinsic, pedagogically aligned feature, rather than as generic usage analytics.

1.1 Research Objectives

To address the identified design gap, this study pursued the following four research objectives:

RO1: To identify the needs, challenges, and expectations of in-service mathematics teachers in West Java, Indonesia, regarding the design of a digital ecosystem for contextual, project-based, and STEAM-oriented junior secondary mathematics learning.

RO2: To design and develop a first-cycle prototype of MathSTEAM Space (a web-based digital learning ecosystem organized around the six-stage MathSTEAM cycle) using analysis, design, development, implementation, and evaluation (ADDIE) development logic embedded within a design-based research (DBR) framework.

RO3: To evaluate the pedagogical alignment, usability, and implementation readiness of the MathSTEAM Space prototype through structured teacher evaluations ($n = 26$) and an initial proof-of-concept classroom trial ($n = 80$ seventh-grade students).

RO4: To derive a set of preliminary, transferable design principles for developing contextual STEAM mathematics ecosystems in resource-aware junior secondary educational settings.

Accordingly, the study was guided by the two research questions: (RQ1) What needs and challenges do mathematics teachers experience in relation to contextual, project-based, and STEAM-oriented mathematics learning? (RQ2) How can MathSTEAM Space be designed as a digital learning ecosystem that operationalizes contextual mathematics learning through STEAM pedagogy under realistic classroom constraints? By answering these questions, the study contributes both a functioning design artifact and a set of empirically grounded design principles to the literature on digital learning ecosystems for STEAM mathematics.

Table 1: Comparison of representative digital tools and MathSTEAM Space across core pedagogical functions

Tool / platform	Primary pedagogical function	Contextual framing	STEAM/ project scaffolding	Progress monitoring
Quizizz/ Kahoot	Gamified quizzes and formative checks	Limited	No	Partial (quiz scores)
Google Classroom	Assignment distribution and management	No	No	Partial (submission status)
GeoGebra	Dynamic visualization and exploration	Partial	No	No
General LMS/ worksheet banks	Content delivery and repository	Limited	Limited	Partial
MathSTEAM Space	Integrated contextual + STEAM ecosystem	Yes (context stage)	Yes (MathSTEAM cycle)	Yes (Learning & Activity Progress)

2. Literature Review

2.1 Contextual Mathematics Learning

Contextual mathematics learning is based on the assumption that students learn more meaningfully when mathematical ideas are connected with everyday situations, social practices, and authentic problem solving. Within contextual teaching and learning, students are positioned not as passive recipients of formulae but as learners who construct mathematical meaning through inquiry, modeling, collaboration, reflection, and authentic assessment. Meta-analytic and empirical studies show that contextual approaches improve mathematical understanding and literacy when implemented coherently (Afni & Hartono, 2020; Kusnirova et al., 2026).

For mathematics education, contextualization also serves a conceptual function. It does not simply situate mathematics within real-world stories; it helps learners recognize why concepts are needed, how representations work, and how quantitative reasoning can inform action. This is closely related to mathematical literacy, in which students formulate, employ, and interpret mathematics across varied situations (Kolar & Hodnik, 2021). Contextual learning therefore requires instructional design that moves from context toward concept, rather than from formula memorization toward artificial application.

2.2 STEAM Pedagogy and Project-Based Mathematics

STEAM pedagogy extends contextual learning by positioning mathematics within interdisciplinary inquiry and creative production. In STEAM activities, students may use mathematics to analyze patterns, estimate quantities, design structures, model data, or optimize solutions while also drawing on scientific, technological, engineering, and artistic modes of thinking. This interdisciplinary character makes STEAM well suited to project-based learning, in which students create products, models, or explanations that respond to authentic problems (Bertrand & Namukasa, 2020; Herro & Quigley, 2017; Montero, 2018).

Nevertheless, research repeatedly emphasizes that authentic STEAM integration requires more than a project label. Teachers need support in designing tasks that are mathematically meaningful, feasible within classroom constraints, and connected to students' contexts. Reviews of STEAM education indicate that successful implementation depends on project design, teacher preparation, collaboration, and the availability of appropriate learning resources (García-Fuentes et al., 2023; Martín-Cudero et al., 2024; White & Delaney, 2021).

A recurring and insufficiently addressed challenge is the issue of mathematical rigor, in cases when interdisciplinary STEAM projects can become predominantly craft-like or performative activities. While these activities are engaging, they often become detached from formal mathematical concepts and targeted learning objectives. A related difficulty is the absence of explicit integration maps, which are structured frameworks that clarify how specific mathematical content connects to each stage of a STEAM project workflow. This absence leaves teachers without guidance for preserving conceptual coherence across project activities (Herro & Quigley, 2017; Kelley & Knowles, 2016).

Creative-pedagogy frameworks add that technology-enhanced environments are most effective when they actively foster ideation and student agency rather than merely providing a platform for tasks (Yilmaz, 2021). Of particular relevance is the role of the 'A' (arts) in STEAM. Arts, design thinking, and creative expression introduce aesthetic reasoning, iterative prototyping, and multimodal communication that can deepen mathematical engagement and problem-solving (Halverson & Sheridan, 2014; Retno et al., 2025). However, reviewers of STEAM education observe that the arts dimension is frequently underdeveloped in practice and is often reduced to visual decoration rather than genuine creative inquiry (Bertrand & Namukasa, 2020).

In MathSTEAM Space, the art dimension is provisionally addressed through the creating stage, in which students design contextual artifacts, and the communicate stage, which encourages multimodal representation of mathematical outcomes. Future cycles should strengthen this integration through structured design challenges and arts-informed reflection activities.

2.3 Digital Learning Ecosystem

The concept of a digital learning ecosystem is useful for understanding how technology can support learning beyond the delivery of materials. A digital ecosystem encompasses digital content, user roles, interaction spaces, data flows, feedback mechanisms, and institutional support. In mathematics and STEAM education, such ecosystems may include project repositories, interactive media, discussion spaces, teacher dashboards, and progress-tracking features that frame learning as a connected process (Azrai et al., 2025; Kummanee et al., 2020; Nguyen & Tuamsuk, 2022). In the Indonesian secondary education context specifically, studies of digital platform adoption highlight that ecosystem usability, low-bandwidth operability, and teacher-facing design support are decisive factors shaping whether platforms are sustained beyond initial deployment (Adiyono et al., 2024).

Learning analytics can further strengthen a digital ecosystem when student actions are translated into interpretable information for teachers and learners. In early-stage development, such analytics may take the form of learning progress, activity completion, submission histories, and teacher-accessible summaries. More advanced systems may incorporate automated scaffolding and predictive models, but even basic progress analytics can support formative assessment when aligned with pedagogical stages and evidence-centered design (Kubsch et al., 2022; Siemens, 2013).

Critically, the literature on digital learning ecosystems points to an unresolved integration gap: while individual tools address one or two pedagogical functions well, comparatively few systems combine contextual problem framing, project-based scaffolding, formative feedback, and progress monitoring within a single, pedagogically designed environment. This gap is particularly acute in resource-aware junior secondary settings, where teachers require a coherent digital environment that integrates contextual mathematics framing, STEAM project workflows, and pedagogically aligned progress monitoring without demanding

expensive infrastructure or extensive preparation time. This gap motivated the present study's design approach.

2.4 Design-Based Research in Educational Technology

Design-based research is appropriate for studies that develop educational interventions, while simultaneously generating design knowledge. It is conducted in authentic educational settings, proceeds through iterative cycles of analysis, design, implementation, and refinement, and seeks to connect theory with practice (Anderson & Shattuck, 2012; Brown, 1992; Wang & Hannafin, 2005). In technology-enhanced learning, DBR is particularly valuable because the quality of an intervention depends on the alignment among pedagogy, user needs, technical design, and implementation constraints.

Recent studies in STEAM and mathematics education have applied DBR to develop digital environments and pedagogical supports, including STEAM-based massive open online courses, digital learning websites, artificial intelligence (AI) powered teachable agents, and project-based digital ecosystems (Azrai et al., 2025; McKenney & Reeves, 2019; Sahara et al., 2025; Sudirman et al., 2026; Xing et al., 2025). The present study followed this tradition by treating MathSTEAM Space not only as a software product but as a pedagogical design intervention whose trustworthiness rests on the alignment among teacher needs, theoretical principles, and platform features.

Collectively, the four areas of reviewed literature converge on a shared design imperative for MathSTEAM Space. Contextual mathematics learning establishes that mathematical meaning is built through connection to authentic situations, rather than abstract procedure, and this principle is operationalized in the MathSTEAM cycle's context and concept stages. STEAM pedagogy demonstrates that interdisciplinary project-based inquiry can deepen mathematical engagement, but only when the mathematical content is preserved through explicit integration structures that prevent project 'drift'. This is addressed through conceptualization and creating stages, which maintain mathematical concept coherence within project work.

The digital learning ecosystem literature shows that a single, pedagogically coherent environment integrating project scaffolding, feedback, and progress monitoring yields more equitable and sustainable outcomes than fragmented tool use, particularly in resource-constrained settings such as Indonesian junior secondary classrooms. Finally, DBR provides the methodological rationale for developing MathSTEAM Space through iterative, evidence-informed design cycles, rather than as a finished product, as each cycle generates both a refined artifact and transferable design principles. It is the intersection of these four domains, namely contextual mathematics, STEAM pedagogy, ecosystem design, and iterative design-based methodology, that defines the scholarly contribution and design logic of MathSTEAM Space.

3. Methodology

3.1 Research Design and DBR Cycle Documentation

This study employed DBR as its overarching methodology. The DBR framework was selected because the aim was not to test a finished intervention or to measure the effect of MathSTEAM Space on student achievement under controlled experimental conditions, but rather to design, implement, analyze, and refine an educational solution in an authentic context. DBR is appropriate when researchers seek to connect theory, design, and practice through iterative intervention and the generation of design principles (Brown, 1992; McKenney & Reeves, 2019; Wang & Hannafin, 2005).

The ADDIE model provided the operational development logic within the broader DBR methodology (Branch, 2009), and the full first DBR cycle unfolded as an explicit sequence of design → implementation → evaluation → refinement across five phases. In the analysis phase, open-ended teacher interviews and needs-analysis questionnaires identified four converging design priorities: contextual project scaffolding, structured formative feedback, progress monitoring, and low-barrier digital access under resource-constrained conditions. These findings directly informed the feature architecture of MathSTEAM Space.

In the design phase, analysis findings were translated into the MathSTEAM cycle pedagogical architecture (context → concept → conceptualize → create → confirm → communicate), a role-based user flow (student, teacher, administrator), and a feature map specifying module types, submission workflows, and progress-tracking mechanisms. In the development phase, these specifications were implemented as a web platform built with PHP: hypertext preprocessor (PHP) (Laravel framework) and a MySQL database, with iterative internal testing to verify feature completeness and navigational coherence.

In the implementation phase, the prototype was deployed first in a professional-development workshop with 26 in-service teachers and subsequently in a proof-of-concept classroom trial with 80 seventh-grade students; teacher and student responses were documented systematically. In the evaluation phase, usability feedback, questionnaire responses, platform performance data, and classroom observations were synthesized to identify refinements, producing MathSTEAM Space version 1.0 and a set of preliminary design principles. Subsequent DBR cycles will extend and test these principles in broader implementation contexts (McKenney & Reeves, 2019; Obczovsky et al., 2025). This manuscript reported the complete first cycle.

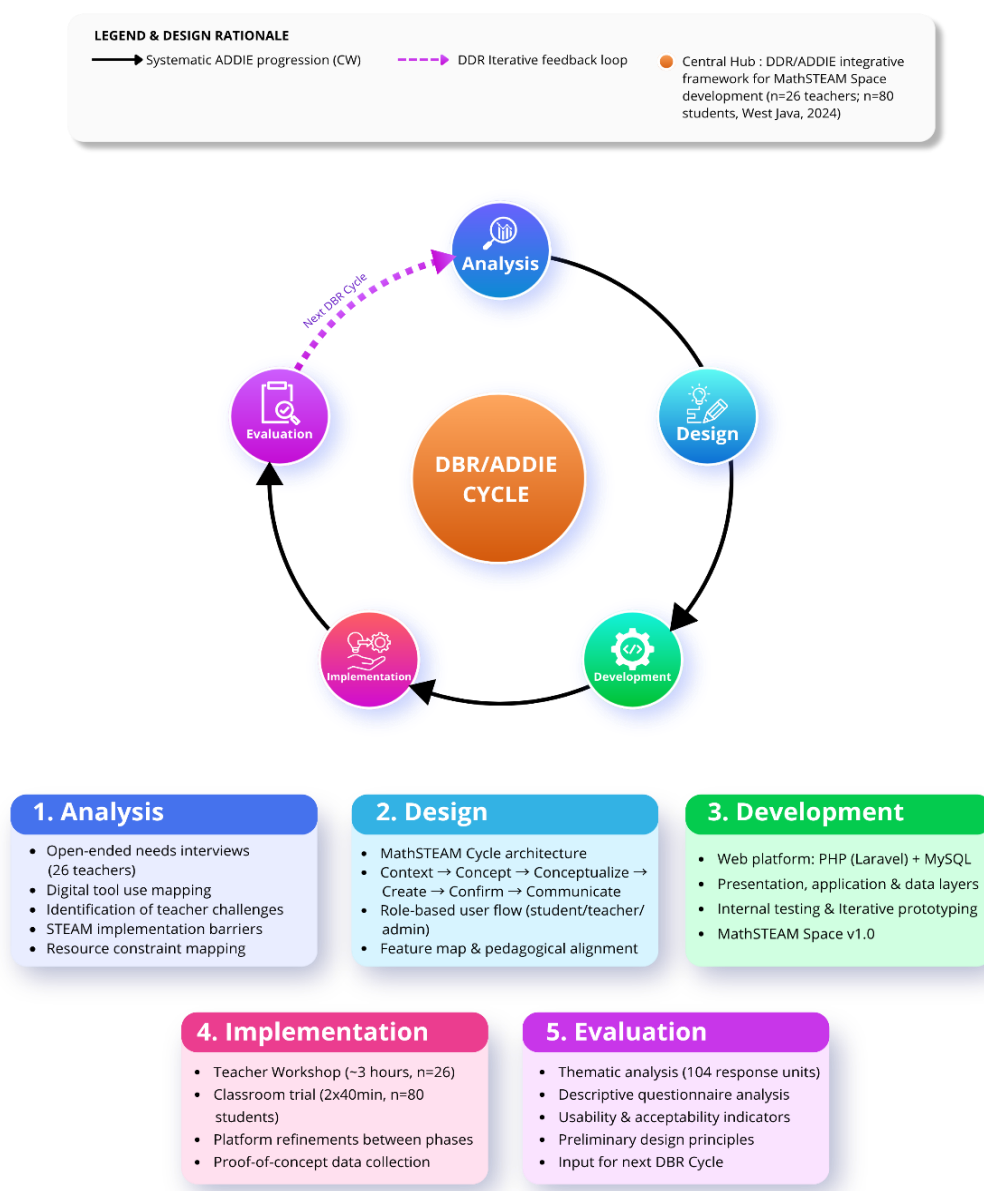


Figure 1: ADDIE cycle flowchart

3.2 Setting and Participants

The study was conducted in West Java, Indonesia, and was deliberately framed as a local design-insight study; the evidence was not treated as a population-representative sample. Teachers were recruited through purposive sampling; participants were selected from in-service junior-secondary mathematics teachers who voluntarily attended a university-facilitated professional-development workshop on STEAM-oriented mathematics learning.

Participant inclusion criteria were: (1) currently teaching mathematics at junior-secondary level (Grade 7–9); (2) willingness to engage with MathSTEAM Space during the workshop and complete the needs-analysis instruments; and (3) provision of written informed consent. All 26 teachers who attended the workshop and met these criteria were included. Data from each participant were

further accepted only when: questionnaire records were complete across both closed and open items; and responses were sufficiently detailed to support cross-source interpretation. This selective strategy strengthened internal design validity while avoiding overgeneralization.

The teacher sample reflected varied experience: nine teachers had fewer than 5 years of teaching experience, 11 had 5–10 years, five had 11–20 years, and one had more than 20 years. All teachers participated voluntarily, and no financial incentives were offered. The teacher-facing professional-development workshop lasted approximately three hours, covering STEAM-oriented mathematics project design and a hands-on orientation to MathSTEAM Space.

For the classroom trial, convenience sampling was used: one partner public junior secondary school in Bandung, West Java, was selected on the basis of its willingness to participate, availability of a computer laboratory, and the involvement of a consenting mathematics teacher. One intact seventh-grade cohort ($n = 80$ students) taught by a teacher participated. School permission was obtained from the principal; written parental or guardian consent and student assent were secured prior to data collection. The classroom trial focused on a statistics and data analysis unit, a topic selected because it offers natural connections to real-world contexts and STEAM project activities. The trial took place over two class sessions of approximately 40 minutes each.

Table 2: Trial-protocol summary for the proof-of-concept classroom implementation

Parameter	Teacher Workshop	Student Classroom Trial
Participants	26 in-service mathematics teachers	80 seventh-grade students + 1 teachers
Setting	University workshop room	Public junior secondary school, Bandung
Duration	~3 hours (1 session)	2 sessions $\times$ ~40 minutes
MathSTEAM Cycle stages addressed	Full cycle orientation	Context $\rightarrow$ concept $\rightarrow$ conceptualize $\rightarrow$ create $\rightarrow$ confirm $\rightarrow$ communicate
Stage distribution	All 6 stages introduced in sequence	Session 1: Context, concept, conceptualize; Session 2: Create, confirm, communicate
Platform access	School/personal devices; browser-based	School desktop computers; browser-based
Data collected	Open-ended needs analysis; Likert evaluation	Login success; navigation; mini-project upload
Primary purpose	Needs analysis + platform evaluation	Proof-of-concept usability trial

Students accessed the platform through school-provided desktop computers in a computer laboratory equipped with a Wi-Fi internet connection. Computers ran Windows 10 with Google Chrome; shared Wi-Fi bandwidth was intermittently variable, with brief loading delays observed on approximately three of the 20 workstations. The classroom teacher remained present throughout both sessions,

introduced the platform, facilitated stage transitions within the MathSTEAM cycle, and offered on-demand technical and pedagogical support. Students were encouraged to navigate modules and upload mini projects as independently as possible. For the purposes of this study, “independently” is defined as the student completing the project upload action without the teacher performing the submission on their behalf; procedural guidance (oral directions and on-screen prompts) was available and used by some students, and approximately seven students required individual teacher assistance with file-format issues during the upload stage.

Data for this study were drawn from four complementary sources. First, teacher needs and perceptions were collected through a structured open-ended interview completed by the 26 mathematics teachers, covering digital-tool use, implementation challenges, required platform features, priority content areas, ideal platform characteristics, project-implementation experiences, and support expected from an automatic project-design application. Second, closed-ended responses were collected using a Likert-type questionnaire administered after teachers had been exposed to a STEAM-oriented project and to MathSTEAM Space; addressing three areas: STEAM project alignment, LMS usability and pedagogical support, and implementation readiness.

Third, development documentation was analyzed, including the system architecture, user journey, feature list, interface design, and pedagogical design of MathSTEAM Space. Fourth, proof-of-concept implementation evidence was obtained from the classroom trial, used to examine access, navigation, project submission, and initial acceptability rather than learning effectiveness.

3.3 Instruments and Data-Collection Procedures

The open-ended interview protocol consisted of four guiding questions concerning desired platform features, experiences and constraints in implementing project/STEAM/problem-based learning, realistic mathematics projects suited to school contexts, and the support expected from an automatic project-design application. The complete interview guiding questions and Likert-scale items are provided in Appendix B.

The closed-ended questionnaire used a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Items were grouped into three evaluation blocks: STEAM module/project alignment (5 items), MathSTEAM Space usability and pedagogical support (8 items), and professional-development and implementation readiness (10 items). Item wording was reviewed by the research team for content relevance and clarity prior to administration. To support replication, the complete item set and the initial qualitative coding matrix were retained as an audit-trail file.

3.4 Data Analysis

Open-ended interview responses were analyzed using reflective thematic analysis following Braun and Clarke (2006, 2019). The 104 response units were defined as discrete meaning units segmented from the open-ended responses of the 26 teachers across the four guiding questions; in cases when a single teacher response

addressed more than one design concern, multiple units were extracted and coded independently (Creswell & Creswell, 2018). The analysis proceeded through five stages: (1) familiarization through repeated reading of all responses; (2) initial coding, conducted closely to participants' own wording to minimize interpretive overlay; (3) consolidation of initial codes into candidate themes encompassing time constraints, contextual problem design, project or module generation, clear scaffolding, feedback mechanisms, and low-cost feasibility; (4) review of candidate themes against the full dataset; and (5) definition and naming of final themes with representative quotations.

The analysis was conducted by two team members (B.C.R.B. and R.S.) who independently coded all 104 units and then negotiated to consensus on disputed codes. Inter-coder agreement was assessed through a consensus-based negotiation process: both coders (B.C.R.B. and R.S.) independently coded all 104 response units, after which disputed codes were discussed until full consensus was reached. A formal inter-coder reliability coefficient (e.g., Cohen's κ) was not computed prior to this first DBR cycle; this is acknowledged as a methodological limitation, and systematic κ computation is planned as a standard procedure for subsequent cycles to further strengthen the trustworthiness of the thematic analysis.

The lead researcher (B.C.R.B.) also served as the primary platform developer, introducing a potential reflexivity concern. Bias-reduction strategies included: grounding all codes closely to participants' own wording; involving a second coder (R.S.) who was not involved in platform development; conducting an independent expert review of instruments; including open-ended prompts that invited critique and constraints (not only praise); and deliberately searching for and reporting negative and discrepant responses. A small number of teachers expressed skepticism about platform reliability in schools with limited internet access; these were coded as feasibility constraints, reported in Table 1A (Appendix A), and treated as design inputs rather than omitted. Quotations were selected to represent the range of views, including divergent ones.

Closed-ended responses were analyzed descriptively. Multiple-response items were counted by category and converted into percentages ($n = 26$). Likert items were summarized as construct means and positive-response rates (the proportion of responses in the agree/strongly-agree range). Internal consistency (Cronbach's α) was computed for each construct as a descriptive quality indicator and is reported in the following instrument validity and reliability subsection. Classroom trial indicators (login success, navigation, and independent project upload) were summarized as frequencies and percentages.

3.5 Instrument Validity and Reliability

The open-ended interview protocol and Likert-type questionnaire were reviewed for content validity and face validity by two mathematics education researchers external to the project, both holding doctoral degrees in mathematics education with experience in digital learning research, who confirmed content relevance and alignment with the study's design objectives. Expert feedback was incorporated

into item wording before administration. Items were mapped to the constructs they were intended to measure, which included STEAM module or project alignment, MathSTEAM Space usability and pedagogical support, and professional development and implementation readiness. These items were then reviewed for relevance, clarity, and representativeness. Item-level content validity was assessed through expert consensus review; no quantitative content validity index (CVI) was computed in this first cycle, which is acknowledged as a limitation. No separate external pilot test was conducted, given the formative purpose of the study and the small available sample; item performance from the present sample will inform instrument refinement in subsequent DBR cycles.

Internal consistency was computed for each of the three questionnaire constructs as a descriptive quality indicator: Cronbach's $\alpha = 0.83$ for the STEAM module/project-alignment block (5 items), $\alpha = 0.97$ for the MathSTEAM Space usability and pedagogical-support block (8 items), and $\alpha = 0.96$ for the professional-development and implementation-readiness block (10 items). These values indicate strong inter-item consistency within each construct. However, they should be interpreted cautiously: high alpha values with small samples ($n = 26$) and relatively few items per block may partly reflect item overlap or construct homogeneity rather than definitive scale maturity. Accordingly, these alpha values are reported as descriptive quality indicators rather than as confirmatory evidence of construct validity (Creswell & Creswell, 2018). All 26 teacher questionnaires were completed in full; no missing responses were recorded.

3.6 Platform Refinements after Feedback

The DBR approach requires that design decisions and revisions be systematically documented. Based on teacher feedback collected during the professional-development workshop, the following concrete refinements were enacted prior to the classroom trial: (a) a simplified, step-by-step navigation guide was added to the student interface to reduce first-use confusion; (b) project-submission instructions were clarified, including explicit file-format requirements following teacher reports that students encountered format-related barriers; (c) the rubric display was redesigned for greater readability; and (d) the communicate stage prompts were revised to more clearly specify the expected form of the student product.

Each refinement was linked to its feedback source: items (a)–(c) were prompted by open-ended teacher responses and low Likert mean on navigation-clarity items; and item (d) arose from teacher workshop discussion. No further structural changes to the platform architecture were made between the workshop and the classroom trial, because teacher feedback indicated that the core feature set was functionally adequate for the proof-of-concept implementation. These refinements constituted the first feedback-to-revision loop in the DBR cycle and are reported here to enable scrutiny of design decisions and replication in similar contexts.

3.7 Ethical Considerations

Ethical procedures for this study were reviewed and approved by the Research Ethics Committee of Universitas Pendidikan Indonesia (approval reference: B-5048/UN40.A4/PT.01.04/2025). Prior to data collection, written permission was obtained from the participating schools and the relevant district education office. Teachers participated voluntarily and provided written informed consent for the use of anonymized data for research publication. For the classroom trial involving minors, written parental or guardian consent and student assent were obtained before participation.

All questionnaire and interview data were de-identified before analysis; individual respondents are identified only through anonymized codes (e.g., T12, S05). Photographs and screen capture of implementation activities were obtained with explicit permission from participants, teachers, and guardians; individuals are not identified in any image included in this article. Data have been stored securely on password-protected university servers and will be retained for 5 years in accordance with institutional data-management policy. No financial incentives were offered for participation.

3.8 Limitations

The study has three limitations which are acknowledged at the outset. First, the teacher-response data were collected from a relatively small purposive sample and should be interpreted as formative evaluation evidence rather than as generalized survey results. Second, the classroom implementation was a limited proof-of-concept trial that did not include a control group, a pretest-posttest design, or long-term learning-outcome data. Third, a formal inter-coder reliability coefficient was not computed for this cycle, and Content Validity Index (CVI) was not quantified; both are planned for subsequent DBR cycles. These limitations are consistent with the design-based orientation of the study and are revisited in the discussion.

4. Results and Finding

4.1 Problem Analysis: Teacher Needs for a Contextual STEAM Mathematics Ecosystem

The needs analysis (RQ1) confirmed that teachers already used digital tools, but their use was concentrated on assignment distribution, presentation, and evaluation rather than on project-based or STEAM-oriented mathematics learning. The most frequently reported tools were Quizizz (88.5%), Google Classroom (80.8%), Kahoot (53.8%), and GeoGebra (38.5%). However, only 23.1% of respondents reported using technology for projects or practical work. Teachers were thus familiar with digital tools, yet a dedicated ecosystem for contextual, project-based mathematics learning remained necessary.

Teachers also identified several persistent learning challenges. The most frequent were students' low conceptual understanding (84.6%), low motivation (69.2%), time constraints (53.8%), and limited learning media (50.0%). For project-based or STEAM learning specifically, the dominant challenges were time constraints (69.2%), determining project contexts (65.4%), and a lack of suitable examples (42.3%). These patterns align with prior evidence that STEAM implementation is

constrained by teacher readiness, resources, and task-design complexity (García-Fuentes et al., 2023; Martín-Cudero et al., 2024; White & Delaney, 2021). Table 3 summarizes the main needs and constraints that informed the design of MathSTEAM Space.

Table 3: Teacher needs and constraints informing the design of MathSTEAM Space

Area	Dominant response	Frequency
Current mathematics challenges	Low conceptual understanding	22 (84.6%)
	Low motivation	18 (69.2%)
	Time constraints	14 (53.8%)
	Limited learning media	13 (50.0%)
Project/STEAM implementation challenges	Time constraints	18 (69.2%)
	Determining project contexts	17 (65.4%)
	Lack of suitable examples	11 (42.3%)
Needed digital platform features	Digital worksheets	23 (88.5%)
	Learning videos	22 (84.6%)
	Teaching modules	21 (80.8%)
Content areas needing support	Geometry	25 (96.2%)
	Algebra	15 (57.7%)
	Data analysis	15 (57.7%)

Open-ended responses provided richer explanations of why a digital ecosystem was needed. Teachers described the ideal platform as one offering digital worksheets, videos, modules, contextual explanations, step-by-step feedback, adaptive exercises, interactive activities, and progress monitoring. They further emphasized that realistic mathematics projects should be relevant to students' daily lives, low-cost, and connected to school or community problems such as waste management, classroom design, healthy canteens, surveys, and data analysis. To interpret these expectations systematically, the 104 open-response units were subjected to reflective thematic analysis. The full coding matrix is presented in Appendix A. Table 4 presents the condensed summary of principal themes and their design implications.

Table 4: Local design insights from the reflective thematic analysis and their implications for MathSTEAM Space

Local design insight	Implication for MathSTEAM Space
Contextual project work requires conceptual scaffolding before students are asked to create products.	Strengthen the concept and conceptualize stages with step-by-step explanations, examples, and feedback.
STEAM implementation is shaped by feasibility constraints such as time, facilities, and student/teacher readiness.	Provide bounded project templates, adjustable complexity, time estimates, and classroom-ready guidance.
Realistic MathSTEAM projects should be local, familiar, low-cost, and connected to school or everyday problems.	Build project banks around local issues such as waste, school gardens, canteens, class data, and simple measurements.
Automation should support teachers as co-designers rather than replace their creativity.	Generate editable project ideas, modules, activity steps, rubrics, and contextual examples that teachers can adapt.
Adoption depends on affective accessibility, including interest, reduced boredom, ease of access, and affordability.	Prioritize engaging videos, animations, games, intuitive navigation, and low-barrier access.

The evidence reported in this section derives from a small, purposively selected teacher sample consisting of 26 participants and a limited proof of concept classroom trial involving 80 students. The instruments measured teacher perceptions of pedagogical alignment and platform usability, as well as classroom indicators related to access, navigation, and project submission. No learning outcome measures, assessments conducted before and after the intervention, or control group comparisons were included. This approach is consistent with the first cycle and the design focused orientation of the study. Claims about the effectiveness of MathSTEAM Space in improving mathematical literacy or STEAM competence require further investigation through longitudinal and experimental studies.

The primary requirements identified by teachers included digital worksheets, contextual project exemplars, scaffolded feedback, and learning progress monitoring. These needs correspond directly to the core design decisions of MathSTEAM Space. The concept and conceptualized stages address the need for scaffolded conceptual support. The creation and confirm stages facilitate project submission and structured feedback. The context stage provides contextual problem framing. The learning and activity progress features address the need for monitoring student progress. In the classroom trial, the selected indicators included login success at 92.5%, navigation completion, and independent mini project upload at 91.2%. These indicators were selected because they corresponded to the platform's design features and provided initial evidence that the translation from design to implementation was feasible under authentic school conditions.

4.2 Design Intervention: MathSTEAM Space as a Digital Learning Ecosystem

In response to RQ2, the needs analysis was translated into a digital ecosystem rather than a stand-alone repository. The ecosystem was designed to incorporate role-based users, contextual modules, project activities, STEAM-oriented tasks, assessment and feedback features, learning-progress monitoring, and spaces for communication. The key design decision was to position contextual mathematics learning as the beginning and STEAM pedagogy as the structure for project-based exploration. Table 5 shows how the MathSTEAM cycle was operationalized within the platform.

Table 5: Operationalization of the MathSTEAM cycle within MathSTEAM Space

Stage	Pedagogical function	Digital support
Context	Introducing a real-world or school-based phenomenon as a mathematical problem.	Contextual text, images, videos, guiding questions.
Concept	Clarify the mathematical concepts needed to reason about the problem.	Concept explanation, examples, interactive tasks.
Conceptualize	Help students plan, model, or formulate possible solutions.	Exploration prompts, short questions, planning tasks.
Create	Guide students to produce a project response or artifact.	Project instructions, upload features, group task submission.
Confirm	Support teacher feedback, revision, and formative assessment.	Feedback field, assessment/rubric support, progress data.
Communicate	Allow students to share, present, and discuss outcomes.	Project gallery, comment/discussion spaces, presentation prompts.

This design reflects the core aim of bridging contextual mathematics learning and STEAM pedagogy. Contextual learning is represented by the initial problem and real-life situation, whereas STEAM pedagogy is represented by the project-based, interdisciplinary movement from exploration to creation and communication. In this way, the platform avoids treating STEAM as an activity appended after mathematics instruction; instead, mathematical concepts are embedded within a structured project cycle.

4.2.1 Prototype development and platform architecture

MathSTEAM Space was developed as a web-based platform using PHP with the Laravel framework and a MySQL database. The architecture comprised presentation, application, data, and infrastructure layers. The presentation layer provided interfaces for students, teachers, and administrators; the application layer managed authentication, learning flow, assessment, and progress calculations; the data layer stored users, courses, modules, questions, answers, submissions, and activity records; and the infrastructure layer supported access security, secure communication through secure sockets layer, backup, and system reliability. Figure 2 presents representative user interfaces of the platform.

The image displays the MathSTEAM Space user interface. The top navigation bar includes links for Dashboard, Materi, About, Inspire, and Explore. The main section is titled 'Daftar Materi' (Material List) with a subtitle 'Pilih materi berdasarkan kelas dan topik untuk mulai belajar' (Choose material based on class and topic to start learning). Below this are filters for 'Bidang' (Field) and 'Topik' (Topic), both set to 'Semua' (All). A search bar labeled 'Cari Materi' (Search Material) is also present. Three material cards are shown:

- Bidang ALJABAR (File):** 'Bilangan Bulat dan Pengukuran: Membuat Termometer Sederhana' (Integer and Measurement: Making a Simple Thermometer). Description: 'Modul ini dirancang untuk memecahkan masalah nyata terkait penggunaan pendingin ruangan (AC) di sekolah. Anda akan ditantang untuk...' (This module is designed to solve real problems related to the use of room cooling (AC) in schools. You will be challenged to...). Button: 'Buka Materi' (Open Material).
- Bidang GEOMETRI (Video):** 'Garis dan Sudut: Optimalisasi Lahan Parkir' (Lines and Angles: Parking Space Optimization). Description: 'Video pengantar sudut dan garis sejajar' (Introductory video of angles and parallel lines). Button: 'Buka Materi' (Open Material).
- Bidang GEOMETRI:** 'Bangun Ruang Sisi Datar: Pembangunan Prototipe Rumah Susun' (Prism: Construction of Prototype Apartment Building). Description: 'Video permasalahan tentang Prototipe Rumah Susun' (Video problem about Prototype Apartment Building). Button: 'Buka Materi' (Open Material).

The bottom section shows a detailed view of the 'Garis dan Sudut' (Lines and Angles) project. It includes an 'Overview' section with text about parking space optimization in Indonesia. Below the text is a video player showing 'Operasi Penertiban PKL di Pasar Anyar Bogor' (Traffic Regulation of Street Vendors in Bogor Market). The video player has controls for 'Watch later' and 'Share'. Below the video, there are navigation buttons: 'Sebelumnya' (Previous), 'Langkah 1 dari 10' (Step 1 of 10), and 'Selanjutnya' (Next). A green button labeled 'Simpan Semua Jawaban' (Save All Answers) is at the bottom.

Figure 2: User interface of MathSTEAM Space

The prototype included several active and developing features. Active features comprised user management, registration/authentication, profile management, module and material management, multimedia content support, project-based assessment, learning progress, activity progress, user comments, events/webinars, and administrative control. Features still in beta or under development included class management, question banks, teacher rubrics, student activity history, badges, media management, and project templates. Additional features such as automatic quizzes, automatic feedback, a teacher

analytics dashboard, a discussion forum, a project gallery, audit logs, interactive simulations, and experiment data visualization were planned for the next cycle. Table 6 summarizes the main ecosystem components and their functions.

The learning progress and activity progress features are particularly important because they transform the platform from a static repository into a formative ecosystem. Learning progress records the proportion of learning stages or materials completed, whereas activity progress records the proportion of questions or activities answered. Although the prototype did not yet implement advanced predictive analytics, these features established a basis for teacher monitoring and future learning-analytics development. This is consistent with the argument that learning analytics should be aligned with learning progression and evidence-centered design rather than collecting data for its own sake (Kubsch et al., 2022).

Table 6: Main components of the MathSTEAM Space ecosystem and their functions

Component	Function
User and access management	Role-based access for students, teachers, and administrator; registration; profile management.
Contextual modules and materials	Teacher/admin material creation, multimedia content, and MathSTEAM cycle-based module structure.
Project and assessment support	Project-based assessment, project upload, and feedback/rubric development.
Progress and activity monitoring	Learning progress and activity progress calculated from learning completion and activity responses.
Communication and dissemination	Comments, events/webinars, and planned forum and project gallery.
Administration and security	Admin panel, account security, backup, media management, and audit log.

4.3 Initial Proof-of-Concept Implementation (Teacher and Student)

The implementation phase was conducted in two bounded settings. The first was a teacher-facing implementation delivered through a training session on STEM-oriented worksheets and the use of MathSTEAM Space, intended to examine teachers' perceptions of pedagogical alignment, usability, and implementation readiness before wider use. The second was a student-facing classroom implementation conducted as a limited trial in a real school setting, intended to examine whether first-time student users could access, navigate, and submit project work through the prototype (Figure 3).



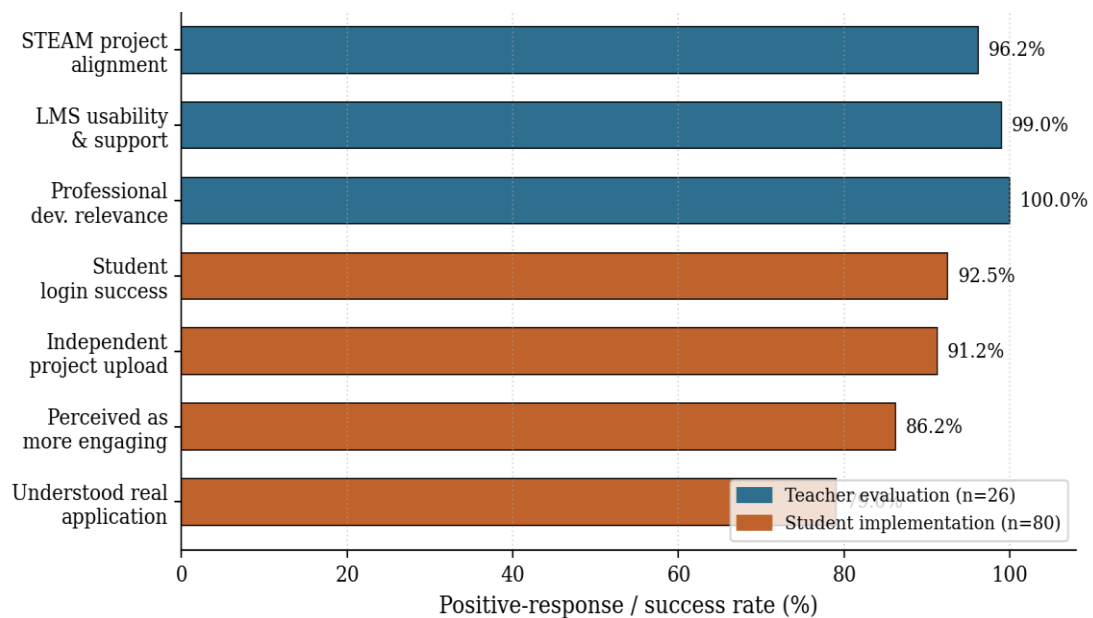
Figure 3: Implementation of MathSTEAM Space in the workshop and classroom settings

In the teacher-facing implementation, closed-ended responses were generally positive. The STEAM module and project alignment block produced an overall mean of 4.32, which is 96.2% positive. The LMS usability and pedagogical support block produced a mean of 4.27, or 99.0% positive. The professional development and implementation readiness block produced the highest mean of 4.43, with all responses being positive. The high internal consistency values for the three blocks, with alpha values of 0.83, 0.97, and 0.96, suggest coherent responses. However, these figures should be interpreted cautiously given the small sample and the formative purpose of the questionnaire. Table 7 reports the descriptive summary.

The item-level results also indicate useful design priorities for the next iteration. The lowest item mean in the STEAM block concerned the feasibility of classroom time allocation, with a mean of 4.08. This result echoes the open-ended finding that time constraints are a persistent implementation barrier. In the LMS block, first-time navigation and teacher feedback each produced means of 4.19. While these are still positive, they signal that onboarding and the feedback workflow warrant improvement. The teacher-facing implementation therefore provided formative evidence that MathSTEAM Space was perceived as pedagogically relevant and usable while also identifying practical refinements needed for wider adoption.

Table 7: Descriptive summary of closed-ended teacher responses (n = 26)

Construct	No. of items	Mean	Positive responses	Cronbach's alpha
STEAM module/project alignment	5	4.32	96.2%	0.83
MathSTEAM Space usability and support	8	4.27	99.0%	0.97
Professional-development relevance	10	4.43	100.0%	0.96

**Figure 4: Positive-response and success rates across teacher-evaluation constructs (n = 26) and student-implementation indicators (n = 80)**

The student-facing classroom implementation offered early evidence that the prototype could function in a real school setting under the resource conditions described in the methodology section. In a limited trial with 80 seventh-grade students, 92.5% logged in without major difficulty. All students navigated the learning stages from context to communicate, although first-time users needed time to familiarize themselves with the interface.

Of the 80 students, 73 independently uploaded project work, which was defined as completing the upload action without the teacher submitting on their behalf. The remaining 7 students required individual teacher assistance owing to file format issues involving specific unsupported types such as .bmp. This finding led directly to a design refinement in the subsequent iteration by adding clearer upload guidance specifying accepted formats to the create stage interface. Student responses further indicated that 86.2% found the experience more interesting than usual mathematics learning, and 79% reported that the platform helped them understand how mathematics applies to contextual problems. These self-report figures reflect perceived engagement rather than measured learning gains.

The classroom teacher's observational notes and post-trial remarks reinforced both the platform's potential and its current limitations. The teacher noted that the MathSTEAM cycle gave students clear guidance through the project sequence and that the structured feedback feature of the confirm stage reduced informal question and answer interruptions during the create phase. At the same time, the teacher observed that students required more time than anticipated for the conceptualized stage, which suggests that the planning prompts need to be more scaffolded in subsequent iterations. Approximately seven students required individual teacher assistance with file format issues during project upload, representing a feasibility constraint that directly informed the refinement of the upload guidance mentioned previously.

5. Discussion

This study adds a local design perspective to the literature on contextual mathematics, STEAM pedagogy, and digital learning ecosystems. The existing literature emphasizes interdisciplinary design, active learning, teacher preparation, learning analytics, and equity (Azrai et al., 2025; Kubsch et al., 2022; Nguyen & Tuamsuk, 2022; White & Delaney, 2021). The present findings show how these broad ideas become concrete when translated into an Indonesian secondary mathematics context.

Classroom manages assignment distribution but provides no STEAM or contextual mathematics structure. GeoGebra affords dynamic visualization but does not support project workflows or progress tracking. General LMS or worksheet banks offer content delivery and partial monitoring but no integration of contextual framing with project scaffolding. MathSTEAM Space is distinct in intentionally combining all four functions, including contextual framing in the context stage, STEAM project scaffolding through the full MathSTEAM cycle, formative feedback in the confirm stage, and progress monitoring within the learning and activity progress section, all within a single pedagogically designed environment. This is not a claim of superiority in any one function but rather a claim of integration. The platform addresses the gap documented in the literature by treating these four elements as architecturally inseparable rather than as supplementary features.

The findings suggest three principal ways in which MathSTEAM Space may bridge contextual mathematics learning and STEAM pedagogy. First, it embeds contextual problems at the beginning of the learning sequence, which is consistent with contextual mathematics learning theory (Afni & Hartono, 2020; Kolar & Hodnik, 2021; Tamur et al., 2020). Second, the MathSTEAM cycle structures STEAM integration by rendering the pedagogical sequence visible, which may help teachers preserve mathematical focus and prevent projects from becoming craft-like activities that are detached from formal concepts (Martín-Cudero et al., 2024). Third, the platform functions as a digital ecosystem that links resources, project tasks, feedback, and progress data, thereby extending ecosystem conceptions found in the literature (Habrusiev et al., 2025; Kummanee et al., 2020). Crucially, the trial evidence addresses usability and acceptability only, as claims about learning effectiveness await longitudinal and experimental investigation.

It is also important to note a critical limitation of the current activity progress and learning progress features. They index completion and engagement proxies, such as stages accessed, questions attempted, and materials viewed, rather than the quality of mathematical thinking or the depth of STEAM integration in student project work. While this is appropriate for a first cycle prototype, future cycles must develop more nuanced analytics that can capture mathematical reasoning quality, conceptual understanding, and project work depth in line with evidence-centered design principles (Kubsch et al., 2022; Siemens, 2013).

5.1 Teacher Readiness and Practical Feasibility

The study reinforces the centrality of teacher readiness and practical feasibility to MathSTEAM implementation. Teachers were positive about the platform yet repeatedly identified time constraints, project context selection, and example availability as barriers. This is consistent with evidence that teacher preparation, beliefs, and digital competence shape technology integration in mathematics and STEAM classrooms (Herro et al., 2018; Lavicza et al., 2022).

Time constraints warrant particular analysis because they emerged both as a dominant needs analysis theme among 69.2% of teachers and as the lowest rated Likert item regarding classroom time allocation feasibility with a mean of 4.08. This convergence identifies time as a critical design target rather than merely an implementation complaint. MathSTEAM Space responds through ready-to-adapt project modules, bounded cycle stages, and visible progress tracking that reduces the teacher planning demands, but this response is only partial. Time pressure in STEAM mathematics is not fully solvable by a platform alone; instead, it requires curricular space, institutional scheduling flexibility, and sustained professional development. Future development must therefore advance not only platform features but also teacher guides, exemplar project banks, and time realistic rubrics that demonstrate how the MathSTEAM cycle can be enacted within standard lesson periods.

The low-cost project emphasis also carries equity relevant significance beyond practical convenience. In resource aware settings where project materials must be affordable for families, the design principle of locally sourceable and low-cost projects is not a compromise but is instead an equity design choice. Platforms that require expensive materials, personal devices, or stable high bandwidth internet structurally exclude students from lower income households. The lightweight web architecture, browser-based access, and emphasis on everyday context projects in MathSTEAM Space reflect a deliberate effort to avoid these exclusionary design patterns. This rationale should be foregrounded in dissemination and policy contexts.

5.2 Theoretical Contributions

This study makes two theoretical contributions to the literature on digital learning ecosystems for STEAM mathematics. First, it extends contextual learning theory by demonstrating how the general principle of connecting mathematics to real situations can be operationalized as a structured, stage by stage digital cycle known as the MathSTEAM cycle, rather than as an instructional strategy applied at the teacher's discretion. This operationalization makes the contextual learning

principle replicable, inspectable, and refinable through iterative DBR cycles, which contributes a visible design artifact to theoretical literature. Second, it extends STEAM integration theory by proposing that the central challenge of interdisciplinary project drift, where STEAM activities become craft-like at the expense of mathematical rigor, can be addressed architecturally. By embedding explicit mathematical concept stages such as concept and conceptualization within the project workflow before students move to create, the platform structures the disciplinary focus rather than leaving it to teacher improvisation. Together, these contributions reframe digital ecosystem design not as content delivery with analytics incorporated as a supplementary component but as the architectural instantiation of pedagogical theory.

The study also contributes to DBR methodology by illustrating how the ADDIE development logic can operationalize a full first cycle DBR sequence involving analysis, design, development, implementation, evaluation, and refinement in an authentic Indonesian resource constrained context. This process generated both a refined artifact, MathSTEAM Space version 1.0, and six transferable design principles. These principles are preliminary, but their explicit derivation from locally grounded teacher and classroom evidence gives them greater specificity than generic design heuristics. Furthermore, their documentation enables scrutiny and replication by other researchers working in similar contexts.

5.3 Practical Implications and Design Principles

Based on the first cycle of development and evaluation, six design principles can be formulated for contextual STEAM mathematics ecosystems in resource-aware junior secondary settings. These principles are preliminary and should be refined through broader implementation:

1. Begin with a contextual problem close to students' everyday life, school environment, or community issues.
2. Make the mathematical concept explicit so that project work remains mathematically meaningful rather than merely creative activity.
3. Use a visible pedagogical cycle to scaffold movement from context to concept, project creation, feedback, and communication.
4. Provide teachers with ready-to-adapt modules, projects, examples, and rubrics to reduce the planning demands of STEAM projects.
5. Embed progress and activity monitoring as formative information for teachers and students.
6. Maintain a lightweight, accessible web-based architecture before adding more advanced analytics, AI, or immersive features.

For schools and teachers, these findings suggest that technology adoption depends less on platform sophistication than on feasibility, local relevance, and the preservation of teacher agency. Platforms should provide editable, context-rich project templates, bounded cycle stages that fit within standard lesson periods, and low-barrier access requiring no specialized hardware or high-bandwidth connectivity.

For curriculum development, the MathSTEAM cycle offers an alignment tool for the Indonesian Kurikulum Merdeka, which mandates contextual, project-based, and interdisciplinary approaches including *Projek Penguatan Profil Pelajar Pancasila* (P5) activities. The six stages of the cycle can serve as a curriculum scaffold that maps P5 project phases onto targeted mathematical concepts, making interdisciplinary integration pedagogically explicit rather than incidental.

For teacher education, both pre-service and in-service, the study suggests that designing with the MathSTEAM cycle instead of merely using the MathSTEAM Space platform should be embedded in mathematics methods courses and STEAM-oriented professional development. Teachers who understand the pedagogical logic of the cycle are better positioned to adapt it to new topics, design their own contextual projects, and evaluate whether student work meets both STEAM and mathematical learning objectives.

For education policy and digital procurement, the findings underscore that investing in STEAM mathematics digitalization without accompanying teacher professional development and locally adaptable project banks is insufficient. Procurement decisions that prioritize pedagogically integrated ecosystems over generic LMS features and that support platform adoption with funded professional development are more likely to yield sustainable instructional change. Platform maintenance, content updating, and hosting sustainability should also be planned at the outset of procurement rather than being considered only at later stages.

For platform developers working in similar resource-aware contexts, the study recommends several key actions. These include maintaining lightweight browser-based architecture as a non-negotiable baseline and building editable content templates as first-priority features rather than advanced analytics. Furthermore, developers should design teacher-facing dashboards before student-facing gamification and sequence feature releases according to teacher readiness evidence gathered from iterative cycles.

5.4 Limitations and Future Research

Several limitations bound these claims. The teacher-response data derive from a small, purposively selected sample ($n=26$) and constitute formative rather than confirmatory evidence; the reported reliability coefficients should be read considering that. The classroom trial was a short, single-site proof of concept without a control group or pre-post measurement, it speaks to usability and acceptability rather than to learning effectiveness. Comparative or quasi-experimental designs are proposed as future work once the platform has matured. The absence of formal inter-coder reliability coefficients and quantitative CVI values are acknowledged as methodological limitations to be addressed in subsequent cycles. The design insights are locally bounded and should be interpreted in terms of transferability to similar resource-aware settings, not as statistical generalization.

Platform maintenance and sustainability also deserve forward-looking attention: as MathSTEAM Space moves toward broader deployment, questions of server hosting costs, content updating workflows, teacher support structures, and long-term data management will need to be planned systematically. These considerations are not addressed in the present first-cycle study but are identified as necessary components of future scale-up planning.

Future research should pursue several key directions. First, researchers should conduct broader and longer DBR cycles involving multiple schools, teachers, and student cohorts across diverse regions of Indonesia to test the generalizability of the design principles and refine the platform through additional feedback loops. Second, there is a need for structured interdisciplinary teacher collaboration, such as co-design workshops where mathematics teachers work alongside science, technology, and arts teachers to build MathSTEAM projects. Such collaboration would deepen cross-subject integration beyond what a single-subject teacher can design alone. Third, development should prioritize content modules in algebra, statistics, and data analysis, as these were identified as high-priority areas by 57.7% of teachers, while geometry support modules remain a high priority with a 96.2% teacher rating.

Fourth, the platform requires multi-format upload support and clearer student guidance to address the file-format failures observed during the trial. Fifth, developers should consider a parent or guardian progress-view feature in a later development cycle to enable family involvement in monitoring student project work. Sixth, once the platform matures through at least two additional DBR cycles, quasi-experimental and longitudinal studies should be conducted to examine its effects on mathematical literacy, STEAM engagement, creativity, and project quality outcomes. Seventh, education authorities investing in STEAM mathematics digitalization should couple platform adoption with funded teacher professional development and locally adaptable project banks instead of treating platform procurement as a standalone intervention.

6. Conclusion

This study developed MathSTEAM Space through a first cycle of DBR, producing both a web-based prototype and preliminary design principles for integrating contextual mathematics learning and STEAM pedagogy in Indonesian junior secondary education. A needs analysis involving 26 teachers and a proof-of-concept classroom trial with 80 seventh-grade students indicated that teachers required structured digital support to design feasible contextual projects, scaffold student understanding, and monitor learning progress. These needs were translated into the six-stage MathSTEAM cycle, which consists of context, concept, conceptualize, create, confirm, and communicate, and were embedded in a role-based web platform.

Initial teacher evaluations and the classroom trial provided formative evidence of pedagogical alignment and usability while identifying areas for refinement in user guidance, project assessment rubrics, and analytics visualization. Crucially, this first-cycle evidence addresses usability and acceptability rather than learning

effectiveness, as claims about the platform's impact on mathematical literacy or STEAM outcomes await longitudinal and experimental investigation. The thematic analysis further showed that the platform's value lies in balancing innovation with classroom realism. Specifically, projects should be low-cost and contextually relevant, automation should support teachers as co-designers, and accessibility should drive adoption.

The principal contribution is a set of transferable, resource-aware design principles for secondary mathematics contexts. These include beginning with a contextual problem, making the mathematics explicit, scaffolding through a visible cycle, providing adaptable project resources, embedding formative progress monitoring, and maintaining a lightweight, accessible architecture. For policy, investment in STEAM mathematics technology must be paired with sustained teacher professional development and context-sensitive project resources. Future research should pursue broader longitudinal cycles and, once the platform matures, experimental studies to examine effects on mathematical literacy and engagement. Digital learning ecosystems that bridge contextual mathematics and STEAM pedagogy hold genuine promise, but this potential can only be realized through sustained and evidence-driven design.

7. Author Contribution

The authors confirmed their specific contributions to this study as follows: Nanang Priatna served as the lead investigator, providing conceptualization, methodology, software management, and supervision, as well as handling validation and the writing of the original draft. Bill Chairy Rizki Bustaren contributed to conceptualization, data curation, formal analysis, and investigation, while also participating in the writing, review, and editing process. Bambang Avip Priatna Martadiputra provided expertise in methodology, resources, and supervision, and was responsible for validation and final manuscript review.

Data management and project oversight were conducted by Ririn Sisipiyati and Lukman, who both handled data curation, investigation, and project administration; Lukman also contributed to the visualization of the results. Further analytical support was provided by Agus Hendriyanto, Lukman Hakim Muhaimin, and Deshinta Arrova Dewi, who performed formal analysis, validation, and manuscript editing. Additionally, Agus Hendriyanto and Deshinta Arrova Dewi contributed to software operations, with Deshinta Arrova Dewi further supporting the study through resource procurement.

Conflict of Interest

The authors declare no conflict of interest.

8. Declaration of AI Use

This paper was assisted by AI tools, including ChatGPT for translation, text refinement, and coherence enhancement, as well as Grammarly for proofreading. These tools were used to improve readability and adherence to academic

standards. The authors are fully responsible for the content and interpretations presented.

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Appendices

Appendix A: Qualitative Thematic Coding Matrix (Needs Analysis)

Table 1A: Thematic coding matrix of teacher needs analysis (N = 26 teachers, 104 response units)

Theme	Category / Sub-code	Example Quotations (Translated from Indonesian)	Design Implication for MathSTEAM Space
Conceptual Scaffolding & Task Clarity	Need for progressive guidance; transitioning from real-life context to formal math	"Students often get confused when jumping directly from a problem story to formulas. They need step-by-step guidance before making anything." (T04) "Clear foundational concepts must precede project tasks so that math is not neglected." (T11)	Scaffold the Concept and Conceptualize stages with sequential explanations, guiding questions, and self-checks prior to product development.
Feasibility & Resource Constraints	Time limitations; school infrastructure; shared computer labs	"Project work takes too much class time, and our 40-minute periods are very tight." (T08) "Internet connection in the computer lab is sometimes slow or shared with other classes." (T19)	Design bounded stage activities; optimize lightweight web pages for low bandwidth; allow asynchronous project continuation.
Authentic & Low-Cost Local Projects	Contexts grounded in school environment, canteen, waste, and daily student life	"Projects must not require expensive materials because parents will complain. Low-cost items like school waste, cardboard, or school canteen surveys are best." (T15) "Connecting math to real situations in our surrounding environment makes it meaningful." (T02)	Provide pre-designed project exemplars centered on school-based data, simple measurements, and recycled materials.
Automation & Teacher Co-Design Support	Demand for adaptable templates, rubrics, and automated module generation	"We need a system that provides ready-to-use rubrics and module templates that we can edit to fit our class conditions, rather than starting from zero." (T21) "Automated suggestions for project tasks save a lot of lesson preparation time." (T07)	Implement editable project templates, automatic progress calculation, and structured rubric frameworks supporting teacher agency.
Affective Accessibility & Engagement	Student motivation; interactive media; multimedia appeal; intuitive interface	"Junior high students get bored easily with long texts. Visual explanations, videos, and clear menus keep them engaged." (T13) "Simple navigation is essential, so students do not spend half the class just asking how to submit." (T26)	Embed instructional videos and clean interface layouts; provide clear on-screen instructions for file uploads (Create and Communicate stages).

Appendix B

Research Instruments (Open-Ended Protocol and Closed-Ended Questionnaire)

a) Part 1: Open-Ended Needs Analysis Interview / Questionnaire Protocol

1. What digital tools and media do you currently use in your mathematics teaching, and what specific features do you feel are missing when facilitating project-based or STEAM learning?
2. What are the primary challenges and constraints you face when designing and implementing contextual or project-based mathematics activities in your school?
3. What kinds of real-world or school-based contexts (e.g., local environment, daily student activities) are most realistic and feasible for junior secondary mathematics projects?
4. What specific support or features do you expect from an automated/digital learning platform to assist you in designing, managing, and assessing STEAM mathematics projects?

b) Part 2: Teacher Evaluation Questionnaire (5-point Likert Scale) (Scale: 1 = Strongly Disagree [SD], 2 = Disagree [D], 3 = Neutral [N], 4 = Agree [A], 5 = Strongly Agree [SA])

1. Block 1: STEAM Module and Project Alignment ($\alpha=0.83$)

- A1. The project activities effectively connect everyday real-world contexts to junior secondary mathematics concepts.
- A2. The MathSTEAM cycle stages (*Context, Concept, Conceptualize, Create, Confirm, Communicate*) preserve mathematical rigor while fostering interdisciplinary creativity.
- A3. The suggested project tasks utilize accessible, low-cost materials suitable for standard school environments.
- A4. The interdisciplinary tasks appropriately incorporate science, technology, engineering, and arts into mathematical inquiry.
- A5. The project workflow can be feasibly managed within standard curriculum time allocations.

2. Block 2: MathSTEAM Space Usability and Pedagogical Support ($\alpha=0.97$)

- B1. The platform interface is clean, intuitive, and easy for first-time users to navigate.
- B2. The sequential organization of the six MathSTEAM stages helps structure student learning progression.
- B3. The multimedia features (videos, contextual text, module viewers) enhance student engagement.
- B4. The project submission interface provides clear instructions and supports necessary file formats.
- B5. The Confirm stage allows teachers to provide structured, formative feedback efficiently.
- B6. The Learning Progress tracking feature clearly shows student completion across learning stages.
- B7. The Activity Progress indicator effectively tracks student engagement with tasks and prompts.
- B8. The platform operates reliably under standard school internet and computer laboratory conditions.

3. Block 3: Professional Development and Implementation Readiness ($\alpha=0.96$)

- C1. The workshop training provided adequate guidance on how to integrate STEAM pedagogy into mathematics.
- C2. The platform provides sufficient flexibility for teachers to adapt project templates to their classroom needs.
- C3. The assessment rubrics and guides are clear and assist teachers in evaluating project artifacts.
- C4. Using MathSTEAM Space reduces teacher preparation time for project-based learning.
- C5. I feel confident in facilitating the MathSTEAM cycle in my mathematics classroom.
- C6. The platform promotes independent student learning and problem-solving skills.
- C7. MathSTEAM Space supports the contextual and project-based objectives of Kurikulum Merdeka.
- C8. The platform is suitable for deployment across diverse junior secondary schools.
- C9. I would recommend MathSTEAM Space to other mathematics teachers in my professional learning community (MGMP).
- C10. I am motivated to implement MathSTEAM Space in my upcoming mathematics teaching units.