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Defining an Adaptive Learning Platform Framework for Challenge-Based Mathematical Numeracy in Local Shoe Manufacturing Entrepreneurship

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Abstract
The growing demand for mathematical numeracy skills in vocational entrepreneurship is not accompanied by adaptive learning solutions that integrate authentic industrial contexts into mathematics instruction. This study aims to formulate the conceptual specification framework of an Adaptive Learning Platform (ALP) for challenge-based mathematical numeracy learning in the context of local shoe manufacturing entrepreneurship. This study employed the Four-D (4D) Research and Development model, limited to the Define stage. The research included needs analysis, concept analysis, learner characteristics analysis, and product specification analysis. Data were collected through curriculum document analysis, field observations, semi-structured interviews with industry practitioners, a systematic literature review, and a preliminary learning-needs questionnaire. The results indicate a significant gap between students' mathematical numeracy competencies and the numeracy skills required in entrepreneurial activities, particularly in cost estimation, product pricing, profit calculation, percentages, comparisons, and statistical reasoning. The study produced a conceptual specification framework that defines pedagogical, functional, and adaptive learning requirements for an ALP to be developed in the subsequent Design stage. This framework provides a foundation for future adaptive learning innovations integrating intelligent tutoring principles with vocational mathematics education.

Keywords
Adaptive Learning Platform (ALP); Entrepreneurship; Local Shoe Manufacturing; Mathematical Numeracy Literacy; Research and Development (4D Model)

INTRODUCTION

The rapid transformation driven by the Industrial Revolution 4.0 has fundamentally reshaped educational priorities, requiring learning systems to prepare students with competencies that extend beyond content mastery toward higher-order thinking, problem solving, and digital adaptability (Putri et al., 2022). Within this transformation, twenty-first-century competencies—particularly critical thinking, computational reasoning, and problem solving—have become essential for both professional and entrepreneurial success (Sukirman, 2017; Ahmatika, 2017). Mathematics education therefore plays a strategic role in equipping learners with analytical competencies required in increasingly technology-driven industrial environments (Fardan et al., 2016). Without contextual learning experiences that integrate these competencies, mathematics instruction risks producing graduates who possess procedural knowledge but lack the reasoning skills required to solve authentic workplace problems (Martin & Marsh, 2020).

Mathematical numeracy literacy has consequently emerged as one of the most important competencies supporting informed decision-making in everyday life, business, and entrepreneurship (Syarif & Nugraha, 2019). Numeracy literacy encompasses the ability to interpret, analyze, reason, and communicate quantitative information across various contexts rather than merely performing arithmetic calculations (Firmansyah & Husna, 2021). Within entrepreneurial activities, numeracy competencies are indispensable for estimating production costs, calculating profit margins, evaluating risks, and determining competitive pricing strategies (Rustina, 2018). Strengthening numeracy literacy is therefore increasingly important in response to data-driven economic environments that require individuals to interpret numerical information accurately for sustainable decision making (Fadilah, 2021).

Despite its recognized importance, previous studies consistently report that students continue to experience difficulties applying mathematical knowledge to authentic situations requiring critical reasoning and contextual problem solving (Maufiroh & Lukmana, 2020). Mathematics learning remains predominantly procedural, limiting students' opportunities to connect abstract concepts with real-world applications such as financial planning, production management, and entrepreneurial decision making. Consequently, students frequently struggle when confronted with contextual mathematical problems that require interpretation rather than memorization. This condition indicates the need for instructional innovations capable of situating mathematical learning within meaningful professional contexts that simultaneously enhance motivation and critical thinking (Khazim & Andarini, 2021).

One promising strategy for addressing this challenge is challenge-based learning that situates mathematical concepts within authentic entrepreneurial activities (Tanamal et al., 2023). Through contextual learning, mathematical concepts such as percentages, ratios, comparisons, and statistics become meaningful tools for solving practical business problems, including production planning, pricing decisions, inventory management, and sales analysis (Utari et al., 2022). Learning mathematics through entrepreneurial challenges not only

strengthens conceptual understanding but also develops analytical thinking and entrepreneurial competence simultaneously (Indroyono et al., 2024).

The present study adopts the local shoe manufacturing industry as its authentic learning context because this sector represents one of Indonesia's prominent local manufacturing ecosystems, where mathematical reasoning is continuously applied throughout production and marketing activities. Field observations and interviews with local entrepreneurs indicate that production planning, raw material estimation, operational cost calculation, profit determination, and online marketing all require accurate mathematical reasoning (Observation Results; Shopee Documentation). However, students are rarely exposed to these authentic industrial situations during mathematics learning, creating a mismatch between school learning experiences and workplace expectations. This discrepancy indicates that vocational mathematics education should be redesigned to incorporate realistic industrial contexts capable of strengthening students' numeracy competencies before entering entrepreneurial careers (Yanto & Aprilian, 2023).

Advances in educational technology provide opportunities to bridge this gap through Adaptive Learning Platforms (ALPs), which personalize learning experiences according to students' characteristics, prior knowledge, and learning progress (Arifin, 2015). Recent developments in Artificial Intelligence have accelerated the implementation of adaptive learning and Intelligent Tutoring Systems capable of delivering individualized instruction and continuous formative feedback. Adaptive learning is particularly relevant for mathematical numeracy because students demonstrate substantial variation in prior competencies and learning preferences (Fadiini et al., 2022). By continuously monitoring learner performance, ALPs can recommend personalized learning pathways, provide targeted remediation, and optimize learning experiences according to students' current levels of understanding (Pratama & Septiyaningsih, 2022). Consequently, adaptive learning has significant potential to improve both learning effectiveness and learner engagement within vocational mathematics education (Sukirman, 2017).

Although previous studies have demonstrated the educational benefits of digital learning media and technology-enhanced instruction (Khazim & Andarini, 2021), existing research has primarily focused on evaluating learning outcomes or technology implementation. Few studies have specifically investigated how adaptive learning principles can be systematically integrated with authentic entrepreneurial contexts to strengthen mathematical numeracy literacy in vocational education. Furthermore, research addressing adaptive mathematics learning for local manufacturing industries remains limited. This gap suggests the need for a systematic instructional analysis before developing adaptive educational technology capable of addressing authentic industrial needs.

To address this gap, the present study employed the Define stage of the Four-D (4D) Research and Development model, which emphasizes comprehensive instructional analysis before product design and development (Ikramullah et al., 2020). The Define stage consists of needs analysis, concept analysis, learner characteristics analysis, and product specification analysis that

collectively establish the instructional foundation for subsequent development activities. Rather than producing a validated instructional product, this stage aims to formulate a conceptual specification framework that identifies pedagogical, contextual, and functional requirements necessary for designing an Adaptive Learning Platform. The instructional analysis integrates evidence obtained from field observations, interviews with local shoe manufacturing entrepreneurs, curriculum analysis, and a systematic literature review to ensure that future platform development is grounded in authentic educational and industrial needs (Mayasari et al., 2022; Yudhiarma et al., 2021; Rustina, 2018).

Based on these considerations, this study addresses an important research gap concerning the absence of adaptive learning frameworks that integrate mathematical numeracy with authentic entrepreneurial practices in local manufacturing industries. Accordingly, the objectives of this Define-stage research are to: (1) identify the mathematical numeracy competencies required within local shoe manufacturing entrepreneurship; (2) determine the contextual mathematical concepts that should become the instructional foundation of the Adaptive Learning Platform; and (3) formulate a conceptual specification framework that will guide the Design stage of Adaptive Learning Platform development for challenge-based mathematical numeracy learning (Nauvalia & Indrijati, 2023; Palangda et al., 2024; Ni Made Rianita, 2022; Sukardi, 2016).

RESEARCH METHOD

This study employed a Research and Development (R&D) approach using the Four-D (4D) instructional development model developed by Thiagarajan, Semmel, and Semmel (1974), which consists of the Define, Design, Develop, and Disseminate stages. Unlike many previous R&D studies that implement all four phases, this research was intentionally limited to the Define stage because its primary objective was to establish the empirical and pedagogical foundations required for the subsequent design of an Adaptive Learning Platform (ALP), rather than to develop or validate a finished instructional product. The Define stage emphasizes systematic identification of instructional needs through learner analysis, concept analysis, task analysis, and instructional objective formulation before entering the design phase (Thiagarajan et al., 1974). Accordingly, the expected outcome of this study was a conceptual specification framework consisting of pedagogical requirements, contextual mathematical concepts, learner characteristics, and functional instructional requirements that will guide the Design stage of future platform development. This methodological positioning ensures consistency between the research objectives, analytical procedures, and the intended outputs of the study, while avoiding premature claims regarding prototype development or product validation.

The research was conducted in local shoe manufacturing enterprises in Pasuruan Regency, East Java, Indonesia. The research context was selected because mathematical numeracy is continuously applied throughout entrepreneurial activities, including calculating production costs, estimating raw material requirements, determining selling prices, analyzing profit margins, managing inventories, and evaluating sales performance. These authentic

industrial practices provide meaningful contexts for integrating mathematical concepts into vocational learning and entrepreneurial education (Sukardi, 2016; Sukirman, 2017). Participants were selected purposively to obtain comprehensive information regarding instructional needs and industrial mathematical practices. They consisted of local shoe manufacturing entrepreneurs, production managers, vocational education practitioners, and prospective student users of the Adaptive Learning Platform. Their diverse perspectives enabled a comprehensive understanding of contextual mathematical competencies, learning characteristics, and instructional requirements necessary for designing adaptive learning environments.

Data were collected using multiple techniques to enhance the completeness and credibility of the instructional analysis. Curriculum document analysis was conducted to identify mathematical competencies relevant to vocational education. Field observations within local shoe manufacturing enterprises were undertaken to examine authentic entrepreneurial activities involving mathematical reasoning. Semi-structured interviews explored industrial expectations regarding mathematical competencies and contextual learning needs, while a systematic literature review synthesized current developments in adaptive learning, intelligent tutoring systems, mathematical numeracy, and vocational education. In addition, a preliminary learner-needs questionnaire was administered to identify students' prior knowledge, learning preferences, digital readiness, and perceived difficulties in mathematical numeracy. The research instruments consisted of observation guidelines, interview protocols, curriculum analysis sheets, learner-needs questionnaires, and mathematical numeracy diagnostic instruments, all of which were developed based on the instructional analysis principles of the Four-D model (Thiagarajan et al., 1974; Palangda et al., 2024).

The collected data were analyzed using a qualitative descriptive approach supported by thematic analysis. The analytical process involved data reduction, coding, categorization, theme identification, and synthesis of instructional findings derived from observations, interviews, curriculum documents, learner questionnaires, and the literature review. Methodological triangulation was employed by comparing evidence obtained from multiple data sources to strengthen the credibility of the findings. The trustworthiness of the research was ensured by applying the criteria of credibility, transferability, dependability, and confirmability proposed by Lincoln and Guba (1985). Rather than producing an instructional prototype, the analytical process generated a conceptual specification framework comprising learner profiles, contextual mathematical concepts, pedagogical requirements, adaptive learning characteristics, and functional design specifications that provide the empirical foundation for the subsequent Design stage of the Four-D Research and Development model. This methodological approach is consistent with instructional design theory, which emphasizes that rigorous needs analysis and contextual specification should precede product design and technological implementation (Branch, 2009; Thiagarajan et al., 1974).

RESEARCH RESULT AND DISCUSSION

The first activity conducted during the Define stage was a needs analysis to identify the discrepancy between students' existing mathematical numeracy competencies and the competencies required in authentic entrepreneurial settings. Field observations conducted in local shoe manufacturing enterprises in Pasuruan Regency demonstrated that mathematical reasoning is embedded throughout the production process. Entrepreneurs continuously perform calculations involving raw material estimation, production costs, selling prices, profit margins, and inventory planning before making business decisions.

The observation results indicate that these mathematical activities require not only computational accuracy but also logical reasoning and contextual decision-making. However, interviews with practitioners revealed that many graduates entering vocational employment possess procedural mathematical knowledge but experience difficulties applying mathematical concepts to authentic industrial situations. This finding supports the argument that mathematics instruction should emphasize contextual problem solving rather than isolated procedural exercises. According to Rustina (2018), mathematical learning becomes more meaningful when students are encouraged to solve authentic problems that require reasoning and decision making. Likewise, Ahmatika (2017) emphasizes that inquiry-oriented learning contributes significantly to the development of students' critical thinking skills, which are essential components of mathematical numeracy.

The curriculum analysis further revealed that Percentage, Ratio, Comparison, and Statistics are formally included within vocational mathematics curricula. Nevertheless, these concepts are generally taught independently from entrepreneurial contexts, reducing opportunities for students to understand their practical applications. Consequently, a substantial gap exists between school mathematics and workplace mathematics. These findings strengthen the need for an adaptive instructional model capable of integrating mathematical concepts with authentic industrial challenges, consistent with the objectives of vocational entrepreneurship education (Sukardi, 2016).

Following the identification of instructional needs, concept analysis was conducted to determine which mathematical topics should become the instructional foundation of the proposed Adaptive Learning Platform. The analysis synthesized curriculum documents, industrial observations, interview findings, and relevant literature to identify mathematical concepts most frequently applied in local shoe manufacturing activities.

The findings demonstrate that three mathematical domains dominate entrepreneurial decision-making. The first is percentages, which are extensively applied when calculating discounts, taxes, profit margins, and production efficiency. The second is comparison and ratio, which support calculations related to material composition, production scaling, labor productivity, and inventory planning. The third is statistics, which assist entrepreneurs in analyzing sales trends, customer demand, and production performance.

These concepts represent authentic mathematical situations that students are likely to encounter in vocational employment. Therefore, presenting

mathematics through realistic manufacturing cases is expected to increase conceptual understanding while simultaneously strengthening entrepreneurial competence. Sukirman (2017) argues that entrepreneurship education should cultivate analytical thinking and independent decision-making by exposing learners to practical business situations. Similarly, Ikramullah et al. (2020) explain that entrepreneurial competencies develop more effectively when learning activities simulate authentic workplace experiences rather than relying exclusively on theoretical instruction.

The concept analysis therefore confirms that contextual mathematical learning should become the pedagogical foundation of the proposed Adaptive Learning Platform. Rather than teaching formulas separately, the platform should present mathematical concepts as integrated components of industrial problem solving.

The third analytical activity focused on identifying learner characteristics that influence the design requirements of the Adaptive Learning Platform. Data obtained from preliminary questionnaires indicate considerable diversity among prospective users regarding mathematical ability, learning preferences, digital literacy, and learning motivation.

Most respondents expressed positive attitudes toward digital learning environments but indicated that conventional mathematics instruction often fails to relate mathematical concepts to everyday experiences. Students also reported difficulties understanding contextual word problems involving percentages, proportional reasoning, and statistical interpretation despite demonstrating adequate procedural calculation skills.

These findings suggest that learners require individualized instructional support capable of accommodating differences in prior knowledge and learning pace. Such diversity reinforces the importance of adaptive learning principles, where instructional content, feedback, and learning pathways are adjusted according to learner performance. Pratama and Septiyaningsih (2022) emphasize that adaptive instructional approaches provide opportunities for students to receive learning materials appropriate to their current competency level, thereby reducing learning difficulties and increasing engagement.

Furthermore, Palangda et al. (2024) argue that effective instructional design should begin with comprehensive learner analysis before selecting instructional strategies and learning technologies. Consistent with this perspective, the present study identifies learner characteristics as an essential empirical basis for determining adaptive learning mechanisms. Rather than adopting a one-size-fits-all instructional approach, the proposed ALP should provide differentiated learning pathways, immediate feedback, learning progress monitoring, and personalized recommendations based on students' mathematical performance.

These findings demonstrate that learner diversity is not an obstacle but rather a design consideration that informs the functional requirements of the platform.

Based on the synthesis of needs analysis, concept analysis, and learner characteristics analysis, this study formulated a conceptual specification framework for the Adaptive Learning Platform as the primary outcome of the

Define stage. It is important to emphasize that this framework should not be interpreted as a software prototype or finalized product design. Instead, it represents a comprehensive set of instructional and functional specifications that will guide development during the subsequent Design phase of the Four-D model.

The framework identifies several essential instructional components. First, learning activities should be organized around authentic entrepreneurial cases derived from local shoe manufacturing processes. Second, mathematical concepts should be integrated into real production scenarios involving cost estimation, pricing strategies, inventory management, and sales analysis. Third, adaptive mechanisms should continuously evaluate learner performance and recommend appropriate learning resources based on identified learning needs.

In addition to pedagogical requirements, the framework also defines several functional characteristics, including learner progress tracking, diagnostic assessment, adaptive feedback, learning analytics, and teacher monitoring facilities. These components are intended to support personalized learning experiences while maintaining alignment with vocational mathematics competencies.

The findings indicate that successful implementation of adaptive learning depends heavily upon rigorous instructional analysis conducted during the Define stage. According to Thiagarajan et al. (1974), careful identification of learner needs and instructional objectives constitutes the most critical prerequisite for effective instructional product development. Likewise, Branch (2009) explains that systematic instructional planning significantly improves the quality and relevance of educational technology products developed during later implementation stages.

Therefore, the conceptual specification framework produced in this study serves as an evidence-based foundation for designing an Adaptive Learning Platform that integrates intelligent instructional support with authentic vocational mathematics learning.

The findings demonstrate that mathematical numeracy instruction should move beyond procedural computation toward contextual reasoning that reflects authentic workplace demands. Unlike conventional mathematics learning, which frequently separates mathematical concepts from practical application, the proposed Adaptive Learning Platform positions mathematical knowledge as a tool for solving entrepreneurial problems encountered in local manufacturing industries.

This study also confirms the importance of conducting comprehensive instructional analysis before designing educational technology. By limiting the research to the Define stage, the study establishes empirical justification for future product development while maintaining methodological consistency with the Four-D instructional development model. Instead of claiming product validation or implementation outcomes, the research contributes a conceptual specification framework grounded in learner needs, curriculum analysis, industrial practice, and current instructional theory.

From a pedagogical perspective, integrating authentic entrepreneurial contexts into mathematics instruction has the potential to increase learning

relevance, improve students' critical thinking, and strengthen mathematical reasoning required for vocational employment. The adaptive characteristics proposed for the platform further extend this contribution by recognizing learner diversity and providing individualized instructional support throughout the learning process. These findings are consistent with the principles of learner-centered instructional design and adaptive educational technology discussed by Branch (2009), Thiagarajan et al. (1974), and Palangda et al. (2024).

Overall, this study contributes theoretically by providing a structured instructional specification framework for adaptive mathematics learning and contributes practically by identifying pedagogical and functional requirements necessary for developing an Adaptive Learning Platform that integrates mathematical numeracy with authentic entrepreneurial experiences in local shoe manufacturing. The resulting framework provides a strong empirical basis for proceeding to the Design stage, where instructional architecture, interface design, and adaptive algorithms can be systematically developed and validated in subsequent research.

CONCLUSION

This study successfully achieved its objective of formulating a conceptual specification framework for an Adaptive Learning Platform (ALP) designed to support challenge-based mathematical numeracy learning within the context of local shoe manufacturing entrepreneurship. Through the Define stage of the Four-D (4D) Research and Development model, the study systematically identified instructional needs, relevant mathematical concepts, learner characteristics, and functional learning requirements necessary for future platform development. The findings indicate a significant gap between students' mathematical numeracy competencies and the numeracy skills required in authentic entrepreneurial activities, particularly in cost estimation, pricing strategies, profit calculation, percentage, ratio, and statistical reasoning. These findings confirm that contextualizing mathematics learning through real industrial challenges provides a strong empirical foundation for designing adaptive learning environments that are responsive to learners' needs and vocational demands.

This study contributes to educational practice by providing an evidence-based framework for integrating adaptive learning, mathematical numeracy, and authentic entrepreneurial contexts within vocational education. The conceptual specification framework developed in this research offers practical guidance for educators, instructional designers, and educational technology developers in designing learning experiences that are more personalized, contextual, and relevant to twenty-first-century competencies. Furthermore, the study enriches the discourse on adaptive learning in mathematics education by demonstrating that instructional design should be grounded in comprehensive needs analysis before technological implementation. Consequently, the findings provide an important foundation for the subsequent Design, Develop, and Disseminate stages, while contributing to the advancement of adaptive and context-based mathematics education that better prepares learners for industrial and entrepreneurial environments.

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