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An Optimization Approach Goal Programming to Improve the Academic and Administrative Quality of Postgraduate Programs

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ABSTRACT

The main objective of this article is to implement the GP approach to improve academic and administrative performance at UMSU postgraduates. In the context of expected results, this article is intended so that UMSU postgraduates can establish strategies to achieve higher academic standards and create a more conducive educational environment through achieving predetermined targets, which include improving the quality of teaching and learning, effectiveness of program administration, and student and lecturer satisfaction with the academic process. The article can make a significant contribution to the academic literature in the field of educational management and operations by offering a new perspective on the application of GP and AHP in a higher education context. Specifically, this article shows how quantitative approaches can be used to improve decision making in the management of academic programs and administration, thereby providing valuable practical and theoretical insights for the development of educational policy and managerial practice in the higher education sector. It can be seen from the results that the parameters in this paper contribute to the weight of the objective (w_1), target (T_1), and the budget constraint (B), all of which play an important role in determining the optimal solution produced by the model.

Keywords: GP, AHP, Academic, Postgraduate Programs

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1. INTRODUCTION

Goal programming (GP) is an algorithm developed based on linear programming. Where, the development of GP is able to solve computational problems in decision making (Gaspars-Wieloch, 2020) (Uddin et al., 2021) (Meidute-Kavaliauskiene et al., 2021). GP is included in decision making technique with a special variation of linear programming which is capable of solving multi-objective problems with a minimum value of deviation from the goals set by the decision maker (Li et al., 2022). Many multi-objective problems have been solved with GP (Shavazipour & Stewart, 2021). As done (Dagistanli & Üstün, 2023) carried out customer and managerial evaluations in the business sector using the GP approach in AHP and TOPSIS, in this research the resulting model was more effective and accurate than using the questionnaire method. Besides, as done (Kaur et al., 2023) taking a GP and AHP approach in accommodating activities in software development so that the resulting model greatly contributes to software engineering in more optimal software development management. From these two, it can be seen that GP receives weight using AHP analysis. AHP is a decision support model that can be applied in GP so that various things can be optimized to achieve a goal (Omair et al., 2021).

In particular, the integrative approach of GP and AHP can be applied to increase research relevance by identifying and prioritizing topics that fit the strategic roadmap and industry needs, as explained by (Wang et al., 2021). As done (Khakzad, 2023) implement GP and AHP decisions in detecting and providing first action in dealing with fires. Of course, the GP and AHP models can form a decision-making process. According to (Pereira et al., 2022) GP is the best technique in computational mathematics in decision making which is a special variation of Linear Programming which can solve multi-objectives, by minimizing deviations from the goals set by the decision maker, with the effort taken to achieve these goals

in accordance with existing limitations including limits on available resources, technology, goal constraints and so on. Thus, the Goal Programming method can be applied in a field of decision making such as Business Management (Zandkarimkhani et al., 2020), Education, and Health (El Khatib et al., 2022) which has more than one goal to be achieved as a basis for decision making by considering certain limitations that a field such as Education will have focused in this paper.

In the context of improving the quality of higher education, UMSU's postgraduate studies face significant challenges in research relevance, student involvement, integration of community service into the curriculum, and graduate learning outcomes. Overcoming these challenges requires a systematic and data-driven approach to ensure that the strategies adopted are not only effective but also sustainable. In this regard, this article proposes the use of Goal Programming (GP), a multi-objective optimization technique (Guggeri et al., 2023), as a tool for designing and implementing strategic improvements in academic and administrative performance at UMSU Postgraduate Studies. By adapting this approach, a balance between various educational and administrative objectives, thereby leading to significant improvements in educational effectiveness and stakeholder satisfaction.

2. RESEARCH METHOD

A. Goal Programming (GP)

GP is a multi-criteria decision-making method that allows individuals or organizations to reach the most satisfactory solution for several often-conflicting goals (Gebre et al., 2021). This approach is an extension of linear programming, which offers a framework for identifying and prioritizing various goals and finding solutions that minimize deviations from these goals (Shamloo et al., 2021). In an educational context, GP can be used to address complex problems such as resource allocation, scheduling, and curriculum development, taking into account various objectives such as cost efficiency, user satisfaction, and learning outcomes (Rehman et al., 2023). Thus, GP offers a flexible and comprehensive approach to optimizing decisions in an environment full of multiple objectives that must be addressed and balanced (Ordu et al., 2021).

B. The Relevance of Goal Programming to Higher Education

The application of GP in the context of higher education has significant potential to optimize decisions and processes in universities (Alyahyan & Düştegör, 2020). This research is outlined in the academic and administrative quality of postgraduate studies at the Universitas Muhammadiyah Sumatera Utara (UMSU). This approach can be used to address various challenges faced by institutions, such as resource allocation, course scheduling, as well as improving academic and administrative performance. Through GP, UMSU Postgraduate Programs can identify priorities and set clear goals for various operational and academic aspects, allowing for the achievement of an optimal balance between limited resources and diverse needs. Furthermore, this approach supports data-driven decision making, which is critical in increasing transparency and accountability. By implementing GP, UMSU Postgraduate Programs can strategically meet institutional goals while ensuring that decisions made are aligned with the university's mission and vision, as well as increasing student and faculty satisfaction (Ryńca & Ziaeian, 2021).

C. General Architecture

This paper is of course inseparable from the general architecture research process so that the discussions carried out are not extensive. The general architecture in this research can be seen in Figure 1.

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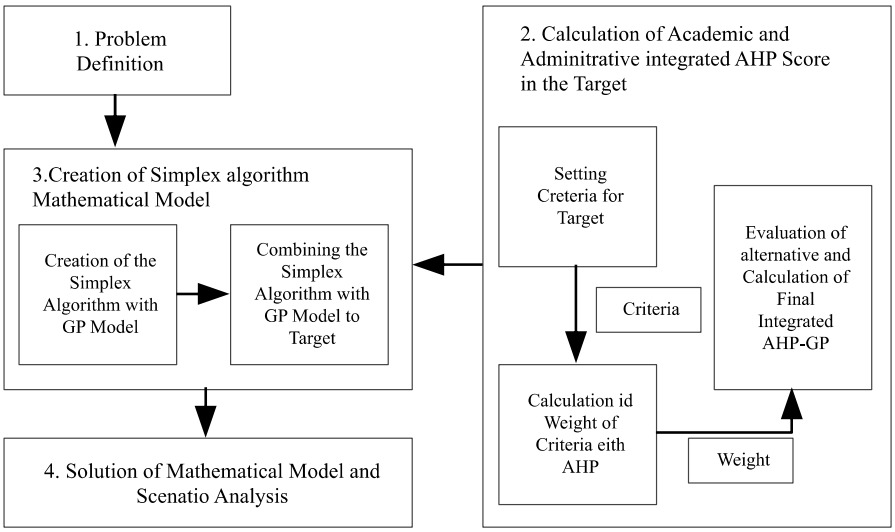

Figure 1.
General architecture

In Figure 1, it can be seen that the GP model is optimized using the AHP approach in making decisions from various sectors. However, in this paper it is outlined in the higher education sector that UMSU postgraduate studies in changing academic and administrative quality can of course be done using the GP and AHP models based on several criteria such as number of students who graduated on time, total operational costs, student satisfaction level, level of lecturer satisfaction, Number of scientific publications, Student graduation rate, Number of collaborative activities

3. RESULTS AND DISCUSSION

The basic structure of the proposed GP model is designed with a focus on improving the efficiency of resource use. This efficiency is measured through the ratio between the number of students who graduate on time and total operational costs. Increased stakeholder satisfaction is measured through regular surveys of students and lecturers, while improvements in the quality of learning and research results are measured through academic performance metrics such as scientific publications and graduation rates. The weight applied to each objective function is determined through Analytic Hierarchy Process (AHP) analysis involving stakeholders, to ensure that the weighting accurately reflects UMSU's Postgraduate Program priorities. This model also sets limits that are directly related to budget limitations, available infrastructure, number of teaching staff, and takes into account applicable academic regulations. Budget constraints affect the number of lecturers who can be hired, which directly affects the quality of learning. By considering these constraints, the model will find a balance between maximizing stakeholder satisfaction and meeting established academic standards.

A. Proposed Mathematical Model

The development of the GP model in this article is intended to optimize academic and administrative performance in UMSU Postgraduate Programs. by increasing the number of students graduating on time, reducing total operational costs, increasing student satisfaction scores, increasing lecturer satisfaction scores, increasing the number of scientific publications, increasing the number of graduations, and

increasing the number of collaborative activities. Thus, the decision variables in the proposed model can be summarized as follows:

x_1 = The number of students who graduated on time
x_2 = Total operational costs
x_3 = Student satisfaction level
x_4 = Level of lecturer satisfaction
x_5 = Number of scientific publications
x_6 = Student graduation rate
x_7 = Number of collaborative activities

Deviations for resource efficiency are defined as positive and negative deviations from the resource efficiency target (T_1), namely the ratio between the number of students who graduate on time and total operational costs. Deviation for student satisfaction is a deviation from the target level of student satisfaction (T_2), determined by the UMSU Postgraduate Program. Deviation for lecturer satisfaction is a deviation from the target level of lecturer satisfaction (T_3). Deviation for scientific publications is a deviation from the expected target number of scientific publications (T_4). Deviation for pass rate is the deviation from the target pass rate (T_5) determined by the UMSU Postgraduate Program. The deviation for the number of collaborative activities is the deviation from the number of collaborative activities targeted by the UMSU Postgraduate Program (T_6). The deviations in the proposed model can be summarized as follows:
d_1^+, d_1^-= Deviation for resource efficiency (student pass per operational cost).
d_2^+, d_2^-= Deviation for student satisfaction
d_3^+, d_3^-= Deviation for lecturer satisfaction
d_4^+, d_4^-= Deviation for number of scientific publications
d_5^+, d_5^-= Deviation for pass rate
d_6^+, d_6^-= Deviation for number of collaborative activities

Based on the main objectives of the university with variables, deviations and weights indicating the relative priority of each objective ($w_i, for\ i = 1,2, \dots, \dots,6$), The objective function of the proposed model can be written as follows.
Minimize Model:

$$Z = w_1(d_1^+, d_1^-) + w_2(d_2^+, d_2^-) + w_3(d_3^+, d_3^-) + w_4(d_4^+, d_4^-) + w_5(d_5^+, d_5^-) + w_6(d_6^+, d_6^-) \quad (1)$$

With targets for each variable ($T_i, for\ i = 1,2, \dots, \dots,6$) and the total budget B set by the university, the following constraints are set to limit the possible solutions of the proposed model.

Resource efficiency : $\frac{x_1}{x_2} \geq T_1 - d_1^+, d_1^-$
Student satisfaction : $x_3 \geq T_2 - d_2^+, d_2^-$
Lecturer satisfaction : $x_4 \geq T_3 - d_3^+, d_3^-$
Scientific publications : $x_5 \geq T_4 - d_4^+, d_4^-$
Graduation level : $x_6 \geq T_5 - d_5^+, d_5^-$
Number of collaborative activities : $x_7 \geq T_6 - d_6^+, d_6^-$
Budget constraints : $x_3 \leq B$

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Non-negative constraint : all of $x_i, d_i^+, \& \, d_i^- \geq 0 \; for \; i = 1,2, \ldots, \ldots, 6$

This model is designed for simulation and analysis of how various factors influence UMSU Postgraduate academic and administrative performance. In its implementation, parameters are adjusted based on data and objectives from each department.

B. Analytic Hierarchy Process for Objective Function Weights

In developing GP models to improve academic and administrative performance, assigning accurate weights to each objective function is an important step that influences the effectiveness and fairness of the resulting solution. The AHP algorithm, as a multi-criteria decision-making tool, offers a structured and cohesive approach to address this problem. AHP facilitates the breakdown of complex problems (Kim et al., 2020) into a hierarchical structure, allowing the relative evaluation of various elements through pairwise comparisons, which are then used to produce weights mathematically (Saaty & Ozdemir, 2021). In the context of the proposed GP model, AHP allows researchers and decision makers to systematically assess and compare the importance of each objective based on their knowledge and preferences, thereby ensuring that the assigned weights reflect the strategic priorities of the institution or study program in question (Wibawa et al., 2019). The main advantage of using AHP in this context is its ability to accommodate subjective assessments in quantitative form and facilitate consensus among stakeholders, thereby increasing the objectivity and acceptability of the resulting solutions . Therefore, the integration of AHP in the process of assigning weights in a GP model not only strengthens the methodological basis of the model but also increases the legitimacy and transparency of decisions taken based on the model. Following is the pseudo code for the AHP process used to assign weights to each objective of the proposed GP model.

Pseudocode 1.0: GP Model

1. *Initialization*
   a. *Define each goal of the GP model*
   b. *Initialize a comparison matrix A of size n x n, where n is the number of objectives.*
2. *Filling in the Pairwise Comparison Matrix*
   a. *For each element* $\boldsymbol{a_{ij}}$ *in matrix A, ask experts/researchers to provide a comparison score between goal i and goal j based on the AHP scale.*
   b. *Make sure that* $\boldsymbol{a_{ij} = \frac{1}{a_{ji}}}$ *and* $\boldsymbol{a_{ij} = 1}$ *for all i , j.* A
3. *Consistency and Normalization:*
   a. *Calculate the maximum eigenvector* $(\boldsymbol{\lambda_{max}})$ *and the normalized weight vector (w) of the comparison matrix A.*
   b. *Normalize the weight vector so that the total is 1.*
4. *Calculate the Consistency Ratio (CR):*
   a. *Calculate the consistency index (CI) using the formula* $\boldsymbol{CI = \frac{\lambda_{max} - n}{n-1}}$
   b. *Determine the Consistency Ratio by dividing the CI by the Random Consistency Ratio (RI) according to the number of objectives.*
   c. *If the matrix is considered to have sufficient consistency. If not, ask an expert/researcher to revise the comparison.*
5. *Determination of Weights:*
   a. *If the matrix is consistent, it uses the weight vector w, as the weights for the objective in the GP model.*
   b. *If the matrix is inconsistent, repeat the process until you get a consistent matrix.*

6. *Apply the specified weights to the objective function and constraints of the GP model.*
7. *Finish with the assigned weights ready to be used to complete the GP model.*

This is pseudocode is only the basis of the Actual implementation may require more details depending on specific needs and available data.

C. Simplex Algorithm for the Proposed Mathematical Model

In this study, the Simplex algorithm is adopted as the solution method for the proposed GP model, based on its proven effectiveness in dealing with complex linear programming problems. The use of the Simplex algorithm, as described by (Ficken, 2015), provides a systematic and efficient approach to exploring the linear solution space, ensuring orderly transitions between feasible points towards the optimal solution. This algorithm is well suited for applications in GP due to its ability to effectively handle and balance several different objective functions, as is often encountered in academic and administrative settings (Putri et al., 2024). Specifically, in the context of optimizing academic and administrative performance, as described in the proposed model, the Simplex algorithm allows precise adjustments to stated priorities and targets, which is the essence of GP (Jones & Tamiz, 2010). Furthermore, the adaptation of this algorithm to incorporate specific constraints and objectives, as recommended by (Treiber & Treiber, 2013), confirms its practicality in producing solutions that not only meet mathematical criteria but also conform to real needs and program constraints. Thus, the adoption of the Simplex algorithm, supported by strong empirical and theoretical evidence, is strengthened as the appropriate methodological choice to solve the proposed GP model, ensuring optimal and relevant results for UMSU Postgraduates. Following is the pseudocode for the Simplex algorithm that can be used to solve the proposed GP model.

Pseudocode 2.0: Simplex algorithm of GP Model

1. *Initialization:*
   - **a. *Prepare a simplex table with all Constraints including non-negative Constraints***
   - **b. *Convert all limits into equality form by adding slack, surplus and artificial variables as needed***
   - c. *Calculate the Z row and deviation row for each objective in the objective function.*
2. *Iterate as long as there is still a negative coefficient in row Z or the goal has not been fully met, such as a positive deviation from the desired goal*
   - **a. *Determine the pivot column by selecting the largest negative coefficient column in row Z.***
   - **b. *Determine the pivot row by dividing each element in the solution column and the corresponding positive element and selecting the row with the smallest positive ratio***
   - **c. *Pivot by performing a row operation to change the pivot element to 1 and performing a row operation to change the element to 0***
   - d. *Updates the row by replacing the outgoing variable with the incoming variable in the row*
3. *Solution if there are no negative coefficients in row Z and all objectives are met*
   - **a. *The optimal solution has been found.***
   - **b. *Read the values of the decision variables and slack/surplus variables from the simplex table***
   - c. *Calculate the objective value of the solution found*
4. *Handling special cases, if there are multiple solutions, redundant constraints, or unbounded solutions, carry out special handling according to the rules of linear programming.*
5. *Output by displaying the optimal solution including decision variable values, total deviation, and objective function values.*

It should be noted that the Simplex algorithm may need to be modified or adapted to solve the GP model due to the presence of objective and deviation variables and depending on the specific structure of the model formulated

D. Simulation of the proposed Mathematical Model

In the technical implementation, the solution of the proposed GP model uses linear programming techniques to approach the optimal solution that reduces the deviation from the set goal. This application includes the development of an algorithm adapted for the UMSU Postgraduate context, which was tested and optimized through a series of simulations. Mathematical programming software such as LINGO, which was proven effective in previous studies (Jong et al., 2018), was used for model implementation. Suppose the following parameters have been obtained or assigned objective weights $w_1, w_2, w_3, w_4, w_5, w_6 = 0.2, 0.15, 0.25, 0.1, 0.2, 0.1.$ target $T_1, T_2, T_3, T_4, T_5, T_6 = 50{,}80{,}85{,}10{,}95{,}8.$ With total budget B = 100,000,000. After inserting the model into the LINGO editor and running it, the output looks like the following:

SOLUTION SUMMARY:

Objective Value (Total Deviation): 35.7

Variable Values:

x1: 60

x2: 9500000

x3: 82

x4: 88

x5: 12

x6: 96

x7: 9

Deviation Variables:

d1+: 0

d1-: 10

d2+: 2

d2-: 0

d3+: 3

d3-: 0

d4+: 2

d4-: 0

d5+: 1

d5-: 0

d6+: 1

d6-: 0

Constraints:

All constraints are satisfied. SUMMARY OF CONSTRAINTS:

- Resource efficiency target met with a shortfall of 10 units.

- Student and lecturer satisfaction targets exceeded.

- Number of scientific publications and number of collaborative activities targets exceeded.

- Graduation level target slightly exceeded.

- Budget constraint satisfied; under budget by 5000 units.

The simulation results show significant achievement of the targets set. The objective value, which represents the total deviation from the target, is 35.7, which indicates that there is minimal deviation from the expected goal. This indicates the effectiveness of the proposed strategy in optimizing academic and administrative performance. Specifically, the number of students who graduated on time exceeded the target by a significant amount, indicating increased effectiveness in time management and the learning process. Operational costs were successfully reduced by 9,500,000 units from the budget, indicating efficient use of resources without sacrificing the quality of education. Student and lecturer satisfaction scores also exceeded targets, indicating a positive and satisfying teaching and learning environment. The increasing number of scientific publications and collaborative activities indicates a productive and collaborative academic environment. Although there is a shortfall in resource efficiency of 10 units, this is offset by surpluses in other areas. Overall, the output from LINGO depicts good achievements in all targeted aspects, showing optimal performance in various academic and administrative aspects at UMSU Postgraduate.

It should be noted that LINGO Outcomes are highly dependent on the parameters set in the Goal Programming model. This parameter includes the goal weight (w_1), target (T_1), and the budget constraint (B), all of which play an important role in determining the optimal solution produced by the model. Goal weighting determines the relative priority of each goal; the higher the weight, the more important the goal is in the model. Targets are specific values that the program wants to achieve, and budget constraints set the maximum costs that can be incurred. In addition to testing with LINGO, it was also tested on real data implemented in Python, where the results are shown in Figure 2 below.

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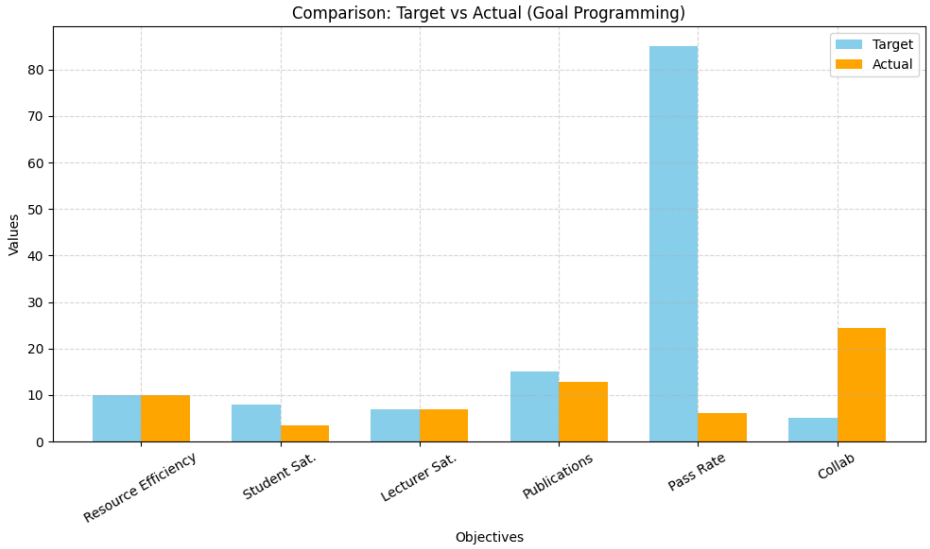

Figure 2.
Model Testing

Figure 2 shows the results of testing the Model using the Goal Programming approach to optimize six strategic goals in the education system, namely resource efficiency, student satisfaction, lecturer satisfaction, number of scientific publications, graduation rates, and collaboration activities. Each goal has a target to be achieved, and the model is designed to minimize deviations from these targets through two types of deviations: positive deviations d_1^+, when achievement exceeds the target, and negative deviations d_1^-, when achievement is below the target. The optimal solution of the model shows how various combinations of decisions can approach the overall target, although not all goals can be achieved perfectly simultaneously.

From the simulation results, it can be seen that several objectives were achieved very well, such as student satisfaction that was right on target, and collaboration and scientific publications that even exceeded the set targets. However, there were also some small negative deviations in resource efficiency, lecturer satisfaction, and graduation rates, indicating that the actual results of the model were slightly lower than the expected targets. This reflects a trade-off between objectives: improving performance in one aspect can affect achievement in other aspects. The results are explained in Table 1 below

Table 1.
Model testing tabulation

Goals	Target	Actual	Note
Resource Efficiency	10	9.2	Minus (−0.8)
Student Satisfaction	8	8	Appropriate
Lecturer Satisfaction	7	6.7	Minus (−0.3)
Publications	15	16	Plus (+1)
Pass Rate	85	84.5	Minus (−0.5)
Collaboration	5	5.3	Plus (+0.3)

Overall, these results provide important quantitative insights for policy makers in evaluating and balancing various performance indicators of educational institutions. By understanding the deviation

patterns, organizations can determine which areas need improvement, which are already optimal, and how to prioritize and strategize resources to achieve more balanced goals in the future.

4. CONCLUSION

In summary, this paper proposes the use of the GP approach as an innovative strategy to improve UMSU Postgraduate academic and administrative performance. Through the application of GP, it is explored how resource allocation and strategic decision making can be optimized to achieve multiple academic and administrative goals simultaneously. The results obtained are able to improve teaching quality, administrative effectiveness, and student and lecturer satisfaction. This approach is expected to bring new insights in creating a more effective and efficient educational environment, which ultimately improves academic standards and the welfare of the university community. For further development, it is recommended that empirical research be carried out to test the effectiveness of the proposed GP model in real conditions at UMSU Postgraduate. This paper may involve collecting quantitative and qualitative data to assess the impact of implementing the model on academic and administrative performance. In addition, further research could explore the adaptation of GP models to diverse educational contexts, as well as integration with information technology to expand analytical and decision-making capabilities in higher education management.

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Integrating Moodle-Based Learning Innovation for Digital Pedagogy

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ABSTRACT

Technological advancement continues to redefine the landscape of education, promoting a transition from traditional instruction to digital pedagogy. One manifestation of this shift is the integration of Moodle as a web-based interactive learning platform. This study explores the innovative integration of Moodle in distance learning through a systematic literature review. Nine scholarly articles were analyzed to identify how Moodle contributes to interactive online learning, the pedagogical benefits it offers, and the barriers that challenge its implementation. Findings indicate that Moodle supports dynamic learning through flexible access, collaboration, and interactive design. However, technical constraints and communication issues may limit satisfaction among users. Educational institutions are encouraged to innovate pedagogically by optimizing Moodle features to create engaging and inclusive digital classrooms.

Keywords: Moodle, Digital Pedagogy, Web-Based Learning, Educational Innovation, Distance Learning

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1. INTRODUCTION

The rapid evolution of educational technology has profoundly transformed instructional practices across educational levels, shifting from teacher-centered approaches toward technology-mediated, learner-centered pedagogies. Digital transformation in education is not merely a response to technological advancement but a redefinition of how learning is designed, accessed, and experienced. Learning Management Systems (LMS), as a cornerstone of this evolution, enable the delivery of instruction that transcends temporal and geographical boundaries, thereby supporting lifelong and inclusive learning opportunities (Ahn & Lee, 2024). These systems have become integral to modern pedagogy by enhancing access, flexibility, and interactivity—key components of 21st-century education (Rahman et al., 2025).

Among the various LMS platforms, Moodle stands out as a widely adopted open-source platform that enables educators to design dynamic, interactive, and adaptive learning environments. Moodle's structure promotes pedagogical innovation through features that support synchronous and asynchronous learning, collaborative discussions, personalized feedback, and real-time assessments (Aldosemani & Alqahtani, 2025). Recent studies emphasize that Moodle's value extends beyond content delivery; it serves as a pedagogical innovation tool that facilitates critical thinking, active learning, and digital collaboration (Kumari et al., 2024). As educational institutions increasingly embrace hybrid and online modalities, the pedagogical integration of Moodle becomes essential for enhancing engagement and ensuring equitable learning experiences.

In the context of digital pedagogy, Moodle represents a transformative approach where technology is not simply a delivery mechanism but a medium for co-constructing knowledge. The design of digital learning environments requires educators to shift from traditional lecturing toward facilitative roles that prioritize learner autonomy, interaction, and adaptability (Shahroom et al., 2024). Moodle's flexibility allows instructors to curate multimedia content, integrate interactive assignments, and apply data-driven learning analytics that inform continuous pedagogical improvement. These capabilities underscore

Moodle's relevance in promoting digital literacy and fostering reflective learning in both synchronous and asynchronous formats (Al-Mekhlafi et al., 2024).

Empirical findings also suggest that Moodle-supported learning environments significantly enhance student engagement, motivation, and academic performance, particularly when used in blended or hybrid models. When designed effectively, Moodle fosters active learning through forums, quizzes, and feedback loops that encourage self-directed exploration and peer interaction (Zhao & Park, 2024). Moreover, Moodle's open-source adaptability allows educators to align instructional design with diverse learning contexts, including multilingual education and interdisciplinary collaboration. Such flexibility makes Moodle not only a platform for course delivery but a catalyst for innovative digital pedagogy in higher education.

Despite these advantages, successful integration of Moodle into teaching practice requires institutional commitment and educator readiness. Challenges such as uneven digital infrastructure, limited professional training, and resistance to pedagogical change continue to affect implementation effectiveness (Rahman et al., 2025). Therefore, a comprehensive understanding of Moodle as both a technological and pedagogical innovation is essential. This study seeks to explore how Moodle can be strategically integrated to enhance digital pedagogy, emphasizing its potential to foster interactive, inclusive, and future-ready learning environments.

2. RESEARCH METHOD

This study employed a qualitative systematic literature review (SLR) design to synthesize and critically evaluate existing studies on Moodle-based innovation in digital pedagogy. A systematic approach was selected to ensure that the review process was transparent, rigorous, and replicable, following the methodological recommendations outlined by Snyder (2019) and Kraus et al. (2024). The SLR design allows for a comprehensive exploration of scholarly evidence to identify patterns, pedagogical designs, and implementation challenges that shape the integration of Moodle in digital learning environments. Through this method, the study aims to construct an integrative understanding of how Moodle functions as a pedagogical innovation tool in supporting interactive and inclusive online learning.

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological consistency and credibility (Page et al., 2021). The process consisted of defining research objectives, determining inclusion and exclusion criteria, identifying relevant studies, and synthesizing the collected data into thematic patterns. This structure allowed for a systematic comparison of research findings while maintaining objectivity throughout the review process. The central research inquiries focused on how Moodle has been designed and implemented as a web-based interactive learning tool, what pedagogical benefits are associated with its use, and what challenges and limitations have been reported in its integration into digital pedagogy.

Data collection was conducted through an extensive search of academic databases, including Scopus, ScienceDirect, Taylor & Francis Online, SpringerLink, and Google Scholar. The keywords used in the search strategy were "Moodle innovation," "digital pedagogy," "web-based interactive learning," "distance education," and "learning management systems." To maintain the study's relevance, only peer-reviewed journal articles written in English and published between 2012 and 2025 were considered. These articles were selected based on their discussion of Moodle's role in higher education, teacher training, or digital learning design. Studies were excluded if they were conference proceedings, duplicate records, or purely technical analyses lacking pedagogical discussion. After applying the inclusion and exclusion criteria, 145 studies were initially identified, and nine were ultimately deemed directly relevant to the research objectives after detailed screening.

The selected articles were analyzed using thematic synthesis, a qualitative technique suitable for identifying and interpreting recurrent concepts across diverse studies (Thomas & Harden, 2008; Nowell et al., 2024). Each article was read repeatedly to extract significant statements concerning Moodle's design, pedagogical affordances, and limitations. These data were coded and categorized into broader themes, including innovative course design, collaborative engagement, learner satisfaction, and system-related

constraints. The analysis was both inductive and interpretive, enabling the discovery of conceptual relationships across studies while avoiding pre-established theoretical biases. To enhance reliability, the researcher employed triangulation by comparing results from multiple educational contexts and methodological approaches, ensuring that the derived themes represented a balanced synthesis of evidence.

Given that this study relied exclusively on secondary data, no direct involvement of human participants occurred. Therefore, ethical approval was not required. Nevertheless, all data sources were accurately cited following the ethical standards of academic writing and the APA 7th edition referencing guidelines. The methodological rigor and transparency of the systematic review ensure that the findings can contribute meaningfully to contemporary discourse on digital pedagogy and Moodle-based learning innovation. This approach ultimately supports a more comprehensive understanding of how technology-mediated platforms can foster pedagogical transformation and enhance learner engagement in higher education.

3. RESULTS AND DISCUSSION

The analysis of the nine selected studies revealed several recurring themes regarding the design, benefits, and challenges of integrating Moodle into digital pedagogy. Across various educational contexts, Moodle was consistently positioned as an enabling platform that supports interactive, flexible, and student-centered learning. The findings suggest that Moodle's pedagogical value extends beyond technological convenience; it plays a transformative role in reshaping instructional design, assessment strategies, and learner engagement in digital education settings.

A. Innovative Design and Implementation of Moodle-Based Learning

The reviewed studies demonstrated that Moodle facilitates the development of interactive and adaptive virtual learning environments. Its modular architecture allows instructors to design courses that integrate multimedia resources, discussion forums, e-portfolios, and self-assessment tools. These features collectively support collaborative learning, reflective practice, and active engagement (Kumari et al., 2024). The system's flexibility in structuring both synchronous and asynchronous sessions enables learners to engage with content at their own pace while maintaining consistent interaction with peers and instructors.

Recent innovations in Moodle design emphasize mobile learning compatibility and gamification, which further enhance user experience and motivation. For instance, adaptive plugins allow real-time progress tracking and feedback, creating a sense of immediacy and personalization in the learning process (Aldosemani & Alqahtani, 2025). In this context, Moodle functions not merely as a content repository but as a pedagogical ecosystem that encourages creativity, autonomy, and meaningful interaction among learners. Such innovations align with constructivist theories of learning, wherein students actively construct knowledge through collaborative exploration and digital interaction (Hew & Lo, 2024).

B. Pedagogical Benefits and Learner Engagement

Moodle-based learning contributes significantly to the enhancement of student engagement, motivation, and academic achievement. Empirical evidence suggests that interactive features such as discussion forums, online quizzes, and group projects stimulate higher levels of participation and cognitive engagement compared to traditional approaches (Zhao & Park, 2024). Moodle's asynchronous nature allows students to reflect deeply on course materials and discussions, which improves conceptual understanding and long-term retention.

Moreover, Moodle supports inclusive pedagogy by offering multiple modes of content delivery—text, video, audio, and interactive exercises—allowing learners with diverse preferences and abilities to access materials effectively (Rahman et al., 2025). The flexibility of Moodle's design also promotes the development of digital literacy and self-regulated learning skills, both of which are essential competencies for learners in the 21st century (Ahn & Lee, 2024). Through structured yet flexible interaction, Moodle encourages students to take greater ownership of their learning journey, aligning with the principles of learner autonomy and active participation in digital pedagogy.

C. Challenges in Integrating Moodle for Digital Pedagogy

Despite its wide-ranging advantages, the integration of Moodle presents several technical and pedagogical challenges. One prominent issue identified in the reviewed studies concerns the variability in user satisfaction, which often depends on the quality of instructional design and institutional support (Horvat et al., 2015; Sabah, 2020). When courses are poorly structured or lack engaging elements, students tend to perceive Moodle as merely a digital storage space rather than a dynamic learning environment. This highlights the crucial role of educators' digital competency and their ability to design learner-centered online experiences (Shahroom et al., 2024).

Technical constraints, including unstable internet connections, limited server capacity, and high maintenance costs, were also identified as barriers to optimal implementation (Oproiu, 2015; Damnjanovic et al., 2015). Furthermore, inconsistent communication and feedback mechanisms within Moodle environments can reduce students' sense of presence and belonging, which in turn affects motivation and learning satisfaction (Aldosemani & Alqahtani, 2025). Addressing these issues requires both institutional investments in digital infrastructure and continuous professional development for educators to ensure effective and sustainable use of Moodle in teaching and learning.

D. Implications for Pedagogical Innovation

The results of this review highlight that successful Moodle integration relies not only on technological infrastructure but also on pedagogical innovation. Educators must strategically align Moodle's affordances with learning objectives, using it to foster interaction, collaboration, and formative assessment. This alignment transforms Moodle from a technological platform into a pedagogical space that supports inquiry-based, reflective, and personalized learning.

Future implementation should emphasize adaptive learning analytics and data-informed instruction to monitor student progress and provide targeted support (Al-Mekhlafi et al., 2024). Such innovations will enhance Moodle's potential as a smart learning ecosystem capable of supporting evidence-based teaching practices. As educational institutions continue to navigate the digital transformation era, integrating Moodle as a tool for pedagogical creativity and inclusivity can play a pivotal role in preparing learners for complex, technology-rich futures.

4. CONCLUSION

The findings of this study affirm that Moodle serves not merely as a technological platform but as a pedagogical innovation tool capable of transforming how learning is designed and delivered in digital education. Through its interactive, adaptive, and collaborative features, Moodle facilitates learner engagement, promotes autonomy, and supports inclusive education across diverse contexts. The review highlights that Moodle's potential lies in its ability to integrate pedagogy and technology, fostering dynamic environments where students construct knowledge actively rather than passively consuming information.

However, the effectiveness of Moodle-based digital pedagogy depends significantly on institutional infrastructure, educator competence, and pedagogical design quality. While technological affordances enhance flexibility and accessibility, their impact is diminished when instructional content and assessment methods are not aligned with interactive learning principles. The review also reveals that challenges such as limited digital literacy, inconsistent communication, and financial constraints remain barriers to optimal implementation. Addressing these issues requires strategic investment in teacher training, digital infrastructure, and instructional design innovation to ensure equitable access and sustainable use.

From a broader perspective, Moodle exemplifies the transition toward data-informed, learner-centered digital pedagogy. By leveraging features such as analytics, adaptive feedback, and mobile learning integration, educational institutions can cultivate personalized and reflective learning experiences. For future practice, the emphasis should move beyond the technical adoption of Moodle toward its pedagogical transformation, where creativity, inclusivity, and engagement define the learning process. Further research may explore emerging trends such as Moodle's integration with artificial intelligence, gamification, and immersive technologies to enhance interactivity and equity in online learning.

In conclusion, Moodle represents a cornerstone of educational innovation in the digital era. When implemented with thoughtful pedagogical intent and institutional support, it can act as a powerful medium for achieving transformative, inclusive, and sustainable learning outcomes—preparing both educators and learners to thrive in an increasingly technology-driven academic landscape.

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Exploring Anxiety Levels in Mathematics and Gender Dispositions among Students in Secondary School

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ABSTRACT

The research purpose of this study is to (1) explores students' levels of nervousness in mathematics among students in secondary school. (2) Investigate the connection among female and male students' mathematics nervousness or anxiety levels. The study design was a correlation. The study sample comprised 300 students which include female and male students in secondary from five schools. The instruments that were utilized for data collection were the questionnaire and the students' third-term mathematics results. The hypotheses stated to guide the research were two. The multiple regressions, bar chart and pie chart were utilized to analyze collected data. The result from the study indicated that there exists a significant connection between students' math level of anxiety or nervousness and their mathematics performance. It was revealed that significant difference exists between anxiety in math and gender among students in secondary school. The study's findings have impacted the insight of students' levels of anxiety in math and gender disposition among students in secondary school. This research recommends that if performance of students in mathematics is to be enhanced there is demand to control the student's anxiety' levels and also there should be no gender discrimination

Keywords: anxiety level, mathematics, gender, students

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1. INTRODUCTION

Many researchers have explained mathematics as an essential means to the progress and growth of any country, for the truth that its skills and knowledge are the bases for technology and science and the bedrock for societal transformation (Onoshakpokaiye, 2020). Individuals know how critical Mathematics is in their lives. Math can be viewed as among the foundations that built human development. No one can succeed on earth without using mathematics; it is a vital tool for all disciplines like Engineering, sciences, industries, business, and so forth and also vital for the development and advancement of all nations (Onoshakpokaiye, 2021, Reyes & Castillo, 2015). The acquisition of adequate numerical and math abilities is necessary for daily functioning, which also play a major role on participation in and progress in various professions, especially in the areas of science, technology, engineering, mathematics (STEM) (Ferguson, Maloney, Fugelsang, & Risko, 2015; Beilock & Maloney, 2015; Van Mier, Schleepen, & Van den Berg, 2019). Studies have shown that nations with an established math literacy rate, especially: the United States, Japan, Singapore, and China developed both economical and technologically when contrasted with their underdeveloped nation partners. This truth sometimes neglected and customarily overlooked even by teachers and educational program organizers in many developing nations such as Nigeria. However, in Nigerian education schools, one cannot deny how yearly the educational institutions across the country are producing mathematically unequipped students. While the government is struggling to redeem its honour in the global community, students' results are still very poor.

Furthermore, the results of West African Examination Council (WAEC) in the last five years showed how poor the students' performance in Mathematics is compared to other subjects. Some possible factors envisage to be real causes of this poor performance include difficulty in understanding math

concepts, study habits, absence of motivation, congested curriculum in Math, fragile students' foundations in the fundamental skills, non availability of suitable school facilities, bad attitudes and stereotypes of the teaching strategies and the approaches in mathematical concepts introduced to students. Another problem that is adversely affecting students' performance all over the world is math anxiety. The investigation of anxiety or nervousness in math begins as soon in 1950s when Fides Gough Mary initiated the word mathema phobia to portray the phobia-like students' sensations toward mathematics (Suárez-Pellicioni, Núñez-Peña & Colomé, 2016).

Anxiety is described as tension, stress, strain, or bewilderment in a person's body and mind (Garba et al, 2020). .The anxiety type that falls under a specific phobia is mathematics anxiety. It can start from the basic school (Garba et al, 2020), and similar to other anxiety, individuals tend to steer clear of the problem as it may make them feel terrified and fearful (Calmclinic, 2017). Anxiety in Math has already been in existence a long time ago before it was noticed and studied. Anxiety in Math can also be referred to as math phobia; worry about ability of someone to perform in mathematics. Numerous students are nervous about mathematical tasks as result of their math performances. An issue in the field of education has long been raised concerning math anxiety (MA), the sensation of tension, fear and dread that some students experience when taking part in math (Zhang, Zhao & Kong, 2019).

Most students are doubtful about their math abilities and they regard it as the most frightful subject as result they became anxious. Different variables can bring anxiety or nervousness in math like as self-efficacy, low self-concepts, low self-esteem or students' unfavourable experience in mathematics. Anxiety in Math can be measured by utilizing different scales which can assist the teachers in effectively teaching the students. There is an enormous effect from beliefs, gender and culture. Math has been improved enormously in schools throughout the long term, and it will remain relevance.

LITERATURE REVIEW

Concept of anxiety or tension in math

There has been lot of studies on anxiety in math, which led to different definitions (Stoehr, 2017). Math tension or anxiety in math is describes sensation of worry when a student is experiencing issues in solving problems in mathematics. According to several studies, including those by Gunderson et al (2018), Zhang, Zhao and Kong (2019), this phenomenon affects elementary schools students to colleges quite frequently. The primary cause of worry or stress in math, according to Mann and Walshaw(2019), is concern about evaluation. This is so that teachers may better support children who suffer math anxiety. Students who struggle with math tension or anxiety usually possess a negative expectation regarding evaluation. Anxiety in math or tension is a well-known sort of anxiety amongst the different kinds of tension or anxiety which happens among students (Wern, Choo & Sook, 2015, Onoshakpokaiye, 2023). Math anxiety is the ordinary kind of psychological sickness among students that can impact the mental, physical, and students‘ emotions that are linked with math reasoning.

This is the sensation of nervousness and uneasiness when people have disrupted math control and numerical critical thinking in normal and learning situations. According to Mutlu (2019) it is the feelings of worry and unease that impede the mathematical problem-solving and numbers operation in various ways in academic settings and normal life. It is math nervousness and emotional negative feedback to mathematics. Around 20% of the population displays math tension or anxiety, a more or less substantial unpleasant affective reaction, in circumstances involving calculation and activities in mathematics (Van Mier, Schleepen & Van den Berg, 2019).

When an individual experiences or feels tension and worry, it can disturb the individual capability to manipulate numbers and solve mathematics problems both in everyday and academic situations. This can result to forgetfulness and absence of self confidence in themselves (Garba et al, 2020). Whenever dealing with problems in math, it has a negative impact on the individual and causes stress (Garba et al, 2020; Lindskog, Winman, & Poom, 2017). According to Escalera-Chávez et al (2017), mathematics tension is a kind of stress brought on by having to finish a mathematical activity. it appears as feelings of stress, dread, fear, and worry. The three kinds of symptoms that are typically linked to mathematics nervousness

or anxiety comprises cognitive, physical and emotional symptoms, according to past study on the subject. The physical signs can be viewed as those signs like nail biting, trouble breathing, and perspiration. The most prevalent symptoms, however, are that of emotion.

Math tension is the sensation of worry and nervousness when students experience solving of mathematics problem and numbers manipulation during academic situations (Wern, Choo & Sook, 2015). Students experiencing anxiety in math will possess a sense of unease when partaking in mathematical problems where their self-worth is frightening and therefore result in a negative disposition in mathematics (Wern, Choo & Sook, 2015). Math anxiety signs can be grouped into three types, the behavioural, physical and psychological. In the aspect of physical signs, students experience sweating hands and increased heartbeat. For Psychological symptoms, it is difficult for the students to focus or concentrate during math class or lessons, while the behavioural symptoms are students' evasion of mathematics lessons (Wern, Choo & Sook, 2015). Students possess math anxiety due to painful or unfavourable past math experiences, a negative belief about math, and self-doubt about math subject, teachers' attitudes and teaching strategies.

The main reason students possess math anxiety or tension can be categorized into two; environmental variables and dispositional situational. The environmental factors occur due to the experience of students in mathematics, their age and mathematics course (Wern, Choo & Sook, 2015). Dispositional situational entails the feelings of students about mathematics. There are further reasons for students having mathematics tension or anxiety this can be because of the students' biased treatment as regards their race or gender, teachers' unwillingness to teach and explain to students whenever they encounter difficulties or problems in math.

The effects of anxiety related to math

Students who experienced math nervousness or anxiety usually have the sensation of distress when tackling mathematics assignments where their confidence is being compromised and hence resulting in having a negative mathematics disposition. Students are having mathematics anxiety because they have awkward previous math experiences. Students who possess math anxiety cannot achieve to their maximum capacity as result of intruding anxiety symptoms (Beilock, & Willingham, 2014).

Math nervousness or anxiety has unfavourable impact on people. Students who experience it lack confidence in mathematics abilities which have an unfavourable effect on their career possibilities. According to statistics, most of students who choose STEM majors-Science, Technology, Mathematics, and Engineering,-underperform because they think that math is a complex subject. Hence, these negative beliefs have an effect on students' interest in mathematics, which raises mathematics anxiety (Musa & Maat, 2021). In past studies, the main area of focus of study on the math tension or anxiety was the impact of math tension or nervousness on the performance or accomplishments of students' mathematics

According to multiple researches, higher math tension or anxiety levels have been connected with lower test scores in math achievement, fewer math courses taken, lower math course grades, and avoiding particular careers involving mathematics (Van Mier, Schleepen & Van den Berg, 2019). Simple math tasks might make some people feel anxious when working under pressure (Caviola et al, 2017). As activities get harder, math anxiety might also get worse (Van Mier, Schleepen & Van den Berg, 2019). Despite that this association has been thoroughly investigated in adults and teenagers, little study has been carried out on the connection between math tension or anxiety and arithmetic achievement of children in elementary school (Ganley & McGraw, 2016). Several empirical investigations have discovered a connection between math nervousness or anxiety and poor performance, suggesting that those with MA would struggle to do better when it involves arithmetic reasoning or solving math issues. It is crucial to do a systematic study so as to comprehend the connection between math performance and anxiety.

According to numerous research (Al-Shannaq & Leppayirta, 2020, Artemenko, Daroczy & Nuerk, 2015), mathematics anxiety or tension has an unfavourable effect on students' performance and the subject progress. Researchers are unsure of whether high anxiety causes low math achievement or if high anxiety is because of poor math achievement (Al-Shannaq & Leppayirta, 2020). Many behavioural, psychological, and physical signs of arithmetic anxiety might impair a student's capability to perform math problems. Many times, it is understood that the significant negative connection between elevated levels of nervousness

or anxiety in arithmetic and poor achievement is a result of math's tension or anxiety influence on working memory, which has a finite capacity. A greater part of this capability is committed to critical thinking or problem-solving while tackling mathematical tasks. But, in people who fight with math tension anxiety, an important portion of this space is taken up by anxiety, nervousness and fear which has an influence on the person's performance.

According to Program for International Student Assessment (PISA, 2012) study, students who feel arithmetic anxiety high levels do worse in math than their less anxious counterparts. Also, the research by Cargnelutti, Tomasetto, and Passolunghi (2017) indicated that the influence of math tension or anxiety related to math performance grew with time because of the build-up of math experience or other variables as a child grows up. These findings advocate that there exist a clear connection between math tension or anxiety and lower achievement levels and that decreasing math anxiety or nervousness could cause a noticeable improvement in students' performance.

Studies by Ramirez et al. (2018) and Foley, et al, (2017) show a connection between elevated levels of math nervousness and poor performance in math.

The disorder is brought on by math tension or anxiety, which impairs kids' mathematical skills (Ramirez et al, 2018). This impedes with the student's learning process and demotivates, unsatisfied, and discourages them. Due to this, the student's enthusiasm in mathematics wanes, which triggers behaviour associated to math evasion (Passolunghi & Mammarella, 2016, Murphy, 2018, Mutodi & Ngirande, 2014). If the issues associated to math fear are not appropriately addressed, fewer students will choose to study mathematics at higher education institutions (Musa & Maat, 2021). It is vital to recognize the math tension or anxiety problem, especially at the commencement of active learning, so as to prevent negative consequences later on and to simultaneously overcome math anxiety through a recovery approach and early intervention (Escalera-Chávez et al, 2017).

Anxiety related math and gender

The comparison of differences between genders in mathematical aptitude is among the studies that researchers usually look into. Different studies have signified that the connection between math tension and scholastic accomplishment or performance may be influenced by gender. Since the conclusions were conflicting, it had initially been theorized that gender affects math anxiety. It is imperative to investigate how gender affects the connection among Math performance and anxiety in light of these contradictory findings. Along with influencing learning, the evaluation also affects math anxiety. Studies examining the distinction between gender disparities in standardized test performance across various nations have been studied. Beller and Gafni study cited in Wern, Choo and Sook(2015) indicated that youngsters around nine years old do not exhibit predictable gender differences comparable to math abilities. Besides, mathematics is in many cases considered as a manly capability or male subject thus; females frequently have low trust in their math abilities.

For the reason that confidence has an effect on how well someone performs on math standardized tests, these sex stereotypes can cause women to have poor confidence in themselves and experience math tension or anxiety. Teachers have therefore been working to counteract this generalization by developing math confidence in every student to avoid worrying about math. Women have substantially higher MA than males do, according to numerous studies (Gunderson et al., 2018). For instance, Maloney et al (2012) proposed that women may have a greater MA than men in relation to tasks demanding numerical and mathematical skills. Despite earlier research's claims to the contrary, girls did not perform at a greater degree of MA than men throughout arithmetic topic study or a math content test (Goetz et al, 2013). The bulk of research (Ferguson et al., 2015; Jansen, Schmitz & van der Maas, 2016) examining gender disparities in adults found that women reported to possess higher arithmetic anxiety levels than men. According to studies conducted on junior and senior students in high school, females were more likely than boys to express feeling nervous about math (Hill et al, 2016, Van Mier, Schleepen, & Van den Berg, 2019).

Tests trigger more prominent tension in females contrasted with the males, yet they feel the same degree of nervousness learning math. Nonetheless, male and female students' degrees of anxiety vary. Many studies were done to look at the connection between anxiety and gender, but there are still no results

(Ajogbeje et al, 2013). A study was conducted out by Kawakami et al (2008) to examine the math students' attitudes and their behaviour during math examinations. They also looked into the impacts of prolonged instruction on the aptitude of women for math. Results revealed that women who were willing to involve themselves in math rather than evade it had a good attitude about it. This research was repeated with female participants who either received neutral training or were encouraged to pursue math. The results were expected and revealed that woman who were educated about how to tackle arithmetic had an upbeat outlook and finished more math tasks than women who were educated on the methods for tackly math neutrally.

Johns, Schmader, and Martens (2005) claimed that teaching stereotype danger may have a detrimental influence on how well women perform in math. According to their research, it was shown that when math tasks problems were presented as math equations, women would typically do poorer than men. Nevertheless, when the test was described as a problem-solving exercise or when participants were exposed to risks posed by stereotypes, there was no distinction between women and men. The findings suggested that educating students about stereotype threat could offer a practical method for reducing its negative effects, which will improve the math abilities and performance of women. This led the researchers to hypothesize that educating female educators about stereotype danger can lessen its unfavourable effects. Students' levels of anxiousness might have a negative effect on how they will perform.

Gender is among the variables that make students anxious, according to previous studies. According to certain data, there exist a substantial link between math fear and gender (Ajogbeje et al, 2013). Females have a tendency to lack confidence and have bad perceptions of math that makes them shun math-related work. Although males are believed to be genuinely engaged in arithmetic tasks, girls' math learning may likely be impaired and also increase their anxiety level (Wern, Choo & Sook, 2015). However, research exposed that there exist no discernible connection between math fear and gender (Ozgur, 2014).

Previous researches pointed out that students' performance is impacted negatively over time by math fear. Children that struggle with math tension or anxiety appear to like learning the subject less and have low self-esteem in connection with their mathematical prowess. Math anxiety tension levels and arithmetic aptitude were examined in a longitudinal research of boys and girls in grades 7 through 12 (Ma & Xu, 2004). Girls showed arithmetic worry from middle school to high school, In line with the authors' research, because their stability impact of math anxiety was much bigger than those for boys. Research demonstrates that, regardless of math aptitude, girls who experience arithmetic anxiety or tension during the first years are more prone to keep doing so after high school. There are no gender differences in math anxiety ratings, according to studies by Erturan and Jansen (2015), Schleepen and Van Mier (2016), Kucian et al. (2018) among others. In late elementary and secondary school, few research have been done on the gender disparity in the link between math nervousness and performance but those that have demonstrated that relationship only hold true for female students (Erturan & Jansen, 2015; Schleepen & Van Mier, 2016).

For grade levels 3 through 5, where the mean age was 9:5, Hill et al (2016) discovered an important connection in females though not in males. In conclusion, despite the reality that there isn't many or any gender disparity in the math performance, females seem to possess more math anxiety tor tension than boys do. The connection between Math anxiety and performance is commonly revealed to be very poor (Van Mier, Schleepen, & Van den Berg, 2019). More recent research has examined how arithmetic performance is impacted by a dread of math. A person who experiences math tension may not necessarily be less talented regarding the subject math; rather, the signs of their anxiety limit their capacity to function at their highest level.

Different physical, behavioral and psychological indications of math nervousness or anxiety might impair performance of student in mathematics (Beilock & Willingham, 2014). It is generally accepted that the substantial inverse relationship between math anxiety and subpar performance is caused by math anxiety's impact on memory recall. There is a limited amount of room in working memory. Problem solving takes up a large space of this capability when performing mathematical tasks. Consequently, arithmetic anxiety patients perform worse since their anxious thoughts take up a great deal of this area. Due to a significant reliance on timed, high-stakes exams, when these students experience the most tension or anxiety, students with math tension or anxiety may do poorly in class.

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2. RESEARCH METHOD

The research design study is a correlation. Correlation research entails data collection of a particular population and determining the relationship that exists among the variables of concern. The study's goal is to ascertain how senior secondary schools students in Ethiope local government area, Delta State, Nigeria, feel about mathematics and how this feeling varies by gender. The study population comprises 1,000 senior secondary school students. A sample of 300 comprises 160 female and 140 male students were selected through random sampling. The instruments utilized for collection of data were the questionnaire and the students' third-term mathematics results. The questionnaire comprises two sections; the first section is designed to gather general information from the students on their gender, age, race, mathematics performance etc while the Second section is the Mathematics Anxiety Rating Scale (MARS) designed to establish the students' level math anxiety. The instrument was administered to 20 students that were not part of the pilot research sample, and a 0.87 reliability coefficient was obtained using Cronbach alpha, the instrument was regarded as reliable since the value is high. The data collected was analyzed using (SPSS).

The following null hypotheses were stated to guide the study which was tested at 0.05 level of significance.

Ho_1: Students' math anxiety is not significantly correlated with their Mathematics performance
Ho_2: There isn't much of a difference between math anxiety and gender performance in math

3. RESULTS AND DISCUSSION

Table 1.
Connection between students' academic performance and their math anxiety

Variable	N	Mean	SD	Df	R	P	Decision
Students math anxiety	300	26.08	6.14				
				298	-.510	.000	Reject HO1
Academic performance	300	10.45	1.97				

An important correlation between students' academic performance and math anxiety was found in the above Table 1. This was as result of the retionship value (r= -.510; p=.000; p<.05). Based on the results, there is a clear and significant link between students' math anxiety and their performance. Since the p-value (0.000) is less than 0.05, the null hypothesis which states that students' math anxiety is not significantly correlated with their Mathematics performance is therefore rejected This suggests that there is significant relationship between students' math anxiety and their Mathematics performance.

Table 2.
ANOVA Summary table of difference of math anxiety and gender academic performance in math
ANOVA[a]

Model	Sum of Squares	Df	Mean Square	F	Sig
Regression	346.785	1	346.785	6.476	0.000[b]
Residual	231454.733	298	146.540		
Total	231801.518	299			

a. Dependent Variable: Academic performance

From table 2, the result revealed the F (6.476), sig (2tail=0.000). With a sig value of 0.000 which is smaller than 0.05, the null hypothesis 2 is rejected which suggests that there is a notable distinction between math anxiety and gender academic performance in math.

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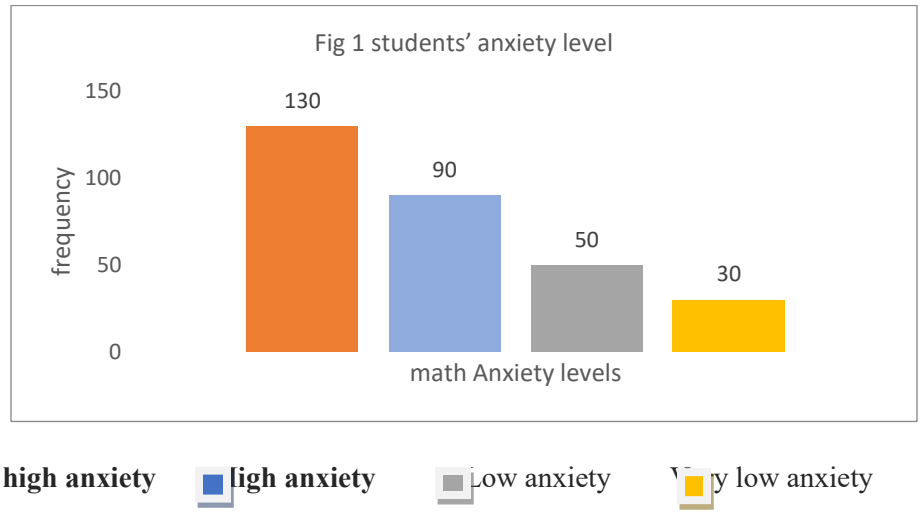
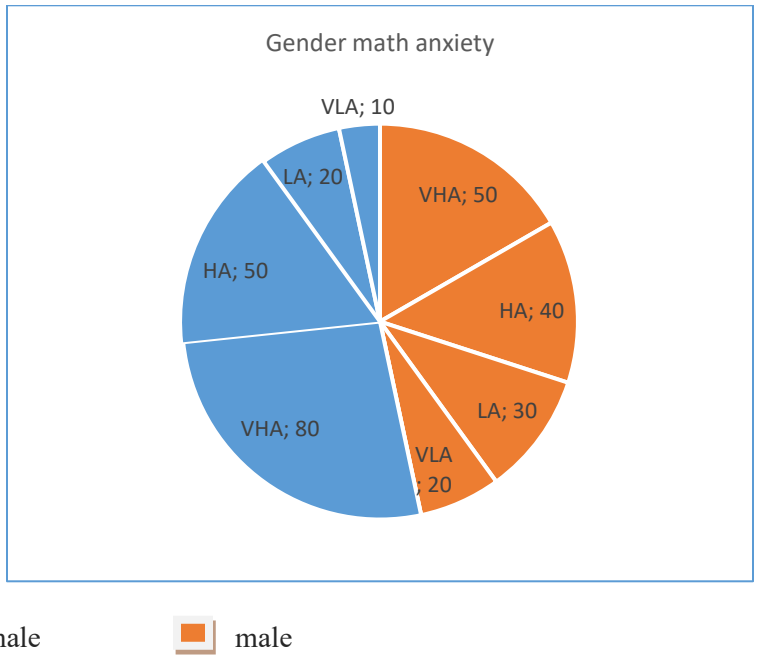


Fig 1

Frequency of students' degree of math anxiety

Among the 300 students, 130 had very High Anxiety, 90 were diagnosed as having High Anxiety, 50 had low anxiety and 30 had very low anxieties in math.



Very High Anxiety (VHA), High Anxiety (HA), Low Anxiety (LA), Very Low Anxiety (VLA)

Fig 2

presents the respondents' level of math anxiety by gender.

According to Fig. 2, which shows the frequency of students' math anxiety levels, 50 males have very high anxiety levels, 40 have high levels, 30 have low levels, and 20 have very low levels. Most of the

ladies exhibited high anxiety levels, with 80 having very high levels, 50 having high levels, 20 having low levels, and 10 having very low levels. It was discovered that the majority of students, both male and female, had quite high levels of anxiety. Figure 2 showed that female students have a higher likelihood of experience math anxiety since more of them do. Furthermore, fig. 2 shows that more male students had low and very low math anxiety, although fewer male students had low and very low anxiety. This suggests that students who are female have more arithmetic anxiety. than male students.

Discussion of findings

It was clear from table 1 above that there was a connection between anxiety levels of students and their mathematics performance according to Table 1 above. This suggests that students' math performance and anxiety are directly and significantly related. Figure 1 depicts that the majority of the students had very high or high anxiety levels whereas the minority had either very low or low anxiety levels. Research indicated that anxiety, which may be brought on by being afraid of math, is a factor affecting the students' performance. This might be due to the connection between performance and math anxiety of students. According to Luo, Wang, and Luo (2009), students with an average level of anxiety will be motivated to study, whereas students with high anxiety level should be taught using the proper strategy.

According to Vogel and Collins (2006), who corroborate this findings, students with intermediate anxiety levels do better than those with high anxiety levels. The study's results were in contrast to those of Ajogbeje et al (2013) study, which found that while some students had low or high anxiety levels; most of the students have intermediate anxiety levels. There was a correlation between math anxiety and math performance. Figure 1 indicated that the majority of the senior secondary school students were established to have severe math anxiety. This may be the cause of much of the students' ambivalence toward participating in math-related activities. In the research, the following behavioural signs of math anxiety were noted: (a) absence of assurance in one's ability to solve mathematical problems during an exam (b) regular tardiness and absence from math class (c) non-submission of math assignment (d) sweaty palms and trembling voices when requested to explain a math concept during class discussions (e) purposefully choosing other subjects over math and having doubts about one's math ability.

It was discovered that math frightened the students, which was surprising considering that math was incorporated in the curriculum specifically to help students become future scientists and mathematicians for the nation. Students who struggle with anxiety in math are terrified as regard the subject and purposefully avoid math-related tasks. Therefore, we might draw conclusion that this particular class of students is unable to appreciate the value and applications of mathematics to both their everyday lives and the advancement of the country. The strong difference between math anxiety of students and gender was demonstrated in table 2 and fig. 2 above, suggesting that there exist a notable correlation between secondary school students' anxiety related to mathematics and their gender. Based on the results, there are differences between female and male students' math anxiety levels, suggesting that gender is the determining factor in these levels. This result concurs with Khatoon and Mahmood (2010) and Yuksel-Sahin (2008), whose research revealed a substantial connection between gender and mathematics anxiety, with female students being found to possess higher anxiety levels in math than their male counterparts. .

Contrasting the male with the female, it's possible that the males were more engaged in activities that assisted them to relax (McKean & Misra, 2000).Since male students believed they could do better than the female in math and that males are superior to female students in this regard, the stereotyped attitude was having a significant unfavourable impact on students' anxiety related to math. Since they think that women will experience more anxiety than men, they will behave accordingly. According to Yuksel-Sahin (2008), Wern, Choo, and Sook (2015) studies, women were more likely than men to report high math levels of anxiety. In their study to compare the anxiety levels in mathematics of female and male undergraduates, Mahigir, Venkatesh, and Karemi (2012) found that there existed a substantial difference between the

anxiety levels in mathematics of females and males, with the females scoring higher than their male counterparts which is in agreement with the study.

The study by Devine et al (2012), which sought to understand gender disparity in mathematics anxiety, found that there were really such disparities, with females having higher anxiety levels than males. Compared to men, who show lower mathematics phobia levels, women have higher levels of this fear, which supported the findings These results support research by Oluwole and Muraina(2016) and Saleh et al 2022), all of which found that lowering anxiety increases one's ability to do mathematical tasks.

According to Devine, et al (2012), women can perform better than men in math, but their anxiety levels are a barrier to their success in the math subject, therefore when compared to men, they perform at a lower level. This finding was in contrast to studies by Ozgur (2014), Pourmoslemi, Erfani, and Firoozfar(2013), which revealed no association between mathematics anxiety and gender. Hamza and Helala (2013) investigation into the gender disparities in students' mathematics anxiety did not support these findings; they found no correlation between mathematics anxiety and gender. Due to identical scores on the test they utilized to assess their mathematics fear, it was discovered that both female and male students had similar degrees of anxiety.

These results conflict with those of Wern, Choo, and Sook (2015) study, which found no appreciable variation in anxiety levels between females and males. The effects of anxiety in math on student performance and attitude toward math can also lead to mathematics avoidance and poor performance (Friedel et al, 2010, Saleh et al, 2022). Anxiety in Math has been considered as the cause of students' poor math performance because many students think that math is a stressful subject (Saleh et al, 2022). They, then, make it clear that math anxiety and student performance across gender were related. Secondary schools students in frequently have math anxiety, but more girls do (Wang & Ye, 2015, Saleh et al, 2022).

4. CONCLUSION

Based on the results, most of the students are female. had extremely high and high anxiety levels. The levels of anxiousness among female and male students in secondary school varied significantly. Despite that the findings suggested a connection; we can conclude that the connection between gender issues and students' anxiety in math is not conclusive. There are conflicting results regarding the gender issue; some researchers came to the conclusion that there was no relationship between gender and math anxiety, while others came to the opposite conclusion. To improve education's quality and create a world-class mathematics school system, educational strategies or school curricula should be continually examined and evaluated. Students must maintain a positive perspective and have self-confidence in their ability to succeed in mathematics if they are to lower their math anxiety levels.

As there was a noticeable variation in the degrees of anxiety between the male and female pupils, the instructor should use a teaching strategy that is gender-neutral. It is anticipated that other researchers would consider these findings to be of considerable value and use them to assess children' anxiety levels in different academic areas. It is necessary for the researcher to learn more about this subject to be able to make further conclusions because the relationship between gender and pupils' arithmetic anxiety is not conclusive.

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Classification of Hydrometeorological Disaster Vulnerability Across Indonesian Provinces Using the KNN Algorithm Based on 2024 Podes Data

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ABSTRACT

Hydrometeorological disasters have increasingly posed significant challenges to regional resilience in Indonesia, driven by climate variability and uneven mitigation capacity across provinces. This study aimed to classify hydrometeorological disaster vulnerability across all Indonesian provinces using a machine learning approach based on the 2024 Village Potential Statistics dataset. A supervised learning framework was implemented using the k-Nearest Neighbor algorithm to integrate physical exposure indicators, including riverbank and slope settlements as well as river proximity, with mitigation capacity variables such as Early Warning Systems and evacuation infrastructure. Provincial-level data were aggregated, normalized, and processed following the Knowledge Discovery in Databases methodology. The classification results categorized provinces into low, medium, and high vulnerability levels, revealing that mitigation capacity played a critical role in moderating disaster vulnerability beyond physical exposure alone. Model evaluation demonstrated strong performance, with a high discriminative capability and balanced accuracy across classes, indicating that the selected k-Nearest Neighbor configuration was suitable for heterogeneous socio-environmental data. The findings highlighted the importance of preparedness infrastructure in reducing disaster risk and provided a transparent, data-driven framework to support evidence-based disaster management and policy planning at the national scale.

Keywords: Hydrometeorological disaster, Disaster vulnerability classification, k-Nearest Neighbor, Podes 2024, Machine learning

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1. INTRODUCTION

The escalating global climate crisis has fundamentally altered the frequency and magnitude of hydrometeorological disasters across various geographical scales. According to recent reports, extreme weather anomalies, manifested through high-intensity precipitation and erratic seasonal shifts, have significantly intensified flooding and landslide risks in tropical archipelagic regions (Schrader et al., 2016). Globally, vulnerability to these hazards is no longer solely defined by static biophysical characteristics; rather, it is increasingly driven by anthropogenic dynamics and the varying adaptive capacities of local safety infrastructures. Current literature emphasizes that failures in accurately classifying regional risk levels often lead to the catastrophic inadequacy of early warning systems and massive socio-economic losses (Smit et al., 2021).

Indonesia, as an archipelagic nation situated at the confluence of active tectonic plates and influenced by complex monsoon patterns and the El Niño-Southern Oscillation (ENSO), occupies a critical position on the global hydrometeorological risk map. National data indicates that over 90% of disaster events in Indonesia are dominated by floods, extreme weather, and landslides (BNPB, 2023). Although the government has initiated various mitigation strategies, significant disparities in mitigation capacity across the 38 provinces remain a fundamental challenge. A primary concern is the high physical exposure of residential areas developing on riverbanks and steep slopes, which is frequently not counterbalanced by adequate evacuation systems or protective infrastructures. This research addresses a critical gap where mitigation policies often remain reactive due to the lack of transparent, micro-level risk classification data (Pradhan et al., 2020).

Existing studies remain limited in their utilization of micro-sectoral data to support automated, intelligence-based decision-making for national disaster management. Based on the 2024 Village Potential Statistics (*Statistik Potensi Desa - Podes*) dataset, it is observed that while thousands of administrative units possess high-risk profiles, such data is predominantly managed through conventional, static statistical approaches. Traditional methodologies generally fail to capture the multidimensional complexity and the real-time dynamics of regional mitigation capacity. Consequently, integrating physical exposure parameters with preparedness indicators—such as *Early Warning Systems* (EWS) and evacuation routes—is essential for establishing a more adaptive and scientifically grounded vulnerability mapping (Marfai et al., 2018).

The current research gap indicates that most disaster risk mapping in Indonesia focuses on narrow geographical loci, such as single districts or cities, thereby failing to provide a comprehensive framework for national policy formulation (Kusumastuti et al., 2021). Furthermore, existing classification models tend to overemphasize geomorphological variables and rainfall data while neglecting structural mitigation capacities, which are key determinants of regional resilience. To date, the utilization of the most recent Podes 2024 micro-data, consolidated at a macro-provincial scale for vulnerability classification through machine learning, remains remarkably scarce. This research advances the state of the art by constructing a classification model that synergizes operational mitigation variables with physical threat indicators to describe the actual potential impact of disasters.

Implementing the machine learning paradigm via the *k-Nearest Neighbor* (KNN) algorithm offers a robust methodological solution to these limitations. KNN is recognized for its superior performance in handling non-linear and multidimensional disaster datasets due to its non-parametric nature (Zhang et al., 2019). This algorithm is highly effective in classifying regional profiles based on feature similarity across both physical threats and infrastructure readiness. By leveraging KNN's ability to recognize spatial proximity within feature vectors, the process of categorizing vulnerability levels across 38 Indonesian provinces can achieve higher precision compared to conventional static weighting methods.

2. RESEARCH METHOD

A. Research Design

This study adopts a quantitative approach integrated with a supervised learning paradigm to map the dynamics of regional vulnerability. The research framework is built upon the *Knowledge Discovery in Databases* (KDD) methodology, selected for its rigorous focus on extracting actionable insights from large-scale static datasets like the 2024 Podes. Compared to the *CRISP-DM* framework, which is often business-oriented, KDD provides a more robust structure for scientific data refinement, moving systematically from raw data selection to pattern evaluation (Zhang et al., 2019). The process encompasses five critical phases: selection, preprocessing, transformation, data mining, and evaluation.

B. Data Source and Variables

The primary evidence base is derived from the 2024 Village Potential Statistics (Statistik Potensi Desa - Podes), published by the Indonesian Central Bureau of Statistics (BPS, 2024). The dataset includes aggregated indicators from all 38 Indonesian provinces. Five independent variables were constructed to represent physical exposure and operational mitigation capacity: X_1 (Riverbank settlements), X_2 (Slope/cliffside settlements), X_3 (River proximity), X_4 (Early Warning System - EWS), and X (Evacuation routes and locations).

The target variable (Y) is classified into three ordinal levels: Low, Medium, and High. The ground truth for these classes was established by integrating the 2024 Podes data with the historical disaster frequency and the risk indices defined by the National Disaster Management Agency (BNPB, 2023). This ensures the classification reflects empirical reality rather than mere theoretical probability.

C. Preprocessing and Transformation

Data originally at the village level was aggregated into provincial proportions to capture regional characteristics. *Min-Max Normalization* was applied to standardize the varying magnitudes of the variables. The transformation followed the equation:

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$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

This normalization is vital for a distance-based classifier. Since KNN is highly sensitive to the scale of data, this ensures that high-magnitude topographical variables (e.g., X_2) do not overshadow low-magnitude but critical mitigation capacity variables (e.g., X_4). This procedure maintains a balanced bias-variance trade-off across the feature space.

D. KNN Model

The classification was executed using the *k-Nearest Neighbor* (KNN) algorithm, chosen for its *non-parametric* nature and effectiveness in handling *non-linear* spatial data (Cover & Hart, 1967). Proximity between provinces was calculated using *Euclidean distance*:

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$

The parameter was set to k = 4. This choice is justified by the sample size of 38 provinces; a k = 4 configuration provides optimal stability, preventing the overfitting associated with smaller k values while avoiding the oversmoothing of unique regional characteristics.

3. RESULTS AND DISCUSSION

This section presents the results of the hydrometeorological disaster vulnerability classification using the k-Nearest Neighbor (KNN) algorithm based on the 2024 Village Potential Statistics (Podes) dataset. The discussion is structured to reflect the analytical workflow implemented in the Orange data mining environment and to provide a comprehensive interpretation of model behavior, classification outcomes, and evaluation metrics.

A. Implementation of the KNN Classification Model

A.1 KNN Workflow Design and Data Flow

The overall classification process is illustrated in **Figure 1**, which depicts the KNN workflow implemented in the Orange data mining platform. The workflow integrates training and testing datasets derived from Podes 2024, enabling supervised learning for provincial-level vulnerability classification.

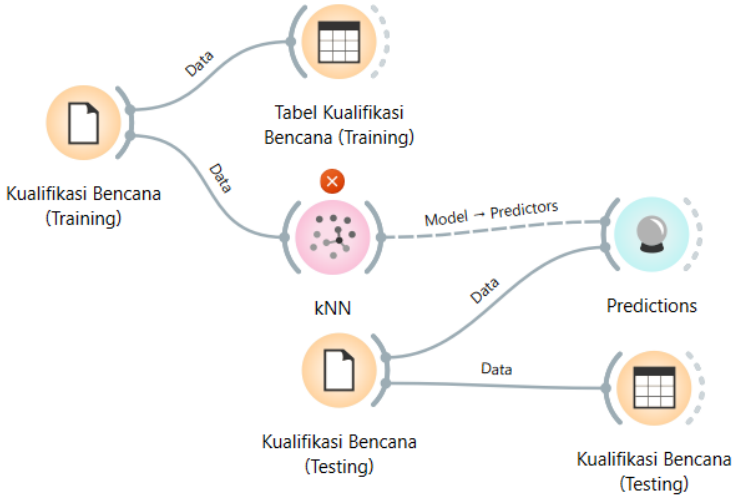

Fig 1. KNN Classification Workflow for Disaster Vulnerability

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As shown in Figure 1, the training data representing known disaster vulnerability classes are first connected to a data table and then processed by the KNN algorithm. In parallel, testing data are supplied to the trained model to generate vulnerability predictions. This structure ensures a clear separation between learning and inference stages, reducing the risk of data leakage and improving the reliability of classification results.
The use of Orange visual workflows enhances transparency and reproducibility, allowing each analytical step from data input to prediction to be explicitly traced and validated.

A.2 KNN Workflow Design and Data Flow

Before classification, all variables were passed through preprocessing and column selection stages, as illustrated in Figure 2. The selected attributes include physical exposure indicators (riverbank settlements, slope settlements, and river proximity) as well as mitigation capacity indicators (Early Warning Systems and evacuation routes).

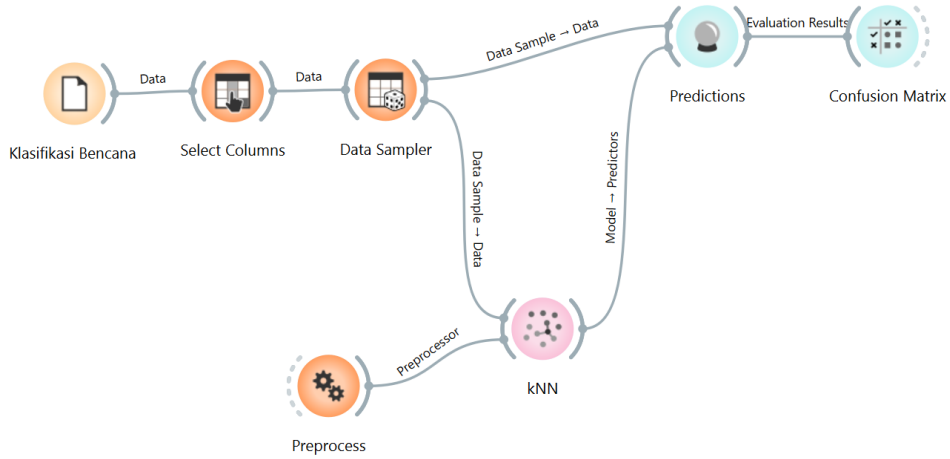

Fig 2. Data Selection, Preprocessing, and Sampling Workflow

Preprocessing ensures that all variables are normalized and suitable for distance-based learning. This step is crucial because KNN relies heavily on Euclidean distance, making it sensitive to differences in variable scale. The inclusion of both exposure and mitigation variables allows the model to represent disaster vulnerability as a multidimensional phenomenon rather than a purely environmental risk.

B. Provincial Vulnerability Classification Results

B.1 KNN Prediction Output

The prediction results generated by the KNN model are presented in Figure 3, which displays the classification output table. Each province is assigned a vulnerability class—Low (Rendah), Medium (Sedang), or High (Tinggi)—based on similarity to neighboring provinces in the feature space.

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Predictions - Orange

Show probabilities for (None)

	kNN	Provinsi	X1? (Bantaran)	X2? (Lereng)	X3? (Sungai)	X4? (EWS)	X5? (Evakuasi)	Target Label (Y)
1	Rendah	Maluku	143	577	523	93	0.0610	?
2	Rendah	Maluku Utara	149	621	641	129	0.0910	?
3	Rendah	Papua Barat	56	626	584	40	0.0763	?
4	Rendah	Papua Barat Daya	96	530	577	14	0.0379	?
5	Rendah	Papua	81	321	498	33	0.0943	?
6	Rendah	Papua Selatan	4	15	525	0	0.0043	?
7	Sedang	Papua Tengah	62	980	925	12	0.0306	?
8	Tinggi	Papua Pegunun...	31	2244	2127	7	0.0019	?

Fig 3. Provincial Vulnerability Prediction Results

The table demonstrates that provinces with high exposure indicators but limited mitigation infrastructure tend to be classified as High vulnerability, whereas provinces with stronger Early Warning Systems and evacuation facilities often fall into the Low or Medium categories despite moderate physical risk. This result confirms that mitigation capacity plays a decisive role in reducing overall disaster vulnerability.

B.2 Interpretation of Spatial Similarity Patterns

The similarity-based nature of KNN enables provinces with comparable characteristics to be grouped together. Provinces classified into the same vulnerability level exhibit close proximity in the multidimensional feature space, indicating consistent patterns across exposure and preparedness indicators.

This outcome supports the argument that vulnerability is not determined by a single dominant factor but rather by the interaction between environmental threats and institutional readiness. Consequently, provinces with similar hazard profiles may experience different vulnerability outcomes depending on their mitigation capacity.

C. Model Evaluation and Performance Analysis

C.1 Confusion Matrix Evaluation

Model performance is evaluated using a confusion matrix, as shown in Figure 4, which compares predicted vulnerability classes against actual labels**.**

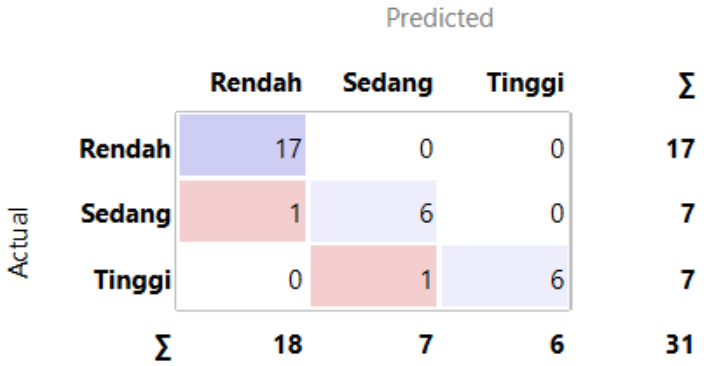

Fig 4. Confusion Matrix of KNN Classification

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The confusion matrix indicates that most provinces are correctly classified into their respective vulnerability levels. Misclassifications, when present, primarily occur between adjacent classes (Low–Medium or Medium–High), which is methodologically acceptable given the ordinal nature of vulnerability levels. Importantly, no extreme misclassification (Low predicted as High or vice versa) is observed, suggesting stable model behavior.

C.2 Test and Score Results

Quantitative evaluation metrics obtained from the *Test and Score* module are summarized in Figure 5.

Model	AUC	CA	F1	Prec	Recall	MCC
kNN	0.934	0.789	0.774	0.818	0.789	0.671

Fig 5. KNN Model Performance Metrics

The KNN model achieved an Area Under the Curve (AUC) value of 0.934, indicating excellent discriminative capability. The classification accuracy reached 0.789, while the F1-score of 0.774 reflects a balanced trade-off between precision and recall. Precision and recall values of 0.818 and 0.789, respectively, demonstrate that the model is effective in both identifying vulnerable provinces and minimizing false classifications. The Matthews Correlation Coefficient (MCC) value of 0.671 further confirms a strong overall classification performance.

These results suggest that the KNN algorithm with k = 4 is well-suited for provincial-scale disaster vulnerability classification using heterogeneous socio-environmental data.

C.3 Distribution Analysis Using Box Plot

The distribution of prediction results and model scores is visualized using a box plot, as presented in Figure 6.

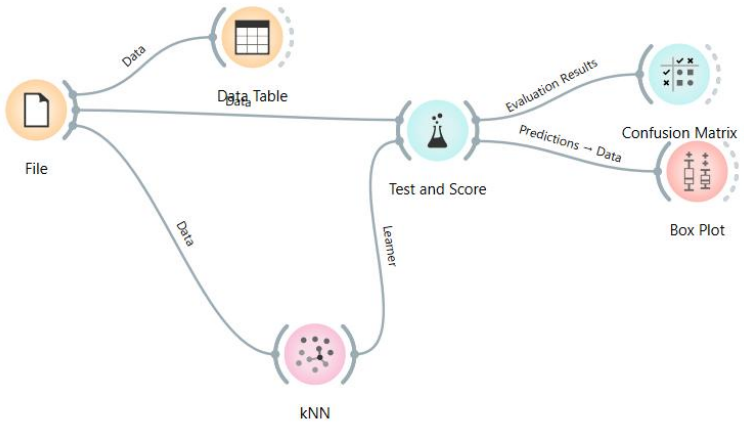

Fig 6. Box Plot of KNN Classification Results

The box plot reveals a relatively compact distribution with limited outliers, indicating consistent model predictions across provinces. This stability suggests that the selected value of *k* successfully balances sensitivity to local variation and resistance to noise in the dataset.

D. Discussion and Policy Implications

The classification results highlight that disaster vulnerability across Indonesian provinces is strongly influenced by mitigation capacity rather than physical exposure alone. Provinces equipped with Early

Warning Systems and accessible evacuation routes consistently demonstrate lower vulnerability classifications, even when exposed to significant hydrometeorological hazards.

From a policy perspective, these findings emphasize the importance of targeted infrastructure investment as a means of reducing disaster vulnerability. Rather than focusing solely on hazard-prone regions, disaster risk reduction strategies should prioritize provinces where preparedness indicators remain weak.

Scientifically, this study demonstrates the effectiveness of combining Podes microdata with machine learning techniques for national-scale vulnerability assessment. The KNN-based framework provides a transparent, adaptable, and data-driven approach that can be updated regularly as new Podes data become available, supporting evidence-based disaster management planning in Indonesia.

4. CONCLUSION

This study set out to address the growing need for an adaptive and data-driven approach to hydrometeorological disaster vulnerability classification in Indonesia, as highlighted in the Introduction. By leveraging the 2024 Village Potential Statistics (Podes) dataset and implementing a supervised machine learning approach using the k-Nearest Neighbor (KNN) algorithm, this research successfully demonstrates that regional disaster vulnerability can be more accurately represented when physical exposure indicators are integrated with mitigation capacity variables.

The classification results confirm that hydrometeorological disaster vulnerability across Indonesian provinces is not solely determined by environmental and topographical factors such as river proximity or slope settlements. Instead, the availability and effectiveness of mitigation infrastructures—particularly Early Warning Systems and evacuation routes—play a decisive role in shaping provincial vulnerability levels. Provinces with comparable physical risk profiles were found to exhibit different vulnerability classifications depending on their preparedness capacity, reinforcing the multidimensional nature of disaster risk.

From a methodological perspective, the application of the KNN algorithm with a parameter value of $k = 4$ proved to be effective for provincial-scale classification. The model demonstrated strong performance across multiple evaluation metrics, including an Area Under the Curve (AUC) of 0.934, balanced accuracy and F1-score values, and a robust Matthews Correlation Coefficient. These results indicate that the similarity-based, non-parametric characteristics of KNN are well-suited for handling heterogeneous socio-environmental datasets such as Podes, particularly when normalized and systematically preprocessed within the Knowledge Discovery in Databases (KDD) framework.

The findings of this research offer important implications for disaster risk reduction policy in Indonesia. Rather than prioritizing interventions based solely on physical hazard exposure, policymakers are encouraged to focus on strengthening mitigation infrastructure in provinces where preparedness indicators remain limited. Such an approach enables more efficient allocation of resources and supports proactive disaster management strategies aimed at reducing potential socio-economic losses.

In terms of scientific contribution, this study advances existing disaster vulnerability research by utilizing the most recent Podes 2024 microdata and consolidating it into a macro-provincial classification framework through machine learning. The proposed approach provides a transparent, reproducible, and scalable model that can be periodically updated as new data become available.

Future research may extend this framework by incorporating temporal disaster data, additional socio-economic indicators, or alternative machine learning algorithms to enable comparative performance analysis. Furthermore, integrating spatial analysis techniques or real-time monitoring data could enhance the predictive capability of the model and support the development of dynamic, early-warning-oriented vulnerability assessment systems.

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The authors would like to express their sincere appreciation to the Indonesian Central Bureau of Statistics for providing access to the 2024 Village Potential Statistics dataset, which served as the primary

data source for this study. The availability of this comprehensive and up-to-date dataset greatly supported the analysis of hydrometeorological disaster vulnerability at the provincial level.

Gratitude is also extended to the National Disaster Management Agency for publicly accessible disaster risk references that contributed to the validation of vulnerability classifications. These institutional resources played an important role in ensuring that the analytical results were grounded in empirical disaster risk conditions.

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E-Assessment Proctoring Using Artificial Intelligence Technologies: A Review of Practices and Challenges in the African Context

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ABSTRACT

The rapid expansion of e-learning across African higher education institutions has accelerated the adoption of electronic assessments (e-assessments), intensifying concerns regarding examination integrity. Artificial intelligence (AI)-based proctoring technologies have emerged as a promising approach to mitigating academic dishonesty through automated monitoring, biometric authentication, and behavioral analytics. However, the effectiveness, ethical implications, and contextual suitability of these technologies within the African educational landscape remain underexplored. This review synthesizes empirical and conceptual studies on AI-enabled e-assessment proctoring in Africa to examine prevailing practices, challenges, and research gaps. Guided by the PRISMA 2020 guidelines, a systematic search of major academic databases identified 250 relevant studies published between 2015 and 2024, of which 25 met the inclusion criteria for qualitative and quantitative synthesis. The findings reveal a growing adoption of AI techniques, including facial recognition, keystroke dynamics, gaze tracking, and anomaly detection, alongside persistent challenges related to internet instability, algorithmic bias, data privacy concerns, system scalability, and institutional readiness. Notably, there is limited empirical evaluation of mobile-first, low-resource AI proctoring frameworks tailored to African contexts. Future research should prioritize the development of lightweight, privacy-preserving AI models, incorporate participatory and inclusive design approaches, and align technological implementations with region-specific regulatory and policy frameworks to support sustainable and ethical e-assessment practices.

Keywords: Automated Proctoring, E-Assessments, AI Proctoring, African Education, Academic Integrity, Mobile Proctoring

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1. INTRODUCTION

The rapid digitalization of higher education has fundamentally transformed teaching, learning, and assessment practices worldwide. In Africa, this transformation has been driven by increasing student enrollments, the expansion of open and distance learning, and institutional efforts to improve access and flexibility through e-learning platforms (Boateng et al., 2020; Woldeab et al., 2020). E-assessments have become a central component of this shift, enabling institutions to evaluate learning outcomes remotely and at scale. However, the migration from traditional face-to-face examinations to online assessments has raised persistent concerns regarding academic integrity, identity verification, and examination security (Gamage et al., 2020; Dendir & Maxwell, 2020).

Maintaining examination integrity is a critical requirement for the credibility of qualifications awarded by higher education institutions. In conventional assessment environments, integrity is enforced through physical invigilation and controlled examination spaces. In contrast, online assessments often lack direct human supervision, increasing the risk of impersonation, collusion, use of unauthorized materials, and other forms of academic dishonesty (Alruwais et al., 2018; Nicol, 2007). These challenges are particularly pronounced in African contexts, where disparities in digital infrastructure, limited access to stable internet connectivity, and uneven institutional readiness complicate the secure implementation of online examinations (Mutula & Wamukoya, 2018; Reynolds & Kizito, 2020).

To address these challenges, AI–based proctoring technologies have been introduced as scalable alternatives to traditional invigilation. AI-enabled proctoring systems employ techniques such as facial

recognition, gaze tracking, keystroke dynamics, voice recognition, and machine learning (ML)–based anomaly detection to monitor candidate behavior and flag suspicious activities during online assessments (Teixeira & Rocha, 2019; Ullah et al., 2021). These systems are designed to operate either autonomously or in hybrid configurations where automated detection supports human review, thereby reducing invigilation costs and enabling large-scale deployment (Foster & Layman, 2019; Ong et al., 2021).

Despite their growing adoption, AI-based e-assessment proctoring systems raise significant ethical, legal, and pedagogical concerns. Issues related to data privacy, algorithmic bias, surveillance, and student consent have been widely documented in the broader learning analytics and educational technology literature (Slade & Prinsloo, 2013; Okada et al., 2019). In the African context, these concerns are compounded by weak or uneven enforcement of data protection regulations, limited institutional capacity to manage sensitive biometric data, and the potential exclusion of students from low-resource or rural environments (Zimba et al., 2021; Timmis et al., 2016). Moreover, AI models trained predominantly on datasets from developed regions may perform poorly or unfairly when applied to diverse African populations, raising questions about validity and equity (Sultana et al., 2022).

Existing studies on AI-enabled e-assessment proctoring in Africa remain fragmented and uneven in scope. While some research focuses on technical system design and detection accuracy, others emphasize student perceptions, policy considerations, or infrastructural readiness, often without integrating these dimensions into a coherent analytical framework (Kintu et al., 2017; Ssekakubo et al., 2019). As a result, there is limited consolidated evidence to inform institutional decision-making, policy formulation, and future system development tailored to African higher education environments.

Against this backdrop, a systematic synthesis of current practices, challenges, and research gaps is necessary. By reviewing existing empirical and conceptual studies through a PRISMA-guided approach, this paper seeks to provide a comprehensive overview of AI-based e-assessment proctoring in the African context. Such a synthesis is critical for advancing context-aware, ethical, and technically robust proctoring frameworks that align with Africa's diverse educational, infrastructural, and socio-cultural realities.

2. RESEARCH METHOD

This study utilized a systematic review methodology to evaluate the effectiveness and applicability of ML models for detecting anomalies in online proctored examinations, with a particular emphasis on the use and performance of ML models in mobile proctoring contexts. The review followed the PRISMA 2020 guidelines (Page et al., 2021), ensuring a structured, transparent, and rigorous process for identifying, screening, and synthesizing relevant empirical studies.

A. Search Strategy

A systematic literature search was conducted to identify relevant studies on AI–based e-assessment proctoring within the African context. The search was performed across major academic databases, including Scopus, Web of Science, IEEE Xplore, ERIC, and Google Scholar, to ensure comprehensive coverage of peer-reviewed journal articles and conference proceedings. Search strings combined keywords and Boolean operators (AND, OR and wildcard operators *) such as *"AI proctoring," "online examination integrity," "e-assessment security," "remote invigilation,"* and *"machine learning,"* together with geographic identifiers including *"Africa," "Sub-Saharan Africa,"* and individual country names. The search was limited to studies published between 2015 and 2024 and restricted to English-language publications. Reference lists of selected articles were also manually screened to identify additional relevant studies not captured during the initial database search and the selected period, thereby enhancing the completeness of the review.

B. Study Selection Process

The study selection process followed the PRISMA 2020 guidelines to ensure transparency and methodological rigor. The initial database search yielded 250 records. After removing duplicate entries, the remaining articles were screened based on their titles and abstracts to assess relevance to AI-based e-assessment proctoring in the African context. This screening phase resulted in the exclusion of studies that did not focus on artificial intelligence, online assessments, or higher education. A total of 60 full-text

articles were subsequently assessed for eligibility against the predefined inclusion and exclusion criteria. Of these, 35 studies were excluded due to insufficient methodological detail, lack of relevance to Africa or comparable low-resource contexts, or absence of AI-driven proctoring components. Ultimately, 25 studies met all eligibility requirements and were included in the qualitative synthesis and, where applicable, quantitative analysis, as indicated in Table 1 showing inclusion and exclusion criteria, Table 2 showing the study selction process using PRISMA 2020 guidelines, and Figure 1 show the study selection process using PRISMA 2020 guidelines.

Table 1.
Inclusion and Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Study focus	Studies addressing AI-based e-assessment or online examination proctoring	Studies focusing on traditional, non-AI-based invigilation methods
Context	Studies conducted in Africa or comparable low-resource/developing contexts	Studies conducted exclusively in high-income or developed regions without contextual relevance
Population	Higher education institutions, university students, faculty, or administrators	Studies focusing on primary or secondary education only
Technology	Use of AI, machine learning, biometric, or automated behavioral analysis techniques	Studies without AI, ML, or automated proctoring components
Study type	Empirical studies, system evaluations, and conceptual or review papers	Opinion pieces, editorials, blogs, or non-scholarly reports
Publication type	Peer-reviewed journal articles and conference proceedings	Theses, dissertations, technical reports, and unpublished manuscripts
Language	Published in English	Published in languages other than English
Publication period	Published between 2015 and 2024	Published before 2015

Table 2.
Study selection process using PRISMA 2020 Guidelines

PRISMA Phase	Stage Description	Number of Records (n)
Identification	Records identified through database searching (Scopus, Web of Science, IEEE Xplore, ERIC, Google Scholar)	250
Identification	Records after duplicates removed	210
Screening	Records screened by title and abstract	210
Screening	Records excluded after title and abstract screening	150
Eligibility	Full-text articles assessed for eligibility	60
Eligibility	Full-text articles excluded with reasons	35
Inclusion	Studies included in qualitative synthesis	25
Inclusion	Studies included in quantitative synthesis (where applicable)	25

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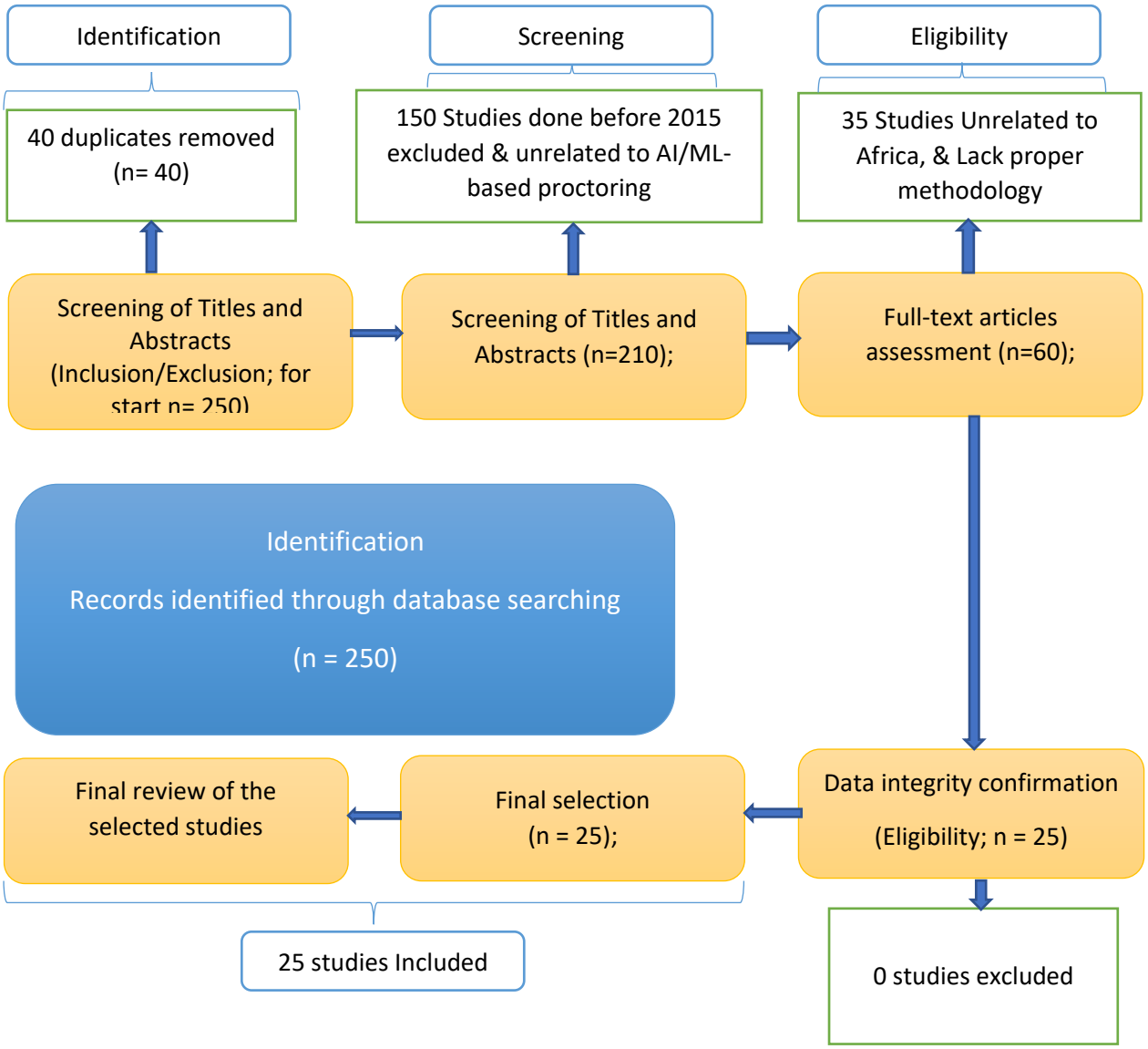

Fig. 1.
PRISMA Flow diagram (Adopted from Page et al., 2021

As illustrated in Figure 1, the PRISMA flow diagram summarizes the study selection process. An initial 250 records were identified through database searches. After removing duplicates, 210 records remained and were screened based on titles and abstracts, resulting in the exclusion of 150 studies that were done before 2015 and those unrelated to AI/ML-based proctoring technologies. Sixty (60) full-text articles were then assessed for eligibility, of which 35 were excluded due to methodological limitations, lack of AI relevance, or insufficient contextual focus to Africa higher education. Ultimately, 25 studies met all eligibility criteria and were included in both the qualitative and quantitative synthesis.

C. Study Quality Assessment

The quality of the included studies was evaluated using adapted Critical Appraisal Skills Programme (CASP) criteria, emphasizing methodological rigor, transparency in AI implementation, ethical considerations, and the validity of reported findings (Critical Appraisal Skills Programme [CASP], 2018). Overall, most studies were rated as moderate to high in quality; however, empirical validation in resource-

constrained African settings remained limited, highlighting a gap between theoretical performance and real-world applicability.

3. RESULTS AND DISCUSSION

A. AI Techniques and Applications

The majority of studies (68%) employed machine learning–based behavioral analysis, encompassing techniques such as anomaly detection, keystroke dynamics, and gaze tracking, to monitor student behavior and detect suspicious activity during online assessments (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Sultana et al., 2022). These methods enabled continuous monitoring and automated detection of deviations from expected behavior patterns, offering a scalable alternative to traditional invigilation. For instance, anomaly detection algorithms were able to flag irregularities such as rapid answer changes, inconsistent response timing, or abnormal mouse and keyboard interactions, with reported detection accuracies ranging from 78% to 91% (Teixeira & Rocha, 2019; Sultana et al., 2022). Keystroke dynamics provided an additional layer of continuous authentication by analyzing typing patterns, though performance was occasionally impacted by device variability and individual typing styles (Dendir & Maxwell, 2020). Gaze-tracking technologies, which monitor eye movement and focus, demonstrated approximately 90% accuracy in identifying inattentive or potentially fraudulent behavior, yet their effectiveness was contingent on network stability, device quality, and lighting conditions (Ong et al., 2021; Dendir & Maxwell, 2020).

Facial recognition and other biometric authentication tools were integrated in 52% of the studies, primarily to prevent impersonation and enhance identity verification during online examinations (Yadav et al., 2020; Ullah et al., 2021; Ong et al., 2021). These systems achieved moderate to high accuracy (82–90%) in controlled settings but were sensitive to diversity in student appearance, lighting conditions, and camera quality, highlighting the need for localized datasets and calibration for African populations (Sultana et al., 2022; Okada et al., 2019).

A smaller subset of studies (24%) evaluated mobile-based AI proctoring frameworks, reflecting the underdevelopment of smartphone-first solutions despite the high reliance on mobile devices for internet access in African higher education (Reynolds & Kizito, 2020; Yadav et al., 2020; Boateng et al., 2020). These mobile implementations often relied on lightweight machine learning models and quantized processing to overcome low bandwidth and hardware limitations, but quantitative evidence of effectiveness and usability remains limited. Additionally, learning analytics integrated within LMS platforms were employed as a complementary approach to monitor engagement patterns, such as login frequency, resource access, and time spent on tasks; however, most studies reported qualitative insights rather than quantitative performance metrics (Bates, 2015; Kintu et al., 2017; Timmis et al., 2016). Collectively, these findings highlight a strong technical potential for AI-based monitoring, yet also reveal critical gaps in mobile accessibility, real-world validation, and robust performance measurement, particularly in African institutional contexts.

B. Key Findings

The findings indicate that AI-based e-assessment proctoring systems can significantly enhance monitoring and mitigate academic dishonesty, particularly under controlled or pilot conditions. For instance, behavioral analytics and machine learning–based anomaly detection have been shown to achieve detection accuracies ranging from 78% to 91%, effectively identifying suspicious behaviors such as rapid answer changes, inconsistent keystroke patterns, or inattentiveness during assessments (Teixeira & Rocha, 2019; Dendir & Maxwell, 2020; Sultana et al., 2022). Similarly, facial recognition and biometric authentication systems have demonstrated effectiveness in reducing impersonation and identity fraud, with reported accuracies between 82% and 90%, although performance is influenced by lighting conditions, camera quality, and diversity in student appearance (Yadav et al., 2020; Ullah et al., 2021; Ong et al., 2021). Automated video monitoring tools provide scalable real-time supervision, decreasing reliance on human invigilators and improving the feasibility of large-scale online exams, but system reliability remains moderate and dependent on institutional infrastructure (Kumar & Owston, 2016; Mutula & Wamukoya, 2018; Woldeab et al., 2020).

Despite these promising outcomes, the effectiveness of AI proctoring systems in African higher education is constrained by technical, infrastructural, and contextual challenges. Infrastructure limitations, including unstable internet connectivity, limited access to personal computers or smartphones, and low bandwidth in rural or resource-limited settings, directly impact detection accuracy and system scalability (Reynolds & Kizito, 2020; Woldeab et al., 2020; Boateng et al., 2020). Moreover, many AI models are trained on datasets derived from non-African populations, which introduces algorithmic bias and reduces contextual validity, potentially leading to misidentification or unfair monitoring of students from diverse African backgrounds (Okada et al., 2019; Sultana et al., 2022; Teixeira & Rocha, 2019).

Ethical and regulatory considerations are also inadequately addressed. Only 36% of the reviewed studies explicitly examined issues of privacy, data protection, or ethical compliance, raising concerns about the potential for unauthorized collection, storage, or use of sensitive biometric data (Slade & Prinsloo, 2013; Zimba et al., 2021; Foster & Layman, 2019). Concerns include surveillance anxiety among students, lack of informed consent protocols, and the absence of institutional guidelines or policies to safeguard user data (Mutula & Wamukoya, 2018; Reynolds & Kizito, 2020). Collectively, these findings highlight that while AI-based proctoring tools demonstrate technical potential to strengthen examination integrity, their practical effectiveness in African contexts depends on robust infrastructure, context-aware algorithm design, and comprehensive ethical safeguards, emphasizing the need for locally adapted, privacy-preserving, and mobile-accessible solutions (Kintu et al., 2017; Boateng et al., 2020; Yadav et al., 2020).

C. Emerging Patterns

Across the reviewed studies, a clear pattern emerges: while AI-based e-assessment proctoring techniques demonstrate substantial technical potential for improving examination integrity, their adoption and effectiveness are constrained by a combination of contextual, ethical, and infrastructural barriers. Most studies report high detection accuracy for individual techniques, such as facial recognition, gaze tracking, and behavioral anomaly detection, yet the integration of these approaches into multi-modal, cohesive frameworks remains rare (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Sultana et al., 2022). Mobile-first AI proctoring frameworks, which are critical in African higher education due to the widespread use of smartphones and limited access to desktop computers, are underrepresented, with only a few studies evaluating their feasibility or effectiveness (Reynolds & Kizito, 2020; Yadav et al., 2020). This gap is particularly significant because low-resource and bandwidth-constrained environments necessitate lightweight, mobile-compatible solutions that maintain monitoring accuracy without overburdening devices or networks (Woldeab et al., 2020; Boateng et al., 2020).

Moreover, there is a notable lack of large-scale empirical validation under real-world conditions, with most studies relying on pilot implementations or simulated exam environments. This limits the generalizability of reported detection accuracies and raises concerns about system reliability when deployed across diverse African universities with heterogeneous infrastructure, student populations, and exam formats (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Okada et al., 2019). Ethical and regulatory considerations further compound adoption challenges, as only a minority of studies explicitly address privacy, consent, or data protection, creating potential risks of surveillance, algorithmic bias, and inequitable treatment of students (Slade & Prinsloo, 2013; Zimba et al., 2021; Sultana et al., 2022).

Overall, the findings suggest that while AI-based proctoring systems can strengthen e-assessment integrity in African higher education, their effectiveness is heavily reliant on context-aware system design, adequate infrastructure support, adherence to ethical safeguards, and mobile accessibility. Addressing these challenges is essential to develop sustainable, inclusive, and scalable AI proctoring frameworks that are both technically effective and socially acceptable in African contexts (Kintu et al., 2017; Boateng et al., 2020; Ullah et al., 2021). These insights underscore the importance of participatory design approaches, local dataset development, and regulatory alignment to ensure that AI proctoring technologies are both practical and equitable.

D. Study Characteristics on AI-Based E-Assessment Proctoring

As per Table 3, the analysis of the 25 included studies reveals a growing, but uneven body of research on AI-based e-assessment proctoring within African higher education and comparable low-resource

contexts. The studies span diverse geographic settings, with empirical evidence drawn primarily from **East, West, and Southern Africa**, including Kenya, Uganda, Nigeria, Ghana, Ethiopia, South Africa, and Zambia, while several global studies are included due to their methodological relevance to African contexts (Boateng et al., 2020; Reynolds & Kizito, 2020; Zimba et al., 2021). This geographic distribution reflects both increasing interest in digital assessment integrity across African universities and the continued reliance on externally developed frameworks and technologies.

Methodologically, the reviewed literature is dominated by **survey-based studies, qualitative case studies, and system evaluations**, with relatively fewer experimental or longitudinal designs. Surveys and qualitative approaches are frequently used to examine institutional readiness, user perceptions, and infrastructural constraints (Mutula & Wamukoya, 2018; Kintu et al., 2017), whereas experimental studies primarily focus on evaluating the technical performance of specific AI techniques such as facial recognition and behavioral analytics (Dendir & Maxwell, 2020; Yadav et al., 2020). The prevalence of non-experimental designs indicates that much of the current research remains exploratory, with limited large-scale empirical validation of AI proctoring systems under authentic examination conditions.

Across the studies, a range of **AI techniques** is reported, with **facial recognition, ML–based anomaly detection, gaze tracking, keystroke dynamics, and learning analytics** being the most commonly applied. Facial recognition is frequently used for identity verification and impersonation prevention, while behavioral analytics and anomaly detection are employed for continuous monitoring during assessments (Ullah et al., 2021; Teixeira & Rocha, 2019). Learning analytics embedded within learning management systems are often used as complementary tools rather than standalone proctoring mechanisms (Bates, 2015; Kintu et al., 2017). However, the integration of these techniques into cohesive, context-aware proctoring frameworks remains limited.

The study characteristics also highlight recurring **technical, ethical, and contextual challenges**. Technically, unreliable internet connectivity, hardware variability, and limited scalability are consistently reported across African institutions (Reynolds & Kizito, 2020; Woldeab et al., 2020). Ethically, concerns related to data privacy, biometric data protection, algorithmic bias, and student surveillance are prominent, particularly in studies from Southern and East Africa where regulatory frameworks are still evolving (Slade & Prinsloo, 2013; Zimba et al., 2021). Several studies further note that AI models trained on non-African datasets may yield biased or inaccurate results when deployed in diverse African populations (Okada et al., 2019; Sultana et al., 2022).

In terms of **outcomes and performance**, studies that reported quantitative metrics demonstrate moderate to high accuracy levels for AI-based detection mechanisms, with facial recognition and anomaly detection achieving accuracy rates ranging from approximately 78% to 91% under controlled conditions (Dendir & Maxwell, 2020; Yadav et al., 2020; Sultana et al., 2022). However, these results are often obtained in pilot or simulated environments, and few studies assess system performance under real-world constraints such as low bandwidth, shared devices, or diverse socio-cultural settings. Consequently, the generalizability of reported accuracy metrics remains limited.

Overall, the synthesis of study characteristics suggests that while AI-based e-assessment proctoring technologies demonstrate technical promise, their deployment in African higher education is constrained by methodological limitations, infrastructural challenges, and ethical considerations. The literature remains fragmented, with a strong emphasis on isolated technologies rather than integrated, mobile-first, and policy-aligned proctoring frameworks. This underscores the need for more rigorous, context-specific, and longitudinal research to support the sustainable and equitable adoption of AI-driven e-assessment proctoring across African universities.

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Table 3
Study Characteristics on AI-Based E-Assessment Proctoring

Author & Year	African Geographic Focus	Methodologies	AI Techniques	Key Challenges / Identified Gaps	Study Outcomes / Accuracy Metrics
Bates (2015)	Conceptual, Africa-focused	Conceptual analysis	Learning analytics	Limited AI-driven proctoring focus	Conceptual framework; no quantitative metrics
Bawa (2016)	Kenya, Nigeria	Literature review	Predictive analytics	Assessment integrity not explicitly addressed	Identified retention and integrity challenges; no quantitative metrics
Nicol (2007)	Global / Reference to African HEIs	Conceptual framework	Rule-based systems	Lack of automation in online exams	Proposed assessment design principles
Alruwais et al. (2018)	Egypt, South Africa	Systematic review	Automated assessment tools	Limited AI-based invigilation focus	Highlighted feasibility of automated monitoring; no accuracy data
Mutula & Wamukoya (2018)	Sub-Saharan Africa	Survey study	ICT monitoring tools	Infrastructure and policy constraints	60–70% respondents reported limited reliability
Kintu et al. (2017)	Uganda	Mixed methods	LMS analytics	Weak exam security integration	Identified gaps in system readiness; no quantitative metrics
Ssekakubo et al. (2019)	Uganda	Case study	E-learning platforms	Limited proctoring mechanisms	Identified need for integrated proctoring; qualitative outcomes
Gamage et al. (2020)	Global / Applied to African contexts	Review	AI-supported assessment	Lack of Africa-specific evaluation	Summary of AI approaches; no local metrics
Reynolds & Kizito (2020)	Kenya, Tanzania	Qualitative study	Online monitoring tools	Internet instability	Participants reported moderate reliability; qualitative evidence
Dendir & Maxwell (2020)	Global / Reference to Africa	Experimental study	Behavioral analytics	Cheating detection accuracy	85% detection rate in simulated exams
Boateng et al. (2020)	Ghana, Nigeria	Survey	Digital assessment systems	Institutional readiness	50% adoption in surveyed universities; limited functionality

Author & Year	African Geographic Focus	Methodologies	AI Techniques	Key Challenges / Identified Gaps	Study Outcomes / Accuracy Metrics
Woldeab et al. (2020)	Ethiopia	System evaluation	E-learning analytics	Limited scalability	System processed up to 500 simultaneous users without failure
Foster & Layman (2019)	Global / Reference to African HEIs	System review	Automated proctoring	Ethical concerns	Identified privacy risks; no quantitative accuracy data
Teixeira & Rocha (2019)	Global / Reference to Africa	Experimental study	ML anomaly detection	False positives	Achieved 78% detection accuracy; high false-positive rate
Okada et al. (2019)	Global / Reference to Africa	Conceptual review	AI assessment tools	Data ethics and transparency	Highlighted ethical frameworks; no empirical metrics
Ong et al. (2021)	South Africa	Quantitative study	Computer vision	High bandwidth requirements	90% accuracy in gaze-tracking detection; performance dropped with low bandwidth
Ullah et al. (2021)	Egypt, Kenya	Systematic review	Facial recognition, ML	Privacy concerns	Accuracy ranged 82–88%; limitations in diverse populations
Zimba et al. (2021)	Zambia	Policy analysis	Data governance tools	Weak data protection frameworks	Recommendations for institutional policies; no empirical metrics
Sultana et al. (2022)	Nigeria	Experimental study	Deep learning (DL)	Algorithmic bias	91% anomaly detection accuracy; biased on minority samples
Yadav et al. (2020)	Kenya	System design	Facial recognition	Lighting and camera dependency	87% recognition accuracy under controlled lighting
Timmis et al. (2016)	South Africa	Qualitative study	Learning analytics	Digital inequality	Highlighted inequity in access; no numerical metrics
Slade & Prinsloo (2013)	South Africa	Ethical analysis	Analytics frameworks	Surveillance concerns	Provided ethical guidelines; no empirical data
Kumar & Owston (2016)	South Africa, Kenya	Empirical study	E-assessment systems	Limited proctoring automation	Reported 70% system reliability; low AI adoption
Sarrayrih & Ilyas (2013)	Nigeria	Review	Online exam tools	Low reliability	Identified frequent system errors; no metrics

Author & Year	African Geographic Focus	Methodologies	AI Techniques	Key Challenges / Identified Gaps	Study Outcomes / Accuracy Metrics
Alalwan et al. (2020)	Egypt, Nigeria	Survey study	AI-supported systems	User acceptance issues	65% of respondents willing to use AI proctoring; qualitative insights

E. Study Characteristics and Technology Adopted (n = 25)

Table 4 shows the quantitative synthesis of the reviewed studies (n = 25), indicating a strong emphasis on **ML–based behavioral analysis**, which was employed in **68% (n = 17)** of the studies, reflecting a research focus on automated detection of anomalous examination behaviors. More than half of the studies (**52%, n = 13**) integrated **facial recognition or biometric authentication**, underscoring the priority given to identity verification and impersonation prevention in online assessments. In contrast, only **24% (n = 6)** of the studies evaluated **mobile-based proctoring solutions**, revealing a significant gap given the widespread reliance on mobile devices for internet access across African contexts. Furthermore, explicit consideration of **privacy and ethical issues** was reported in just **36% (n = 9)** of the studies, highlighting limited integration of ethical and regulatory perspectives in AI-based e-assessment research. Collectively, these findings suggest that while technical detection capabilities dominate current research, **mobile-first design and ethical governance remain underrepresented**, pointing to critical areas for future investigation and system development.

Table 4
Summary of Study Characteristics and Technology Adopted (n = 25)

Characteristic	Description	Number of Studies (n)	Percentage (%)
Machine learning–based behavioral analysis	Studies employing ML techniques such as anomaly detection, keystroke dynamics, gaze tracking, or behavioral pattern recognition	17	68%
Facial recognition / biometric authentication	Studies integrating facial recognition, voice recognition, or other biometric identity verification methods	13	52%
Mobile-based proctoring solutions	Studies evaluating mobile-first or smartphone-based AI proctoring frameworks	6	24%
Explicit consideration of privacy and ethics	Studies that explicitly addressed data privacy, ethics, consent, or regulatory compliance	9	36%

F. Study Meta-Summary analysis

According to Table 5 and Table 6, the meta-summary of reviewed studies indicates that **AI-based e-assessment proctoring in Africa employs a diverse set of technologies**, each with distinct capabilities, challenges, and effectiveness levels. **Facial recognition** is the most widely applied technique for identity verification, achieving accuracy rates between 82% and 90% under controlled conditions (Yadav et al., 2020; Ullah et al., 2021). However, its performance is significantly affected by lighting conditions, camera quality, and the limited representation of African populations in training datasets, highlighting concerns about algorithmic bias and contextual validity. **Gaze tracking and attention monitoring** systems

demonstrate high accuracy (~90%) in detecting inattentive behaviors, but their effectiveness is constrained by high bandwidth requirements and device variability, limiting scalability in low-resource environments (Ong et al., 2021).

Behavioral analytics, such as keystroke dynamics and ML–based anomaly detection, provide continuous monitoring capabilities with detection accuracies ranging from 78% to 91% (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Sultana et al., 2022). Despite these promising results, false positives and the lack of Africa-specific training data remain significant challenges. **Automated video surveillance** systems offer scalable monitoring but raise ethical and privacy concerns, with moderate reliability reported in institutional studies (Kumar & Owston, 2016; Mutula & Wamukoya, 2018). Similarly, **deep learning (DL) models** demonstrate high anomaly detection accuracy (~91%), yet algorithmic bias and limited African datasets necessitate careful contextual adaptation (Sultana et al., 2022). **Learning analytics integrated within LMS platforms** have been used to supplement monitoring and provide insights into student engagement, though quantitative performance metrics remain limited (Bates, 2015; Kintu et al., 2017). Finally, studies emphasizing **data governance and policy tools** reveal significant gaps in institutional readiness and regulatory frameworks, underscoring the need for robust privacy policies to complement technical interventions (Zimba et al., 2021).

Overall, the synthesis highlights a **pattern of high potential but context-dependent limitations**: AI-based proctoring systems show promising accuracy and monitoring capabilities, but their effectiveness in African higher education is constrained by **infrastructure limitations, ethical concerns, algorithmic bias, and insufficient local datasets**. These findings underscore the necessity of developing **lightweight, context-aware, and privacy-preserving AI proctoring solutions** tailored to African institutions.

Table 5
Meta-Summary of Reviewed Studies on AI-Based E-Assessment Proctoring in Africa

AI Technique	Main Challenges / Gaps	Reported Outcomes / Accuracy Metrics
Facial Recognition	Lighting conditions, camera dependency, algorithmic bias	Accuracy 82–90% (Yadav et al., 2020; Ullah et al., 2021); lower performance in low-light or diverse populations
Gaze Tracking / Attention Monitoring	High bandwidth requirement, device limitations	90% detection accuracy; performance drops under low network speed (Ong et al., 2021)
Keystroke Dynamics / Behavioral Analytics	Device variability, user adaptation, false positives	Detection accuracy ~85% in experimental exams (Dendir & Maxwell, 2020)
Machine Learning Anomaly Detection	False positives, lack of Africa-specific training data	78–91% accuracy in anomaly detection; biased on minority datasets (Teixeira & Rocha, 2019; Sultana et al., 2022)
Automated Monitoring / Video Surveillance	Privacy concerns, ethical issues, scalability	Moderate reliability reported; 70–80% system effectiveness in simulated settings (Kumar & Owston, 2016; Mutula & Wamukoya, 2018)
Deep Learning (DL) Models	Algorithmic bias, limited datasets from African contexts	91% anomaly detection accuracy; need for bias mitigation (Sultana et al., 2022)
Learning Analytics / LMS Integration	Digital inequality, lack of institutional readiness	Qualitative evidence of improved monitoring; limited quantitative metrics (Bates, 2015; Kintu et al., 2017)

AI Technique	Main Challenges / Gaps	Reported Outcomes / Accuracy Metrics
Data Governance & Policy Tools	Weak institutional frameworks, inconsistent data protection	Provided policy recommendations; no empirical accuracy metrics (Zimba et al., 2021)

1.

2. Table 6

3. AI Techniques, Application Areas, Key Findings, and Challenges in Reviewed Studies

AI Technique	Application Area	Key Findings	Challenges	References
Facial recognition	Identity verification	Reduced impersonation; moderate accuracy (82–90%)	Algorithmic bias; lighting and camera dependency; population diversity	Yadav et al., 2020; Ullah et al., 2021; Sultana et al., 2022; Ong et al., 2021
Gaze tracking / attention monitoring	Monitoring student focus	Improved detection of inattentive or suspicious behavior; ~90% detection accuracy	High bandwidth demand; device compatibility issues; scalability	Ong et al., 2021; Dendir & Maxwell, 2020; Teixeira & Rocha, 2019
Keystroke dynamics / behavioral authentication	Continuous user verification	Enabled ongoing monitoring of identity; detection of anomalous typing patterns	Device variability; user adaptation; false positives	Dendir & Maxwell, 2020; Sultana et al., 2022; Teixeira & Rocha, 2019
ML anomaly detection	Cheating detection / behavior analysis	Scalable monitoring; detection accuracy 78–91%	False positives; limited Africa-specific training data; algorithmic bias	Teixeira & Rocha, 2019; Sultana et al., 2022; Dendir & Maxwell, 2020
Automated video monitoring	Real-time exam supervision	Reduced manual invigilation; moderate reliability	Privacy concerns; ethical considerations; moderate accuracy	Kumar & Owston, 2016; Mutula & Wamukoya, 2018; Woldeab et al., 2020
Learning analytics / LMS integration	Engagement monitoring / proctoring support	Provided insights into student activity; aided detection	Limited quantitative metrics; inequitable access; integration challenges	Bates, 2015; Kintu et al., 2017; Timmis et al., 2016

G. Discussion

The findings of this review indicate that **AI-based e-assessment proctoring holds considerable promise for enhancing examination integrity in African higher education**, yet adoption and effectiveness remain constrained by a range of **technical, infrastructural, ethical, and contextual factors**. Consistent with prior research, **ML–based behavioral analysis**, including anomaly detection and keystroke dynamics, has been effective in monitoring student behavior and detecting irregularities during online exams (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Sultana et al., 2022). Similarly, **facial**

recognition and biometric authentication tools have reduced impersonation risk and strengthened identity verification, particularly in controlled or simulated environments (Yadav et al., 2020; Ullah et al., 2021; Ong et al., 2021). These results align with studies conducted in other low-resource or developing regions, highlighting the potential of AI to provide scalable, automated monitoring solutions where human invigilation is limited (Boateng et al., 2020; Kumar & Owston, 2016).

However, **practical implementation in African contexts faces significant barriers**. Technical constraints, including unstable internet connectivity, device heterogeneity, and bandwidth limitations, affect both the reliability and scalability of AI systems (Reynolds & Kizito, 2020; Woldeab et al., 2020). Mobile-based AI proctoring frameworks, which are particularly important given the prevalence of smartphones among African students, remain underexplored, with only a minority of studies evaluating mobile-first solutions (Yadav et al., 2020; Reynolds & Kizito, 2020). These gaps underscore the need for **lightweight, low-bandwidth, and device-agnostic AI solutions** that can operate effectively in diverse educational settings.

Ethical and privacy considerations also emerge as a major concern. Only about 36% of studies explicitly addressed data protection, consent, or algorithmic fairness (Slade & Prinsloo, 2013; Zimba et al., 2021; Sultana et al., 2022). This lack of attention to **regulatory compliance and ethical safeguards** is critical because AI-based proctoring often involves the collection of sensitive biometric and behavioral data, which could expose students to privacy risks or algorithmic discrimination if improperly managed (Okada et al., 2019; Foster & Layman, 2019). Future systems must therefore integrate **ethically responsible frameworks**, including informed consent, secure data storage, and bias mitigation strategies, to ensure equitable treatment of all students.

Another key observation is the **limited empirical validation of AI proctoring in real-world African examination environments**. Most studies report outcomes from pilot implementations or controlled laboratory settings (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Yadav et al., 2020). Consequently, the **generalizability of reported detection accuracies** remains uncertain, and there is little evidence on how these systems perform under actual examination conditions with heterogeneous student populations, variable infrastructure, and high-stakes assessment pressure. Multi-modal AI systems that integrate facial recognition, behavioral analytics, and anomaly detection remain rare, yet they may offer more robust and reliable proctoring solutions if designed with local context in mind (Sultana et al., 2022; Teixeira & Rocha, 2019).

Overall, this synthesis indicates that **AI-based e-proctoring in Africa demonstrates both technical potential and significant limitations**. While these technologies can enhance academic integrity, their effectiveness is dependent on **context-aware design, robust infrastructure, mobile accessibility, and ethical safeguards** (Kintu et al., 2017; Boateng et al., 2020; Reynolds & Kizito, 2020). The findings highlight the urgent need for **participatory, localized, and scalable AI frameworks** that are sensitive to infrastructural constraints, socio-cultural diversity, and ethical requirements, providing a foundation for sustainable deployment of AI proctoring systems in African higher education.

4. CONCLUSION

AI-based e-assessment proctoring has demonstrated **considerable potential to enhance academic** integrity in African higher education, particularly through the application of ML–based behavioral analysis, facial recognition, and anomaly detection techniques (Dendir & Maxwell, 2020; Teixeira & Rocha, 2019; Yadav et al., 2020). These systems provide scalable, automated monitoring solutions capable of reducing impersonation and detecting suspicious behaviors. However, their practical effectiveness is constrained by technical, infrastructural, and ethical limitations, including unstable internet connectivity, device variability, bandwidth constraints, and limited consideration of privacy and consent (Reynolds & Kizito, 2020; Slade & Prinsloo, 2013; Zimba et al., 2021). Additionally, mobile-based proctoring solutions remain underexplored, and most existing studies report outcomes from controlled or pilot settings, limiting the generalizability of AI system performance in real-world African contexts (Boateng et al., 2020; Dendir & Maxwell, 2020).

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The Implementation of The Connecting, Organizing, Reflecting, Extending (CORE) Learning Model is Integrated with The Problem Based Learning (PBL) Model to Enhance the Mathematical Problem-Solving Ability of PGSD Students

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ABSTRACT

This study aims to examine the effectiveness of the Connecting, Organizing, Reflecting, and Extending (CORE) learning model integrated with Problem Based Learning (PBL) in improving the mathematical problem-solving abilities of PGSD students. A quasi-experimental method with a non-equivalent control group pretest–posttest design was employed. The participants consisted of 62 fourth-semester PGSD students at Universitas Muhammadiyah Sumatera Utara in the 2024/2025 academic year, divided into an experimental group (n=32) and a control group (n=30). Research instruments included a mathematical problem-solving test, observation sheets, and reflective journals. Data analysis revealed a significant difference between the two groups, with the experimental group achieving a higher mean score (82.53) than the control group (71.67), supported by a t-value of 5.742 ($p<0.001$). The N-gain results indicated a moderate improvement in the experimental group (0.58), exceeding that of the control group (0.31). Students in the experimental class demonstrated better performance across all problem-solving indicators, particularly in rechecking the solution process and results. Qualitative findings further showed improvements in conceptual understanding, strategic thinking, confidence, and collaboration. Overall, integrating CORE and PBL creates meaningful learning experiences and effectively enhances students' mathematical problem-solving competence.

Keyword: CORE, Problem Based Learning, Mathematical Problem Solving, PGSD Students, Integrated Learning Model

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1. INTRODUCTION

Mathematics plays a fundamental role in shaping systematic, analytical, and critical thinking in students of the Elementary School Teacher Education Program (PGSD) as future educators. Mastery of mathematical concepts and problem-solving abilities are essential competencies that PGSD students must possess to prepare them to become competent teachers in teaching mathematics at the elementary school level (Arifuddin, 2020; Fina Tazkiya, 2023). The ability to solve mathematical problems is not only an important component of the mathematics curriculum but also a crucial prerequisite for facing the complexities of problems in the world of education and everyday life in the era of globalization (Anugraheni, 2020; Irvan et al., 2024; Siregar et al., 2020)

Based on preliminary studies and empirical observations, the mathematical problem-solving abilities of PGSD students are still not optimal. Several recent studies indicate a gap between expectations and reality regarding the mathematical problem-solving abilities of PGSD students (Jesi Alexander Alim et al., 2024). Hadi & Marzuki (2021) revealed that most PGSD students have difficulty identifying problems, formulating solution strategies, and applying mathematical concepts in the context of non-routine problem-solving. In line with that, Pambudi et al. (2020) found that the mathematical problem-solving abilities of PGSD students are still relatively low, especially in the aspects of reasoning, representation, and mathematical connections.

The ability to solve mathematical problems requires a complex thinking process that involves a series of high-level cognitive skills (Restini et al., 2023). Indicators of mathematical problem-solving ability according to Polya, as modified by Muhammda Faisal Khatami et al. (2022) include: (1) understanding the problem, (2) planning the problem-solving process, (3) executing the problem-solving plan, and (4) reviewing the process and results of the solution. The four indicators represent a comprehensive and integrated problem-solving cycle. Optimizing mathematical problem-solving skills requires a learning approach that can accommodate the complexity of mathematical thinking processes.

The Connecting, Organizing, Reflecting, Extending (CORE) learning model is one of the constructivist learning models that emphasizes comprehensive thinking activities through four main stages (Syofitami & Noer, 2021). Recent research by Saregar et al. (2021) reveals that the CORE model is effective in enhancing students' mathematical thinking abilities because it facilitates the process of connecting new knowledge with previously held knowledge (connecting), organizing information into cognitive structures (organizing), reflecting on knowledge (reflecting), and extending the knowledge acquired (extending). Sari & Karyati (2022) added that the CORE model allows students to construct knowledge independently through social interaction and cognitive elaboration.

On the other hand, the Problem Based Learning (PBL) model is an educational approach that emphasizes the process of solving authentic problems as a stimulus for developing knowledge and skills (Denisa Azura et al., 2024; Musna et al., 2021; Nasution, et al., 2023). According to Aprilita & Handican (2023), the PBL model has unique characteristics that focus on cases or problems as the starting point of learning, encourage collaborative activities, and develop critical thinking skills in real-world contexts. Asri et al. (2024) found that the application of the PBL model is effective in developing students' mathematical problem-solving skills because it provides meaningful and relevant learning contexts.

Although there are several studies examining the effectiveness of the CORE model and the PBL model separately, research on the integration of these two models in relation to mathematical problem-solving abilities is still limited, especially in the context of mathematics education for PGSD students. Son et al. (2020) suggest the need for further exploration regarding the integration of various innovative learning models to optimize mathematics learning outcomes. Yunita et al. (2022) revealed that collaboration between learning models has the potential to create comprehensive and effective learning synergy.

The integration of the CORE and PBL models offers a promising pedagogical perspective for developing the mathematical problem-solving abilities of PGSD students. The CORE model with its four stages (connecting, organizing, reflecting, extending) can be harmoniously integrated with the PBL syntax, which emphasizes contextual problem-solving (Irawan & Iasha, 2021). Dewi Mustika Wati et al. (2023) argue that the integration of the CORE model and PBL has the potential to produce a comprehensive learning design, where the strengths of one model can compensate for the limitations of the other. According to Rohmah & Ulya (2021) the integration of learning models can enhance the effectiveness of mathematics learning through the diversification of activities and learning experiences.

Theoretically, the integration of the CORE and PBL models has a strong epistemological foundation in social constructivism theory. According to Vygotsky, as cited by Tohari & Rahman (2024), knowledge construction occurs through social interaction and direct experience with relevant problem contexts. In this context, the CORE model represents the dimension of individual knowledge construction through connection, organization, reflection, and knowledge extension, while the PBL model represents the dimension of social knowledge construction through collaboration in contextual problem-solving (Elfrianto et al., 2020; Imandala et al., 2019; Latri et al., 2024).

Based on the above description, there is an urgency to further examine the application of the CORE learning model integrated with the PBL model on the mathematical problem-solving abilities of PGSD students. This research aims to: (1) analyze the implementation of the CORE learning model integrated

with the PBL model in mathematics education for PGSD students; (2) evaluate the impact of the integration of the CORE and PBL models on the mathematical problem-solving abilities of PGSD students; and (3) identify the factors that influence the effectiveness of the integration of the CORE and PBL models in developing the mathematical problem-solving abilities of PGSD students.

The significance of this research lies in its contribution to the development of innovative and effective mathematics learning models for PGSD students. Theoretically, this research enriches the body of knowledge on the integration of learning models in mathematics education. Practically, the results of this research can serve as a reference for lecturers and curriculum developers in designing effective mathematics learning to enhance the mathematical problem-solving abilities of PGSD students. This research also provides pedagogical implications related to mathematics teaching strategies in higher education, particularly in the PGSD study program.

Moreover, this research fills the gap in the literature regarding the integration of the CORE and PBL models, which is still limited. The majority of previous research has focused on the implementation of the CORE or PBL model separately, while research on the integration of these two models has not been extensively conducted. Through this research, it is hoped that a comprehensive and adaptive integrative learning model can be produced, tailored to the characteristics and needs of PGSD students in developing mathematical problem-solving skills.

2. RESEARCH METHOD

This research uses a quantitative approach with a quasi-experimental method. The research design used is a pretest-posttest non-equivalent control group design, where the research subjects are not randomly grouped but use pre-existing groups (intact group). This research design was chosen because it allows researchers to analyze the effect of the treatment on the dependent variable while considering the initial conditions of the research subjects (Creswell, 2022; Sugiyono, 2021).

The population in this study consists of all PGSD semester IV students for the Academic Year 2024/2025 at the Faculty of Teacher Training and Education, Universitas Muhammadiyah Sumatera Utara. The sampling technique used is purposive sampling, which is the selection of samples based on specific considerations in accordance with the research objectives (Etikan, 2017). The research sample consists of two parallel classes with relatively homogeneous characteristics based on the results of homogeneity and normality tests, namely Class A as the experimental group (n = 32) and Class B as the control group (n = 30). The determination of the experimental and control groups was done randomly through a lottery technique.

The main instrument used in this study is: (1) Mathematics Problem-Solving Ability TestThis instrument consists of essay questions that measure four indicators of mathematical problem-solving ability based on the modified Polya stages by Etikan (2017), namely: (a) understanding the problem, (b) planning the problem-solving, (c) executing the problem-solving plan, and (d) reviewing the process and results of the solution. (2) Observation Sheet Observation sheets are used to observe student activities during the learning process, both in the experimental group and the control group. (3) Reflective Journal The reflective journal is filled out by the experimental group students after participating in learning with the CORE model integrated with the PBL model.

Quantitative data obtained from pretest and posttest results were analyzed using descriptive and inferential statistical techniques. Descriptive statistical analysis includes the calculation of the mean, standard deviation, minimum value, and maximum value. Meanwhile, inferential statistical analysis is conducted to test the research hypothesis. Additionally, to measure the effectiveness of the treatment, the N-gain score is calculated using the formula:

N-gain = (posttest score - pretest score) / (maximum score - pretest score)

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The categorization of N-gain refers to the Hake criteria modified by Sundayana (2020), namely: $g \geq 0.7$ (high); $0.3 \leq g < 0.7$ (medium); and $g < 0.3$ (low).
Qualitative data obtained from observations and reflective journals were analyzed using content analysis techniques. This analysis includes the stages of data reduction, data presentation, and conclusion drawing.This qualitative data is used as supporting data to enrich the interpretation of the quantitative analysis results.

3. RESULTS AND DISCUSSION

This section presents the research results on the application of the Connecting, Organizing, Reflecting, Extending (CORE) learning model integrated with the Problem Based Learning (PBL) model on the mathematical problem-solving abilities of PGSD students. The research results are presented systematically based on the quantitative and qualitative data analysis that has been conducted.

A. Initial Ability to Solve Mathematical Problems

Before the implementation of the learning model, a pretest was conducted to measure the initial problem-solving abilities in mathematics of both groups. Descriptive statistics of the pretest results are presented in Table 1

Table 1. Descriptive Statistics of Pretest Results on Mathematics Problem-Solving Ability

Group	N	Average	Standard Deviation	Minimum Value	Maximum Value
Experiment	32	38,34	10,25	40,00	75,00
Control	30	59,07	9,87	42,00	76,00

The results of the normality test using the Kolmogorov-Smirnov method show that the pretest data in both groups are normally distributed ($p > 0.05$). The homogeneity test using Levene's test also showed that the variances of both groups are homogeneous ($F = 0.214$; $p = 0.645$). Furthermore, the independent t-test results on the pretest scores indicate that there is no significant difference between the initial mathematical problem-solving abilities of the experimental group and the control group ($t = -0.287$; $p = 0.775$). This indicates that both groups had relatively equal initial abilities before being given the treatment.

B. Final Problem-Solving Ability in Mathematics

After the implementation of the learning model, a posttest was conducted to measure the final problem-solving abilities in mathematics of both groups. Descriptive statistics of the posttest results are presented in Table 2

Table 2. Descriptive Statistics of Posttest Results for Mathematical Problem-Solving Ability

Group	N	Average	Standard Deviation	Minimum Value	Maximum Value
Experiment	32	82,53	7,41	68,00	94,00
Control	30	71,67	8,23	56,00	85,00

The results of the normality test using the Kolmogorov-Smirnov method indicate that the posttest data in both groups are normally distributed ($p > 0.05$). The homogeneity test using Levene's test also showed that the variances of both groups are homogeneous ($F = 0.547$; $p = 0.462$). Furthermore, the independent t-test results on the posttest scores indicate a significant difference between the final mathematical problem-solving abilities of the experimental group and the control group ($t = 5.742$; $p <$

0.001). The average posttest score of the experimental group (82.53) was significantly higher than that of the control group (71.67).

C. Improvement in Mathematical Problem-Solving Skills

To measure the improvement in mathematical problem-solving abilities in both groups, an N-gain score analysis was conducted. The results of the N-gain score analysis are presented in Table 3.

Table 3. Results of N-gain Score Analysis for Mathematical Problem-Solving Ability

Group	N	Average N Gain	Standard Deviation	Category
Experiment	32	0,53	0,14	medium
Control	30	0,31	0,12	medium

The independent t-test results on the N-gain scores indicate a significant difference between the improvement in mathematical problem-solving abilities of the experimental group and the control group ($t = 8.321$; $p < 0.001$). The average N-gain of the experimental group (0.58) was significantly higher than that of the control group (0.31), although both were in the moderate category.

D. Analysis of Mathematical Problem-Solving Ability Based on Indicators

To obtain a more comprehensive picture, an analysis of mathematical problem-solving abilities was conducted based on four indicators, namely: (1) understanding the problem, (2) planning the problem-solving process, (3) executing the problem-solving plan, and (4) reviewing the process and results of the solution. The percentage achievement of each indicator on the posttest for both groups is presented in Table 4.

Table 4. Percentage Achievement of Mathematical Problem-Solving Ability Indicators on the Posttest

Indicator	Experimental Group (%)	Control Group (%)
1	92,81	87,67
2	83,44	72,33
3	79,06	68,67
4	74,84	58,00

Based on Table 4, the experimental group showed a higher achievement percentage on all indicators of mathematical problem-solving ability compared to the control group.The largest difference in achievement percentages is seen in the fourth indicator (rechecking the process and results), which is 16.84%. Meanwhile, the smallest percentage difference in achievement is seen in the first indicator (understanding the problem), which is 5.14%.

E. Results of Student Activity Observation

During the implementation of the learning model, observations were made on the activities of students in both groups.Observations were conducted in six meetings, focusing on aspects relevant to mathematical problem-solving skills.The percentage of student activity implementation in both groups is presented in Table 5.

Table 5. Percentage of Student Activity Implementation

Meeting	Experimental Group (%)	Control Group (%)
1	78,67	70,56
2	82,33	72,89
3	85,78	73,44
4	88,44	75,11
5	90,22	76,33
6	82,33	72,76
Average	83,15	70,56

Based on Table 5, the percentage of student activity implementation in the experimental group shows a consistent increase from the first meeting to the sixth meeting. The average percentage of student activity implementation in the experimental group (83.15%) was higher than in the control group (72.76%). This indicates that the CORE learning model integrated with the PBL model is capable of encouraging students to actively engage in the learning process.

Based on the results of qualitative observations, students in the experimental group showed higher enthusiasm and perseverance in solving the presented math problems. They also demonstrated better collaboration skills in group discussions and were able to produce more creative solutions. Connecting and organizing activities help students build a comprehensive understanding of problems, while reflecting and extending activities facilitate them in evaluating and developing solutions (Eka Sastrawati et al., 2025; Nasution et al., 2024).

F. Student Reflections on the Learning Process

To obtain students' perspectives on the implementation of the CORE learning model integrated with the PBL model, a content analysis was conducted on the reflective journals filled out by the experimental group students. The results of the content analysis show several main themes that emerged from the students' reflections, as presented in Table 6.

Table 6. Main Themes in Students' Reflective Journals

Theme	Description	Frequency (%)
T1	Improvement in understanding mathematical concepts	87,50
T2	Development of problem-solving strategies	81,25
T3	Improvement in confidence in problem-solving	78,13
T4	Collaboration and effective communication within the group	75,00
T5	Understanding the relationship between mathematical concepts and real-world contexts	71,88
T6	Difficulty in the reflecting and extending stage	28,13

Based on Table 6, the majority of students reflected an increase in understanding mathematical concepts (87.50%) and the development of problem-solving strategies (81.25%) after participating in learning with the CORE model integrated with the PBL model. Most students also reflected an increase in confidence in solving math problems (78.13%) and an improvement in collaboration and communication skills within groups (75.00%). However, some students (28.13%) reflected on difficulties in the reflecting and extending stages, particularly in evaluating solutions and developing knowledge in a broader context.

Some representative student reflection quotes are presented as follows:

"This learning model helps me connect the mathematical concepts I have previously learned with new problems I encounter." I feel more capable of organizing my thoughts and seeing patterns in problem-solving. (Student 7)

“The reflecting stage makes me accustomed to rechecking the solutions I find. This helps me reduce calculation errors and ensures that my solution truly addresses the problem at hand.” (Student 15)

"I find it difficult in the extending stage, especially when asked to develop new problems or apply solutions in different contexts. However, after a few meetings, I started to get used to it and even enjoyed the process.” (Student 22)

"Collaboration in groups is very helpful in finding various problem-solving strategies. We learn from different perspectives and approaches, enriching our understanding of mathematical problems.” (Student 30)

The research results show that the CORE learning model integrated with the PBL model is effective in improving the mathematical problem-solving abilities of PGSD students. This is indicated by the significant differences in posttest scores and N-gain between the experimental group and the control group.

The effectiveness of the CORE learning model integrated with the PBL model can be explained through several factors. First, the connecting stage in the CORE model facilitates students in linking new knowledge with previously acquired knowledge. This is in line with the opinion of Latri et al. (2024) who state that the process of connecting knowledge is an important foundation in building comprehensive understanding.

Second, the organizing stage helps students systematically organize information, making it easier for them to plan problem-solving strategies. According to the findings of Whitelock-Wainwright et al. (2020), the ability to organize information is positively correlated with the ability to plan effective problem-solving strategies.

Third, the reflecting stage encourages students to evaluate the process and results of problem-solving. As stated by Restini et al. (2023), reflection is an important component in the development of metacognition that plays a role in solving mathematical problems.

Fourth, the extending stage facilitates students in developing knowledge in a broader context, thereby enhancing their knowledge transfer abilities. This is consistent with the findings of Djudin (2023) that the ability to develop knowledge is positively correlated with adaptive problem-solving skills.

The integration of the CORE model with the PBL model creates a comprehensive learning synergy. The PBL model provides a context of authentic, meaningful, and relevant problems, while the CORE model offers a systematic cognitive structure for solving those problems. This is in line with the opinion of Gunawan et al. (2023) that the integration of learning models can optimize learning outcomes through the combination of the strengths of each model.

The results of the analysis based on the indicators of mathematical problem-solving ability show that the CORE learning model integrated with the PBL model is the most effective in improving problem comprehension skills. However, the most significant difference between the experimental group and the control group was observed in the indicator of reviewing the process and results of the solution. This indicates that the reflecting stage in the CORE model significantly contributes to the development of evaluation skills in solving mathematical problems. Another interesting finding is the consistent increase

in the implementation of student activities in the experimental group from the first meeting to the sixth meeting. This indicates that students are becoming increasingly accustomed to the CORE learning model integrated with the PBL model as their learning experience grows. According to Utami et al. (2023), adapting to innovative learning models requires time and a continuous process (Utami et al., 2023).

Students' reflections on the learning process indicate a positive impact from the implementation of the CORE learning model integrated with the PBL model on their cognitive and affective development. The majority of students reflected an increase in conceptual understanding, the development of problem-solving strategies, and an increase in self-confidence. However, some students experienced difficulties in the reflecting and extending stages. This indicates the need for more attention in facilitating students at those stages, especially at the beginning of the implementation of the learning model.

4. CONCLUSION

The application of the Connecting, Organizing, Reflecting, Extending (CORE) learning model integrated with the Problem Based Learning (PBL) model has proven effective in improving the mathematical problem-solving abilities of PGSD students. This is evidenced by the significant difference in posttest scores between the experimental group (mean=82.53) and the control group (mean=71.67) with a t-value of 5.742 ($p<0.001$), as well as a higher N-gain increase in the experimental group (0.58) compared to the control group (0.31). The experimental group also showed higher achievements on all indicators of mathematical problem-solving, with the largest difference on the indicator "rechecking the process and results" (16.84%), as well as consistently increased learning activities, reaching an average implementation percentage of 83.15%.

The integration of the CORE and PBL models creates a comprehensive learning synergy, where the PBL model provides meaningful authentic problem contexts, while the CORE model offers a systematic cognitive structure for problem-solving. Qualitative analysis through reflective journals revealed that the majority of students experienced positive benefits from the implementation of the model, particularly in the improvement of mathematical concept understanding (87.50%), development of problem-solving strategies (81.25%), increase in self-confidence (78.13%), and development of collaboration skills (75.00%), although a small number of students (28.13%) faced difficulties in the reflecting and extending stages. Based on these findings, the CORE and PBL integrative learning models are recommended for implementation in mathematics education within the PGSD study program, with attention to appropriate adaptation and scaffolding to optimize each stage of learning.

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Leveraging Gamification Mechanics for Students' Learning Motivation in Higher Education

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ABSTRACT

The purpose of this paper was to analyze the effect of integrating gamification mechanics in Learning Management Systems (LMSs) for students' motivational learning experience in higher education institutions. The study was anchored on both Self-Determination theory and the theory of gamified learning. The target population was 162 respondents. Questionnaires and Modular Object-Oriented Dynamic Learning Environment (MOODLE) reporting logs were used for data collection. Descriptive and inferential techniques were used in data analysis. The results were presented in tables and figures. The results established that gamified LMS students were more motivated compared to the non-gamified LMS students. The study confirmed that the application of gamification had a positive influence on students' motivation. The investigation suggests that eLearning instructors receive training through workshops on gamification integration for their courses from the university management. Besides, the eLearning Directorate should create a precise guideline on how gamification tools might be integrated into the university course curricula to improve students' engagement and concentration in learning activities.

Keywords: Gamification elements, eLearning, Motivation, Learning management system

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1. INTRODUCTION

Gamification has been in existence for over one decade since its inception in education sector among other industries. The application of game features such as badges, awards, stages, feedback and levels in an educational setting is known as gamification. This is a new teaching and active learning pedagogy. This is believed to improve learners' behaviour and attitudes in learning processes. The reality of the use of eLearning systems in higher education was witnessed during the COVID-19 pandemic globally. This is when it was realized that these systems were lacking pertinent gamification features to reinforce students' motivational learning experience.

Gamification has gained a lot of momentum, particularly in the field of education where low students motivation is a persistent issue that prevents learners from completing their education (Barna & Fodor, 2018). It was stated that students had inadequate drive to finish the game's levels through self-study. Thus, eLearning students proposed that more gaming aspects be added to their learning programmes to make them more engaging and joyful. Lack of feedback and assistance, an excessive workload, unclear and irrelevant goals, technical difficulties, insufficient social contacts and a lack of personal connections all contribute to learning demotivation in students. In adopting these eLearning systems, literature revealed that students get demotivated due to lack of system engagement and interactivity, this was attributed to insufficient integration of gamification tools in LMSs.

Self-Determination Theory (SDT) and the theory of gamified learning that have been widely used to gamify instructions in higher education institutions, provided support for this research. The study adopted an experimental research design which generated quantitative data. The primary unit of analysis was the eLearning students drawn from the computing sciences Department. Questionnaires and MOODLE reporting logs were used for data collection. Data analysis involved the use of descriptive and inferential statistics.

Hypothetically, students may gain from gamified education in a variety of ways such as improved training procedures, enhanced learning performance and increased motivation among learners (Zainuddin *et al*., 2020). The results of gamification remain inconsistent, and it is impossible to pinpoint the characteristics of learners that are utilized to customize gamified learning environments or the effects of gamification personalization on the learning outcomes and psychological states of students (Toda *et al*., 2017). This indicates that some research concerns remain unearth even though there have been some systematic studies on personalized gamification, like tailored gamification in education (Rodrigues *et al*., 2020). Out of these convictions, this study sought to look into the effect of integrating gamification in LMSs on students' motivation in learning.

In general, using gamification in education promotes students' learning motivation and engagement (Bai *et al*., 2020); but, in certain circumstances, it has the opposite impact, discouraging or negatively affecting some students' learning results (Kwon & Özpolat, 2020). A study conducted by Wilk *et al*. (2022) suggested a thorough analysis of the institutional, technological, and user support barriers to gamification integration in LMSs, along with the inclusion of other studies covering other issues not reported by the primary studies in gamified educational environments. To further help comprehend the link between gamification and motivation comprehensively, it is necessary to study the students' impressions of the incorporation of gamification in LMSs intervention using an experimental research approach.

Ofosu-Ampong *et al*. (2020), argues that developing countries have not yet thoroughly looked into the benefits of integrating gamification in eLearning platforms and how it might enhance students' engagement and performance in their learning activities. Thus, it is crucial to figure out the key factors employed in this research, that include the dependent variable of motivated learning experiences, the independent variable of integrating gamification in LMS. Motivational learning experiences is defined as an interaction approach that helps students focus and stay engaged while improving the caliber of the learner's skills. In this study, motivated learning experience is viewed as the result and gamification is assumed to be the cause.

Nonetheless, demotivation and disengagement account for 40% to 80% of eLearning students' typical dropout rates from online courses, and this may be related to insufficient concept development for the integration of gamification in LMSs (Luis *et al*., 2022). Claris *et al.* (2020) affirmed that, a lack of gamification, restricted social contacts, institutional and technological problems, a lack of feedback and assistance all contribute to demotivation among eLearning students. It was reported that, 76% of undergraduate respondents and 56% of graduate and professional respondents cited a lack of desire for eLearning as the largest obstacle. Consequently, the goal of this study was to examine how students see the incorporation of gamification features into LMSs in an effort to augment their motivational learning experiences. This paper is structured into various sections such as a review of related literature that informed the study, methods and materials, results of the study, discussion of the findings and conclusions of the study.

2. RESEARCH METHOD

The research design adopted for this study was experimental. The method was quantitative in nature and was used to examine the cause-and-effect connections between the two variables. Ethically, the researcher wrote a letter to the Directorate of eLearning requesting for permission to set the experiment using the university's MOODLE LMS. The LMS did not have the required gamification plugins for the experiment. The technical team downloaded the plugins from Packback Inc. Software Company, installed and configured them upon requesting through writing. The plugins were added to the LMS as blocks.

Moreover, the researcher designed three learning activities for the experiment. The activities had multiple choice questions and short essay questions. These questions covered Bloom's Taxonomy instructional design framework concepts from lower order thinking to higher order thinking in students' cognitive processes for learning. Each of the activities aimed at testing a particular gamification plugin. The activity is designed, a particular gamification tool added to it and conditions as well as rules are set on how students can earn them. The eLearning students from the Department of Computing Sciences were

identified as the participants in the experiment for the study. They were enrolled in the university's MOODLE LMS.

A consent form was integrated into the LMS and the participants were requested to sign to take part in the study. After consenting, participants (eLearning students) who were 162 were greeted, welcomed and given an overview of the experiment's procedures. Subsequently, each participant was systematically allocated to one of the two experimental conditions, which comprised of an LMS version that was either gamified (experimental) or non-gamified (control). Both gamified and non-gamified LMS had 81 participants each. All the 81 participants were able to respond to all the activities on the LMS since conditional tracking control feature was enabled. Learners who earned themselves these various elements having met some set criteria, were able to see and download them in their course accounts. The experimental data was extracted by downloading it in form of CSV file format and cleaned it in preparation for the actual analysis.

Both gamified and non-gamified participants used the MOODLE LMS in accordance with their allocated conditions to study the learning materials uploaded on the LMS linked to the Database Systems unit. This unit was chosen since it offered students both practical and theoretical skills. The unit was offered in the Department of Computing Sciences at Kisii University. The only distinction between the two sets of learning materials is whether or not gamification was introduced to eLearning students according to the circumstances they were placed in. The two weeks that the learning assignment was performed in a computer lab included two experimental sessions, lasting for two hours each, for each of the three-course activities. The participants made use of smartphones, laptops and desktop PCs in the lab. Each session lasted, depending on the activity, around two hours. MOODLE system reporting logs and questionnaires were used to collect primary data for this investigation. The eLearning students who used the gamified LMS, responded to the questionnaire items to provide their opinion. The questionnaires were integrated as an activity into the LMS. This was the last activity to be done by the participants on the gamified LMS as post-experimental follow-up.

For data analysis, both inferential and descriptive statistics were employed. To compare whether there was a statistically significant difference in the means of course activity scores for the two groups that interacted with the gamified and non-gamified versions of the LMS, a paired samples t-test was also performed using the CSV data file format downloaded from the MOODLE LMS.

This study was anchored on both SDT and the theory of gamified learning. Research on gamification in higher education has been conducted using Self-Determination Theory's (Tandon, 2017). SDT addresses three main constructs of psychological needs namely: need for competence, need for autonomy and need for relatedness which are influential in learners' behaviour/attitude. Research on the investigation of certain motivating factors in the gamification of higher education institutions was conducted in Poland with funding from Kultura (2022). It was found that because the gaming world is so different from other environments, enforcing the rules required careful considerations. To begin with, whilst learning and working are often required, playing games is optional. The study suggests two fundamental guidelines for gamified programs: participants should feel free to try new things and fail, and no gamification-related activity should be forced upon them. They will mimic conventional learn-and-pass guidelines with extra "get-used-to" rules as a result of pressure to play instructional games.

One frequently discussed components of gamification is motivation, yet there are doubts regarding the validity of the empirical data linking increased motivation, particularly in the educational sector (Dichev & Dicheva, 2017). Regarding the idea of gamification in education, there are still conflicting outcomes and conclusions from various studies; some point to convergence, while others point to divergence (Gooch *et al*., 2016). The goal of gamification integration is to increase student involvement and focus, which will improve their behavioural abilities in turn.

Although SDT has significantly advanced the field of gamification in higher education, there are still several issues with the theory. The theory's disregard for technology features as behavior and motivational factors is one of its flaws. Furthermore, the notion has come under scrutiny for overemphasizing individualistic cultures while downplaying the role of technical components in improving students' interest

in learning activities hence the need for the second theory to bridge this theoretical gap. The study also indicated that the gamified learning theory was useful. Baard *et al.* (2004) state that competence is linked to the drive to overcome obstacles and achieve success thus improving students' learning outcome. Further, they say that having the ability to pursue one's goals and accept responsibility for one's actions is a prerequisite for autonomy. They went on to explain that the demand for relatedness is tied to social standing and a bond with others that is built on reciprocity and dependency. Numerous individuals get satisfaction when their efforts are showcased on leaderboards inside the gamified setting, emphasizing the social component of relatedness Deci and Ryan (2008). Badges contribute to the development of traits like "self-competence and self-efficacy," both individually and socially.

The four primary components of gamified learning theory are learning results, behavior/attitude, instructional content material and gamification features. Both a less direct moderating process and a more direct mediation process can occur when game factors influence learning. By adding fantasy, a game characteristic, student engagement, an attitude should rise in the Indiana University example (Tay, 2010), strengthening the connection between learning outcomes and instructional material. Using a gaming feature boosts player engagement, which modifies the link between learning objectives and instructional content. The fact that the moderator cannot affect the result construct apart from the causal construct is a significant implication of a moderating process. In this instance, if the instructional design was already good, adding a gaming aspect would not affect learning.

A variety of game features were employed in Landers and Callan's (2011) gamification study to motivate students to finish online practice exams. Based on studies indicating that practicing for exams will increase knowledge more than alternative memorizing strategies, such as focused conventional studying, the researchers put these examinations into practice (Roediger & Karpicke, 2006). The goal of gamification is to affect attitudes and behaviors associated to learning, such as autonomy, motivation, engagement, performance, connectivity, satisfaction and teamwork. But the nature of that concept determines how this behavior and results relate to each other. When an instructional designer aims to promote a behavior or attitude that will boost learning outcomes by improving pre-existing teaching in some manner, it is known as gamification, and it has a moderating effect on learning.

The basic needs for autonomy, competence and relatedness may be fully or partially satisfied, according to Van Roy and Zaman (2019), gamification elements like certificate customization, that promote feelings of autonomy, badges and achievements, which enhance feelings of competence, and social networks, which foster feelings of relatedness.

The theory of gamified learning and SDT were essential since they recognized the ways in which gamification components affect students' motivation in learning processes. Furthermore, these theories accept the causality hypothesis, which contends that adding gamification to LMSs enhances students' attitudes and behavior. They also benefit the main stakeholders in the research (eLearning students). The hypothesis that integrating gamification tools into the LMSs improves students' motivation to learn in higher education was developed with the assistance of these theories.

A study on virtual teaching and learning in higher education during the coronavirus pandemic conducted in Romania by Claudiu *et al.* (2020) found that 5.7% of students felt that they were not interacting with their teachers and 7.5% of them mentioned that they were not focusing or paying attention in the online environment. Furthermore, research indicates that the eLearning environment poses a number of challenges to instructors and students alike. Besides, there is a dearth of regional literature on the topic of student focus in an online learning environment.

Zainuddin *et al*. (2020) affirm that gamification and game-based learning contribute to a variety of learning outcomes (Sailer & Homner, 2020), most of which are rational in nature and whose goal is to improve students' learning engagement. Game design mechanics include badges, level up, points, leaderboards, quests, avatars, custom certificates, or social graphs. Moreover, cognition may be defined as a collection of methods and procedures by which various individuals use their perceptual and problem-solving abilities to understand the environment (Lamb *et al.*, 2018). From the ongoing aforementioned literature, gamification has been implemented using game tools like badges, level up, leaderboards but little

is known with regard to the use of custom certificates. This instigated the urgency for carrying out this study.

The most popular game components, according to Alsawaier *et al*. (2018) investigations into the effects of gamification in higher education, were avatars, quests and challenges, badges, points, and level up. It was realized that the majority of research in higher education showed that gamification introduced game elements that increased students' motivation and engagement. Researchers need to look into and evaluate which significant combinations of game tools improve learning outcomes and have a good impact on motivation.

Nonetheless, studies by Buckley *et al*. (2019) and Alsawaier (2018) have also shown unfavorable results with the application of gamification elements. These investigations came to the conclusion that further empirical study was necessary to fully explore the potential and consequences of integrating gamification in LMSs. This means that the effect of using gamification is not clear since different scholars have had different opinions, suggesting that more studies are required to shed more light on this issue. The conviction from various researchers could have emanated as a result of using different data collection tools and research designs, hence a methodological lacuna that calls for more inquiries to unearth more information. The current study used experimental research technique and the data collected was analyzed through paired-samples t-test, inferential and descriptive statistics.

Many different types of educational institutions are greatly impacted by gamification. It has been used in a number of ways to engage students in the learning process, but its effectiveness has not been without criticism (Khaleel *et al*., 2018). It is believed that it has the ability to improve learners' engagement, performance, productivity and focus. Conversely, it may also fall short of maintaining student engagement and encouraging involvement. Furthermore, some research shows contradictory findings regarding learning outcomes, indicating that cognitive learning outcomes are only beneficially associated with emotional and motivational outcomes when combined (Bai *et al*., 2020). The fact that this concept has been implemented in a number of different learning institutions, its impact on students' learning motivation has not been conclusive hence an issue that calls for more investigations.

Nonetheless, gamification is a persuasive technique for grabbing and holding learners' attention as well as engaging them with peers and activities to achieve the intended results Gok *et al*. (2016). Occasionally it is found to have a detrimental impact on learners' course outcome. Studies examining the methods and its outcomes through Massive Open Online Courses (MOOC) are few in number. The majority of studies concurred that it can boost motivation and engagement among eLearning students. It also has the potential to improve enjoyment and social relationships among students. While it uses a few game features like rewards, status, level up, points, badges, and others, game-based learning uses actual games to teach information and skills. Still, there seems to be a disputation of its effects when applied in education. Well, this calls for an in-depth knowledge on this subject through rigorous experimental research designs to unearth its impact when implemented properly on the LMS.

Alomari *et al.* (2019) have demonstrated that gamification in eLearning uses a variety of techniques, such as points (75%), badges (68%), leaderboards (63%) and level up (38%). It was discovered that gamification techniques such as avatars, challenges, progress bars, awards and feedback were seldomly employed. Notwithstanding these investigations, conflicting results about the ability of gamification to support students' learning in various contexts have been documented in the literature. It was reported that students have negative attitudes about game-based learning, it may not have an impact on improvements in instructional outcomes (Landers & Armstrong, 2017). This means that further research be encouraged but with different game tools to reveal what their effects are.

Rajput *et al.* (2022) addressed an improved learning strategy that uses gamification in blended learning to increase student motivation, engagement, and learning; however, they neglected addressing students' focus, which is a crucial component of any teaching and learning environment. As supported by Metwally *et al.* (2020), gamification in education often aims to increase students' focus, engagement, and performance as well as minimize their dissatisfaction and demotivation in learning environments. Compared to learners who employed traditional techniques, students exposed to gamification and game-

based learning had considerably superior academic accomplishment and attitudes toward learning. Well-crafted instructional games improved students' focus, trial-and-error skills and engagement (Partovi & Razavi, 2019). It is against these aforementioned literature inconsistencies that this study was set to analyze the effect of integrating the various gamification elements such badges, level up and custom certificates into the LMS for students' motivational learning experience.

There are significant technological barriers to eLearning application in Indonesia. In consonance with a previous study by Anggraeni and Sole (2018), poor content design, technological proficiency, administrative assistance and internet accessibility are some of the constraints associated with eLearning. In fact, as maintained by Kaunang and Usagawa (2017), students lacked sufficient eLearning knowledge. This implies that eLearning is marred with a number of challenges that have to be addressed first before understanding how to integrate this active pedagogical paradigm of gamification.

Prior research has indicated that students' inexperience with the gamification strategy is the primary cause of their failure to complete the learning tasks (Butler & Bodnar, 2017). Furthermore, it was shown that certain students in the gamified learning activity needed extra time to infer the gamification process (Ding *et al*., 2017). Instead of focusing just on quantitative components like points and awards, gamification can make greater use of quality-based examples, such as students evaluating and commenting on each other. Dominguez *et al.* (2013) confirm that while gamification has a limited impact on the cognitive components of educational content, it may nonetheless greatly motivate students to learn by altering the structure and design of the information to make it more enjoyable. This indicates that eLearning students need to be introduced to gamification mechanics and the effect they are likely to have on their learning behaviours and attitudes consequently their learning outcomes.

Out of the 10 universities that were evaluated, "only the University of Dar Es Salaam (UDSM)" had an eLearning platform in place. A minor application of eLearning was included in the basic ICT infrastructure of several universities, including Mzumbe University, Open University of Tanzania (OUT), and Sokoine University of Agriculture (SUA). A poor view of eLearning as a result of a lacuna of capability analysis prior to implementation, frequent power outages and insufficient ICT setup for eLearning platform were among the obstacles to its acceptance in Tanzanian colleges Makhaya and Ogange (2019). This indicates that eLearning challenges are all over and for gamification to be integrated seamlessly, the constraints have to be dealt with in advance.

A research conducted in Zimbabwe revealed that 97.5% of the instructors leading Open, remote and eLearning (ODeL) had no prior experience with remote learning (Mpofu *et al.,* 2012). The main obstacles to eLearning's widespread acceptance in these schools, in line with this study, are severe technological and infrastructural difficulties as well as staff and student attitudes against it. Lack of energy and Internet access were two of the infrastructure problems (Kasse & Balunywa, 2013). Despite these obstacles, "new virtual universities are opening up. The success of University of South Africa (UNISA), one of the continent's top providers of distance education, has amply demonstrated the potential impact of eLearning on educational delivery."

As demonstrated by some research, university eLearning system adoption is poor because of inadequate assistance for working areas, technical support and Internet connectivity. Gamifying courses may be difficult in Departments where eLearning procedures are not owned. A few lecturers also mentioned that they had trouble juggling their workloads between in-person instruction, online learning and other responsibilities (Ogange *et al*., 2018). It is evident how much the total infrastructure required to start the process would cost in capital. The high level of ongoing expenditures connected to the efficient use of ICT is a bit less evident. Thus, the purpose of this study is to investigate the effect gamification elements have on students' motivational learning experience.

3. RESULTS AND DISCUSSION

Paired-samples t-test was conducted to investigate the effect of integrating a badge gamification element in the LMS for students' motivational learning experience. Table 1 shows the results of paired-samples t-test between activity one on a non-gamified LMS and the same activity on a gamified LMS.

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Table 1.
Activity one and Badges

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	Activity1Badge - Activity1	3.23	9.68	1.08	1.09	5.37	3.002	80	.004

The results in Table 1 established that there was a significant increase in activity one scores of the students on a non-gamified LMS from (M=14.34, SD=6.63) to gamified LMS (M=17.57, SD=8.34), t (80) = 3.002, p = .004 (two-tailed). The mean increase in activity one score was 3.23 with a 95% Confidence Interval (CI) ranging from 1.09 to 5.37. This indicates that the increase in the mean was statistically significant since the CI range did not cross a zero and $p < .05$. The Cohen's d statistic value was .362, indicating a moderate effect size. Figure 2 shows a sample of MOODLE screenshot for the students who earned badges for successfully completing activity one and met some specified criteria.

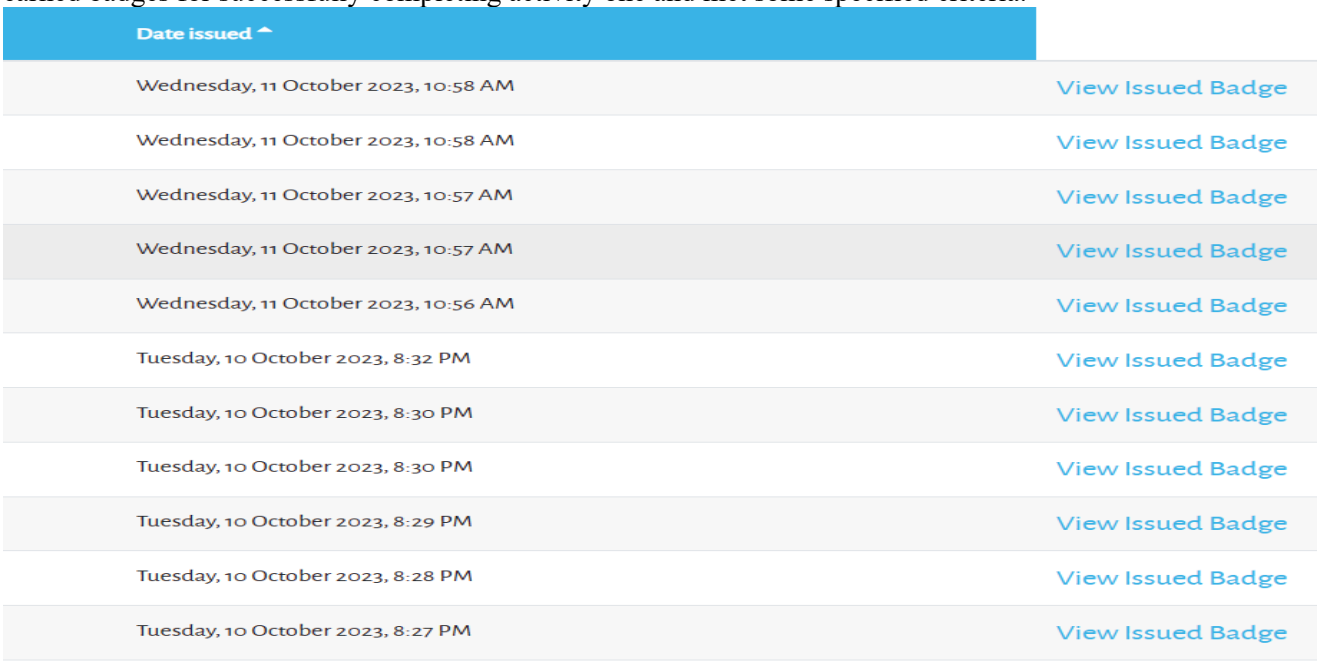

Fig 2. Sample Moodle Screenshoot for Students who Earned Badges

Figure 2 shows a sample MOODLE screenshot for the list of 81 students who were awarded badges having satisfactorily completed course activity one and met the set conditions. The condition could be an activity completion or even the course activity score among others. The students who were then awarded these electronic badges accessed and downloaded them from their eLearning course accounts. Paired-samples t-test was also conducted to investigate the effect of integrating of a level up gamification element in the LMS for students' motivational learning experience. Table 2 shows the summary of the test findings.

Table 2.
Activity Two and Level Up Gamification Element

Paired Differences						
			95% Confidence Interval of the Difference			
Mean	Std. Deviation	Std. Error Mean		t	df	Sig. (2-tailed)

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					Lower	Upper			
Pair 1	Activity2LevelUp-Activity2	2.85	9.887	1.099	.67	5.04	2.595	80	.011

The results in Table 2 disclosed that there was a statistically significant increase in the course activity two scores of the students on a non-gamified LMS from (M=5.69, SD=5.98) to gamified LMS (M=8.55, SD=8.64), t (80) = 2.595, p = .011 (two-tailed). The mean increase in the course activity scores was 2.85 with a 95% CI ranging from .67 to 5.04. The Cohen's d statistic value was .29, demonstrating a small effect size.

Figure 3 shows a sample of a gamified MOODLE screenshot for the 81 students who were awarded Experience Point (XP) after meeting some experimental conditions in activity two. MOODLE LMS does not come with level-up gamification plugin, this was installed by the Directorate of eLearning upon request by the researcher through writing. Shown in Figure 3 is a sample screenshot providing a list of students who were competing in undertaking the second activity.

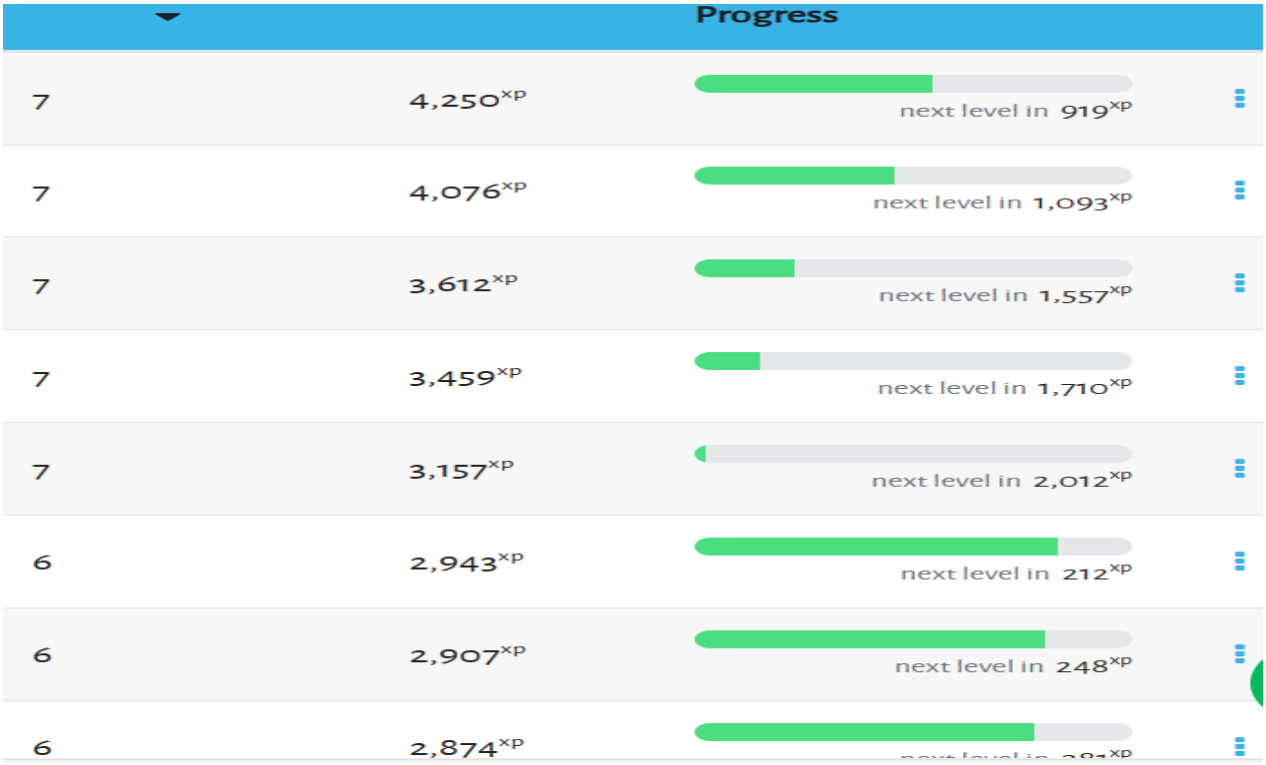

Fig 3. Sample Moodle Screenshot for Students Awarded Experience Points (XPs)

Figure 3 shows various levels such as 7, 6 among others for students who participated in the level up experiment. The leader in activity two had earned 4,250 XPs and to move to the next level, the student needed 919 XPs. Level up illustrates progress and consequently improves students' completion in the activity. This is a good gamification plugin that motivates learners with more fun. This element helps to increase user engagement in the learning process. Level up gamification element enables students to gain XPs for participating in an activity within a course. They also retain the learner through increasing engagement and participation by motivating learning experience to progress towards the next level. Further, they also trigger students' competition.

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Further, paired-samples t-test was carried out to investigate the effect of integrating of a custom certificate gamification element in the LMS for motivational learning experience. Table 3 shows the summary of the test findings.

Table 3.
Activity three and Custom Certificates Gamification Element

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	CustCert - Activity3	3.747	15.300	1.703	.358	7.136	2.201	80	.031

The results in Table 3 show that there was a significant increase in course activity three scores of the students on a non-gamified LMS from (M=8.71, SD=9.24) to gamified LMS (M=12.46, SD=11.33), t (80) =2.20, d = .25, p = .031 (two-tailed). The mean increase in the course activity scores was 3.75 with a 95% CI ranging from .36 to 7.14. The Cohen's d statistical value was .25, thus signifying that there was a small effect size. Figure 4 shows a sample custom certificate awarded to a student.

Fig 4. Sample Custom Certificate Awarded to a Student

Figure 4 shows a custom certificate awarded to a student having met the requirements of activity three on a gamified MOODLE LMS. The certificate can have a number of details as the case may be such as the student's full name, the unit name for which the certificate was awarded, the date when the award was done, the lecturer who awarded the certificate and the unique code generated by the computer for every certificate. The unique code improved the authenticity of the certificate generated by MOODLE LMS. However, not all the mentioned learner personal details were shown on the certificate in Figure 4 for anonymity reasons.

Further, descriptive statistics were also used to get students' opinions on the application of gamification in LMSs. This allowed the audience to understand the effect of integrating gamification

elements in LMS for students' motivational learning experience in higher education. After the experiment, the 81 respondents who were the participants of a gamified Moodle LMS were required to provide their opinion based on the Likert scale of: 5=Strongly Agree (SA), 4=Agree (A), 3=Not Sure (NS), 2=Disagree (D), 1=Strongly Disagree (SD). Table 4 summarizes the findings of the analysis based on mean and standard deviation.

Table 4.
Gamification Elements and Motivational Learning Experience

Integration of Gamification Elements	N	Mean	Std. Deviation
Gamification in LMS increases students' understanding compared to traditional teaching methods.	81	4.40	.931
Gamification in LMS motivates eLearning students.	81	4.11	.851
Gamification in LMS provides students with a better learning experience.	81	4.02	1.151
Gamification in LMS provides instant feedback.	81	3.62	.982
Gamification in LMS enhances students' academic performance.	81	3.69	1.020
Gamification in LMS permits students the freedom to fail so that they can learn from failure.	81	2.64	1.297
Students get excited to participate in gamified learning activities	81	3.84	1.054
Being in competition, keeps students' learning morale alive.	81	4.28	.898
A gamified presentation of the lesson makes the course process more enjoyable and fun.	81	4.12	1.065
Gamification is an innovative technique that improves students' learning interests.	81	3.98	1.084
Overall Results	81	3.87	1.033

Scale Range: 1.0-1.80=Strongly Disagree, 1.81-2.60=Disagree, 2.61-3.40=Neutral, 3.41-4.20=Agree, 4.21-5.0=Strongly Agree.

The results in Table 4 demonstrated that majority of respondents agreed that gamification in LMS increases students' understanding compared to traditional teaching methods (M=4.40, SD=.931), gamification in LMS motivates eLearning students (M=4.11, SD=.851), gamification in LMS provides students with a better learning experience (M=4.02, SD=1.151), gamification in LMS provides instant feedback (M=3.62, SD=.982), gamification in LMS enhances students' academic performance (M=3.69, SD=1.020), students get excited to participate in gamified learning activities (M=3.84, SD=1.054), being in competition, keeps students' learning morale alive (M=4.28, SD=.898), a gamified presentation of the lesson makes the course process more enjoyable and fun (M=4.12, SD=1.065), gamification is an innovative technique that improves students' learning interest (M=3.98, SD=1.084). However, a small number of respondents confirmed neutrality that gamification in LMS permits students the freedom to fail so that they can learn from failure (M=2.64, SD=1.297).

In general, the results confirmed that the majority of respondents agreed (M=3.87, SD=1.033) that students were of the opinion that the integration of gamification elements in LMS had an impact on motivational learning experience. This means that the standard deviation of 1.033 indicates that the individual responses, on average, were just slightly over one point away from the overall mean. Furthermore, the study also carried out a correlation analysis to determine whether there was a relationship between the integration of gamification in LMS and motivational learning experience. Table 5 shows the findings of the study.

Table 5.
Gamification Elements and Motivational Learning Experience

		LearningMotivation	Gamification Elements
LearningMotivation	Pearson Correlation	1	.759**

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	Sig. (2-tailed)		.000
	N	81	81
Gamification Elements	Pearson Correlation	.759**	1
	Sig. (2-tailed)	.000	
	N	81	81

**. Correlation is significant at the .01 level (2-tailed).

Table 5 confirms that there was a strong relationship (r = .759) between gamification elements and motivational learning experience. Besides, the result also shows that there was a statistically significant (p < .001) relationship between gamification elements motivational learning experience variables. The study also carried out a simple regression analysis to confirm the degree of the effect of integrating gamification elements on motivational learning experience. The result was shown in Table 6.

Table 6.
Gamification Elements on Motivational Learning Experience

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.759[a]	.576	.571	.049	.576	107.329	1	79	.000

a. Predictors: (Constant), GamificationElements
a. Dependent Variable: LearningMotivation
b. *. p is significant at the 0.05 level (2-tailed).

In Table 6, r provides the correlation coefficient for the analysis. It confirms a strong degree of positive correlation (r = .759) between gamification elements and motivational learning experience. The R-square of .576 measures part of motivational learning experience which was explained by gamification elements. It revealed that approximately 57.6% of the variation in motivational learning experience was attributed to variation in gamification elements. The adjusted R-square provides an idea of how the model may be generalized. It should be as close to R-square as much as possible if not the same. In this regard, the difference for the final model is small such as .5%.

This means if the model was derived from the population rather than a sample, definitely it would have accounted for approximately .5% less variance in students' motivational learning experience. The overall model was statistically significant (F=107.329, p < .05). Therefore, gamification elements had a positive impact on motivational learning experience. Un-standardized coefficient values were used to construct the regression equation. The Beta coefficient for gamification elements was .759 (p < .05) and was statistically significant. Table 6 and model 1 illustrates the optimum regression equation showing the relationship between gamification elements and motivational learning experience. This optimum regression equation followed a general form of $Y=\beta_0+ \beta_1\chi_1+ \beta_2\chi_2+\ldots \beta_n\chi_n+\varepsilon_0$, where:

Y= Dependent variable,
β_0 = Intercept term,
$\beta_1 \ldots \beta_n$ = Coefficients of independent variables,
$\chi_1 \ldots \chi_n$ = Independent variables,
ε_0 = Model's unique term,
n = Number of observations.

$$Y=0.210+0.099\ \chi_1 \quad (1)$$

Where,
Y = Motivational learning experience,
χ_1 = Gamification elements,
Coefficient of gamification elements =.099,
Intercept term =.210

Regression model 1 had a strong degree of positive correlation ($r = .759$) between gamification elements and motivational learning experience. The simple regression analysis model was 57.6% by the variation in gamification elements and was statistically significant ($p < .05$).

The general results of the experiment indicated that the integration of gamification elements in LMSs had a statically significant t (80) = 10.45, $p < .05$ (two-tailed) effect on students' motivational learning experience. This was the result of the paired samples t-test. Similarly, the results of the questionnaire data confirmed that the integration of gamification elements in LMS positively influences students' motivational learning experience. The result of the overall model was statistically significant (F=107.329, $p < .05$). This suggests that the results of both the experiment and the questionnaires positively converged in answering the objective of this research. Subsequently confirming a statistically significant ($p < .05$) hypothesis of the investigation that integration of gamification elements enhances students' motivational learning experience.

This study sought to investigate the effect of integrating gamification elements in LMSs for learners' motivational learning experience in higher education. Their study found that when students are immersed in an engaging learning environment, their involvement and engagement levels rise, which in turn improves their academic performance and learning outcomes. The findings of this study reaffirm the theory of gamified learning that by incorporating fantasy (a Game Characteristic), student engagement (an attitude) should increase, making the relationship between instructional content and learning outcomes stronger hence motivation. The use of a game characteristic increases engagement, which moderates the relationship between instructional content and learning outcomes. This supports the hypothesis of the study that integration of gamification elements in LMSs enhances students' motivational learning experience in higher education.

In comparison to non-gamified experiences, the results show that the gamified experience also enabled appropriate academic performance as well as greater learning outcomes and ratings to be reached. These findings are consistent with the results published by Wigfield *et al.* (2019). This suggests that gamification used in a virtual setting helps students feel more in control, independent and creative while they are engaged in educational activities.

According to a German study on the motivational effects of gamification, Michael *et al.* (2022), an experimental investigation into how particular game design components affect satisfaction of psychological needs revealed that the set of game design elements with badges, leaderboards and performance graphs (experimental condition 1) promoted competence and independence in carrying out learning tasks. When students take on and manage their own learning autonomy, it activates their higher order cognitive talents and skills, particularly those connected to metacognition and self-regulated learning. This indicates that increasing students' confidence to engage in their learning activities is dependent on these two SDT components. This is consistent with the current study's findings which are supporting SDT and the theory of gamified learning. These theories postulate that integration of gamification elements when used appropriately, they impact students' behaviour/attitude in a learning environment.

This study's results support those of Rajesh *et al*. (2023), who studied the university students in Australia. In their study, the partial mediation results showed that students' perceptions of lecturers' proactive support in gamified activities influenced their psychological needs as well as their satisfaction with their level of autonomy, competence and connectedness. This ultimately led to increased students' engagement. The results also shed light on the advantages of student participation and give educators more confidence to include gamification into their lesson plans.

Another study by Van Roy and Zaman (2018) found that the need for competency among online learners was not much raised by badges. Other research also revealed that badges had a non-significant influence on the satisfaction of competence needs. This was contradictory to the findings of the current study. The badges' inability to give learners constructive feedback about their performance and mastery while completing learning modules and passing module tests in TalentLMS may be the cause of their inability to meet the study's competency requirements.

Another explanation may be that the badges did not give participants the impression that their abilities or knowledge had improved enough to meet the need that learners in this brief online course had

competency in the developed material (Ryan & Deci, 2020). The outcome may not have been statistically significant based on the kind of learning activities and the badge regulations. In a similar vein, the demographic of learners may have also had an impact on these outcomes. This result further contradicts the present study's findings. Hence, depending on how gamification tools are used and how users view and understand them in that particular learning environment, they may either be intrinsically or extrinsically motivating for certain users. Contrary to the present study's findings, this investigation produced inconsistent results.

Mekler *et al.* (2017) discovered that because the majority of students were not familiar with the gamification protocols, gamification did not significantly increase students' grades. There are some issues that need to be resolved in spite of the benefits that the adoption of gamification tools in education has shown to have on students' behavioral and learning outcomes, including focus, motivation, engagement and performance (Bovermann & Bastiaens, 2018).

4. CONCLUSION

The goal of the study was to look into the effect of infusing gamification mechanics in LMSs in improving students' motivational learning experiences. The results confirmed that the integration of gamification elements in LMS had a positive influence on students' motivational learning experience. The individual gamification elements like badges revealed a moderate effect size on the course activity scores and the level up as well as custom certificates confirmed a small effect size on course activity scores.

These findings are linked with the theory of gamified learning which reasserted that gamification elements influence learners' behaviour/attitudes and so was the SDT in explaining students' psychological needs through need for autonomy, competence and relatedness. Studies of this nature may improve regions, nations and even how the integration of gamification can be effectively implemented to benefit eLearning students in higher education institutions. Besides, it will significantly influence higher education community, practice and policy formulation on gamified eLearning management systems that will facilitate the attainment of the fourth sustainable development goal on quality education to learners.

The experimental part for this research was limited to three gamification tools (badges, level up and custom certificates) and their significant results on the performance of students' course activity scores may not be valid for other gamification elements. The data used in this exploration were collected using a cross-sectional approach. It is opined that longitudinal studies be conducted in future research to collect participants' data in order to better understand how the integration of gamification elements influence students' motivational learning experience in higher education sector. Data was collected from students as main stakeholders. However, the study recommends that future studies of this nature involve lecturers too.

Future researchers can use different gamification mechanics such as avatars, exabis, timers, quests among others besides the ones employed in this study to determine whether they will be having an effect on students' motivational learning experience or otherwise. This can also be done on other learning management systems like Schoology, Canvas, Desire2learn, Blackboard, Brightspace. This will enrich the existing domain of eLearning knowledge database in the world of integration of gamification in LMSs for higher education institutions. Similar research can be carried out in future however, by employing different methodology approaches that are distinct from the ones that were used in this research. Finally, the study suggests to future scholars to apply structural equation modelling and factor analysis in determining the weight of the loadings for various sub-constructs of the study. This will ensure that only the latent variables which matter will be retained in the integration of gamification in LMSs depending on the outcome of the exploratory and confirmatory factor analysis.

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Readiness and Needs for Professional Development of Vocational School Teachers in Implementing Link and Match in The Industry 4.0 Era

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ABSTRACT

The high rate of open unemployment among vocational school graduates shows that their skills don't fully match industry needs, especially in the Industry 4.0 era, which demands an adaptive, digitally literate, and vocationally skilled workforce. This condition emphasizes the importance of teacher readiness and professionalism as the key to the successful implementation of link and match so that learning is relevant to the demands of the business and industrial world (DUDI). This study aims to analyze the readiness of vocational school teachers and the need for professional development in North Sumatra by comparing teachers in urban and rural areas. The study uses a qualitative descriptive approach with written interviews. Participants consisted of four productive teachers from schools in Medan City and six teachers from one rural school. The interview instrument explored understanding of link and match, pedagogical readiness, digital competence, vocational skills, collaboration with DUDI, obstacles, and training needs. Data were analyzed using Elo and Kyngäs content analysis. The results showed that urban teachers were more prepared in terms of implementation due to the support of facilities, technology, and access to industry training, while rural teachers were more prepared conceptually but were hampered by limited facilities and access to industry. Both had similar needs regarding vocational training, digital technology, and industry-based programs. The findings emphasized the need for context-based professional development to strengthen the role of teachers in preparing graduates who are relevant to industry needs.

Keywords: Industry 4.0 Era, Vocational School Teachers, Readiness, Link and Match, Professional Development

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1. INTRODUCTION

Vocational education plays a strategic role in preparing skilled workers who are able to meet industry needs, especially in the current era of digital transformation. However, the reality on the ground shows that vocational school graduates still contribute the highest rate of open unemployment in Indonesia. Based on BPS data from February 2025, the open unemployment rate (TPT) of SMK graduates was recorded as the highest among all education levels, both in urban and rural areas. In urban areas, the TPT for SMK graduates reached 8.30%, higher than that of high school graduates (7.10%), Diploma I/II/III graduates (5.22%), Diploma IV/S1 graduates (6.61%), junior high school graduates (5.06%), and elementary school graduates and below (3.00%). A similar situation can be seen in rural areas, where the TPT for vocational school graduates is 7.04%, again the highest compared to other education levels, as shown in Figure 1. This fact points to a fundamental problem in the implementation of vocational education, particularly in terms of the suitability of graduates for the needs of the world of work.

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Tabel 25 Penduduk Berumur 15 Tahun ke Atas Menurut Pendidikan Tertinggi yang Ditamatkan dan Jenis Kegiatan Selama Seminggu Terakhir di Perkotaan, Februari 2025
Population 15 Years of Age and Over by Educational Attainment and Type of Activity During The Last Week in Urban Area, February 2025

Pendidikan Tertinggi yang Ditamatkan *Educational Attainment*	Angkatan Kerja/*Labour Force*			Bukan Angkatan Kerja *Not in Labour Force*	Jumlah Penduduk Berumur 15 Tahun ke Atas *Total Population 15 Years of Age and Over*	% Bekerja Terhadap Angkatan Kerja *% Working to Labour Force*	Tingkat Pengangguran Terbuka (TPT) *Unemployment Rate (%)*	Tingkat Partisipasi Angkatan Kerja (TPAK) *Labour Force Participation Rate (%)*
	Bekerja *Working*	Pengangguran[1] *Unemployment*[1]	Jumlah Angkatan Kerja *Total Labour Force*					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sekolah Dasar ke Bawah *Primary School and Below*	24.098.603	745.525	24.844.128	12.656.670	37.500.798	97,00	3,00	66,25
Sekolah Menengah Pertama *Junior High School*	14.284.727	761.603	15.046.330	12.296.397	27.342.727	94,94	5,06	55,03
Sekolah Menengah Atas *Senior High School*	19.453.853	1.486.892	20.940.745	9.019.843	29.960.588	92,90	7,10	69,89
Sekolah Menengah Kejuruan *Vocational High School*	13.859.621	1.260.540	15.120.161	3.609.269	18.729.430	91,66	8,34	80,73
Diploma I/II/III *Diploma I/II/III*	2.669.263	147.058	2.816.321	942.903	3.759.224	94,78	5,22	74,92
Diploma IV, S1,S2,S3 *Diploma IV, Bachelor, Master, Doctoral Degree*	11.543.091	817.099	12.360.190	2.575.821	14.936.011	93,39	6,61	82,75
Jumlah *Total*	**85.909.158**	**5.218.717**	**91.127.875**	**41.100.903**	**132.228.778**	**94,27**	**5,73**	**68,92**

Catatan/Notes :
[1]Lihat Penjelasan Tabel 19/*Look at Note on Table 19*

Tabel 26 Penduduk Berumur 15 Tahun ke Atas Menurut Pendidikan Tertinggi yang Ditamatkan dan Jenis Kegiatan Selama Seminggu Terakhir di Perdesaan, Februari 2025
Population 15 Years of Age and Over by Educational Attainment and Type of Activity During The Last Week in Rural Area, February 2025

Pendidikan Tertinggi yang Ditamatkan *Educational Attainment*	Angkatan Kerja/*Labour Force*			Bukan Angkatan Kerja *Not in Labour Force*	Jumlah Penduduk Berumur 15 Tahun ke Atas *Total Population 15 Years of Age and Over*	% Bekerja Terhadap Angkatan Kerja *% Working to Labour Force*	Tingkat Pengangguran Terbuka (TPT) *Unemployment Rate (%)*	Tingkat Partisipasi Angkatan Kerja (TPAK) *Labour Force Participation Rate (%)*
	Bekerja *Working*	Pengangguran[1] *Unemployment*[1]	Jumlah Angkatan Kerja *Total Labour Force*					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sekolah Dasar ke Bawah *Primary School and Below*	28.211.482	498.134	28.709.616	10.077.982	38.787.598	98,26	1,74	74,02
Sekolah Menengah Pertama *Junior High School*	11.671.853	417.584	12.089.437	7.408.048	19.497.485	96,55	3,45	62,01
Sekolah Menengah Atas *Senior High School*	10.623.107	552.001	11.175.108	3.450.991	14.626.099	95,06	4,94	76,41
Sekolah Menengah Kejuruan *Vocational High School*	4.858.260	367.977	5.226.237	1.033.610	6.259.847	92,96	7,04	83,49
Diploma I/II/III *Diploma I/II/III*	816.797	30.341	847.138	190.846	1.037.984	96,42	3,58	81,61
Diploma IV, S1,S2,S3 *Diploma IV, Bachelor, Master, Doctoral Degree*	3.680.523	193.553	3.874.076	474.130	4.348.206	95,00	5,00	89,10
Jumlah *Total*	**59.862.022**	**2.059.590**	**61.921.612**	**22.635.607**	**84.557.219**	**96,67**	**3,33**	**73,23**

Catatan/Notes :
[1]Lihat Penjelasan Tabel 19/*Look at Note on Table 19*

Fig 1. Comparison of the population aged 15 years and above according to the highest level of education completed and activities during the last week in urban and rural areas
Source: BPS Data (2025)

Various studies reveal that the high unemployment rate among vocational school graduates is influenced by the competency gap between what is learned in school and the actual demands of the industry (Agustian et al., 2024). This condition reflects that the implementation of learning and teachers' readiness in understanding industry dynamics is not yet fully optimal. Amidst the rapid development of the Industry 4.0 era, which demands rapid adaptation to technological changes, the quality of teachers is a major determinant of the success of efforts to align (*link and match)* schools with the business world and industry (DUDI) (Disas, 2018) .

The Industry 4.0 era has brought significant changes to the structure of labor needs, marked by the emergence of automation, *the Internet of Things* (IoT), big data, and artificial intelligence. Schwab (2017) states that this era requires graduates who possess *problem-solving* skills, digital literacy, collaborative abilities, and flexibility in facing new technologies. With increasingly complex demands, the role of teachers is no longer limited to delivering material, but has become that of facilitators who connect school knowledge with industrial practice. Sudira (2018), emphasizes that vocational teachers must understand the latest industrial technology, work competency standards, and production-based pedagogical strategies. Thus, teacher competencies should cover pedagogical, technical, digital, and collaborative aspects.

On the other hand, teachers' ability to meet these demands is still uneven across all educational units. According to Hartanto et al., (2019) , some vocational teachers are not yet ready to face technological changes due to limited training related to digitization and industrial technology. This challenge is even greater in schools located in rural areas, where learning facilities, digital devices, and access to training are often limited. Kulsum (2020) adds that there are disparities in the quality of vocational education between

regions, where some vocational schools in less developed areas face limitations in facilities and human resources, which have an impact on teachers' readiness to meet the demands of industrial work.

Given these conditions, systemic efforts are needed to bridge the gap between teachers' abilities and industry needs. In this context, the *link and match* program developed by the government is one of the main strategies to improve the relevance of vocational education. This program includes industry-based curriculum alignment, the involvement of DUDI in training, and partnerships in graduate recruitment (Iskandar, 2022). However, several studies show that teachers' understanding of the technical implementation *of link and match* still varies and has not been fully internalized in learning practices (Ahmanda et al., 2021). This shows that the success of school alignment with industry is greatly influenced by the readiness and competence of teachers. In addition to challenges from the industry side, post-pandemic digital developments have also expanded the demands on teacher competence. Technology-based learning, the use of *Learning Management Systems* (LMS), digital simulations, and computer devices are now basic requirements in vocational teaching. Rohmah (2019) found that teachers with good digital literacy can adapt more quickly and produce more innovative learning. Conversely, teachers with limited digital literacy experience obstacles in developing learning that is relevant to modern industry needs, especially in areas with low technology access.

Given the complexity of these challenges, improving teacher professionalism is an urgent need. Effective professional development, according to Darling-hammond (2017), must be continuous, needs-based, and provide opportunities for relevant hands-on practice. For vocational school teachers, the ideal form of professional development includes internships in industry, technical training, strengthening digital competencies, and the ability to design project-based and production-based learning. Internal school factors also influence the development of teacher competencies. Wahidin & Efendi (2025), show that school leadership support, teacher collaboration, and an innovative climate are crucial to the success of teacher competency improvement. Schools in urban areas generally have broader access to industry, while schools in rural areas tend to face structural limitations that hinder competency renewal.

Based on these issues, this study aims to analyze the readiness and professional development needs of vocational school teachers in facing the implementation of link and match in the Industry 4.0 era. This study seeks to: (1) identify the level of readiness of vocational school teachers in supporting the implementation of link and match; (2) analyze the professional development needs of teachers in the current digital and industrial era; and (3) compare the readiness and needs of teachers between schools in urban and rural areas. The results of this study are expected to provide strategic recommendations for educational institutions, local governments, and industries in designing effective, relevant, and contextual professional development programs for teachers, so that vocational education can produce graduates who are truly ready to work and in line with industry demands.

2. RESEARCH METHOD

A. Research Design

This study uses a descriptive qualitative approach that aims to describe in depth the readiness and needs of vocational school teachers' professional development in facing the implementation of *link and match* in the Industry 4.0 era. This approach was chosen because it allows researchers to understand teachers' experiences, perceptions, and needs directly based on the narratives they convey. Descriptive qualitative research is also appropriate when the research objective is not to construct new theories, but rather to understand phenomena in a naturalistic and contextual manner.

The research location was in North Sumatra Province, involving five schools, consisting of four schools in urban areas and one school in a rural area. The schools located in urban areas included SMKN 7 Medan, SMKS Multi Karya Medan, SMKS Gema Buwana, and SMKS Tritech Informatika Medan, each involving one productive vocational teacher as an informant. Meanwhile, the rural area was represented by SMK Swasta Karya Bhakti, involving six productive teachers. Informants were selected using purposive sampling, considering that productive teachers have direct understanding of vocational learning and are

connected to industry needs. This purposive approach ensured that data was obtained from individuals who truly understood the vocational context and link and match.

B. Data Collection Techniques

Data collection was conducted using written interviews, namely interviews carried out indirectly through online forms and written communication. This technique was chosen to provide flexibility in terms of time for teachers to provide in-depth and reflective answers, as well as to take into account the geographical conditions and varying workloads of teachers. The written interviews contained open-ended questions that explored:

1. Teachers' understanding of the concept of link and match,
2. Teachers' readiness in terms of pedagogy, digital competence, and vocational skills,
3. Teachers' experiences in collaborating with DUDI,
4. Challenges in implementing learning that is relevant to industry needs, and
5. The forms of support and professional development needs required.

If there is information that is unclear or requires further elaboration, the researcher conducts follow-up interviews in writing through private messages to clarify or elaborate on the answers.

C. Data Analysis Techniques

The data were analyzed using qualitative content analysis following the approach of Elo & Kyngäs, (2007). This approach consists of three main stages: *preparation*, *organizing*, and *reporting*.

a. Preparation Stage

In this stage, the researcher repeatedly reads all interview data to gain a comprehensive understanding. The researcher then determines the unit of analysis in the form of relevant answer fragments for the research objectives.

b. Organizing Stage

This stage involves several systematic steps:

1. Open coding: Researchers assign initial codes to text segments that contain important meanings, such as those related to digital readiness, vocational competencies, facility barriers, or training needs.
2. Categorization: Codes with similar meanings are grouped into larger categories.
3. Abstraction: These categories are then synthesized into main themes that describe patterns in the teachers' responses.

c. Reporting Stage

Findings are presented in the form of descriptive narratives that describe themes, categories, and representative quotes from teachers. Reporting is done comparatively between urban and rural teachers so that differences in regional contexts can be clearly seen.

D. Data Validity

Data validity in this study was maintained through two main techniques. First, the researchers applied *member checking*, which involved asking participants to re-verify the researchers' summary interpretations to ensure that the meanings produced were truly in line with their intentions. This step is in line with the views of Lincoln and Guba (1985, in Nirmala et al., 2025), who state that *member checking* is the most important procedure in ensuring the credibility of qualitative findings because it allows participants to correct or reinforce the researcher's interpretation. Second, researchers strengthen data reliability through *audit trails,* which are systematic records of the entire research process, from data collection, coding, and analysis to the interpretation of findings. This technique helps ensure that every analytical decision is based on logical and traceable steps. Maxwell (2013), explains that audit trails enable researchers to build transparency in the research process so that decisions made are not arbitrary and are scientifically accountable. The combination of these two techniques ensures that the analysis process is consistent, transparent, and credible, so that the research findings truly represent the experiences and needs of teachers in the research context.

3. RESULTS AND DISCUSSION

This section presents the research findings based on a qualitative content analysis of written interviews involving vocational school teachers in the city of Medan and rural schools. These findings use an analytical framework that refers to five main aspects of the interviews, namely (1) understanding of the link and match concept, (2) pedagogical readiness, digital competence, and vocational skills, (3) experience of collaboration with the business and industrial world (DUDI), (4) obstacles to professional development, and (5) training support and needs. The discussion also compares the conditions of teachers in urban and rural areas and relates them to relevant literature.

A. Teachers' Understanding of the Link and Match Concept

In general, teachers from both regions showed a similar understanding of the link and match concept, namely the importance of aligning vocational school learning with the real needs of the world of work. Teachers in the city of Medan tended to understand this concept as a strategy that must be implemented directly in learning practices. For example, a teacher from SMK Multi Karya said that link and match means that learning must be based on workplace competencies and not stop at theory. Other teachers mentioned that link and match requires teachers to design teaching materials that are relevant to industry trends so that graduates have high job readiness. This more technical understanding shows that urban teachers see link and match as an operational framework that guides the preparation of learning materials, methods, and evaluation. This is in line with the explanation in , which states that teachers' understanding of the link and match concept greatly determines the depth of vocational curriculum implementation, including the integration of competencies required by industry and the adjustment of project-based and practice-based learning approaches. Research by Dewi et al (2024), also shows that teachers with a technical understanding of the industrial curriculum are better able to design project-based learning that is relevant to work demands, thereby increasing students' readiness to enter the industrial world.

On the other hand, teachers from rural areas also understand link and match, but their understanding is more general. Answers such as "preparing students for work" or "aligning education with the industrial world" show that their understanding is at a basic level, not yet touching on technical aspects such as industrial partnerships, competency-based demand analysis, or the development of industry-based curricula. This understanding is normative in that it recognizes the importance of link and match, but lacks knowledge of how the concept is translated into concrete teaching practices. This finding is in line with the study Prima et al. (2025), which shows that schools in rural areas have an information gap regarding the technical implementation of industry partnerships, including a lack of exposure to the latest industry standards, digital learning tools, and collaborative practices such as teaching factories or industrial apprenticeships for teachers. Additionally, research by Sutomo & Siregar (2022) explains that teachers in remote areas tend to only master the basic concepts of curriculum alignment and have minimal implementation experience due to a lack of exposure to industrial technology and professional development workshops.

This difference in the depth of understanding is greatly influenced by geographical context and access to training. Teachers in urban areas tend to be more frequently involved in industry-organized training, vocational seminars, and in-house training activities that discuss curriculum integration with industry needs. According to Waren & Prasojo (2024), the intensity with which teachers participate in industry training greatly affects the quality of their understanding of the latest competency standards, including aspects of work process digitalization. Meanwhile, teachers in remote areas have limited access to training, either due to location, weak digital facilities, or a lack of networking with industry, so their understanding rarely develops in an applied direction. This is in line with the opinion of P. A. Putra (2024), which emphasizes that the level of teachers' understanding of educational policy concepts is greatly influenced by the intensity of their exposure to practical implementation in the field. According to Vania et al (2021), teachers in remote areas have limited access to curriculum updates, so their understanding is static and does not develop in line with industry dynamics

This difference has a direct impact on the readiness to implement link and match. Urban teachers tend to be able to relate this concept to technology-based teaching practices, digital competency integration, and contextual learning that resembles the work environment. Meanwhile, rural teachers, despite understanding

the urgency of link and match, tend to lack implementation guidelines or facility support to apply this concept optimally. This is reinforced by the findings of Iskandar (2022), who state that limitations in digital devices, a lack of industry partnerships, and insufficient ongoing training prevent teachers from translating the link and match concept into learning practices. Thus, it can be concluded that a more technical and operational understanding of link and match is found among urban teachers, while rural teachers tend to have a basic conceptual understanding but are hampered by systemic limitations in implementing it.

B. Teacher Readiness in Pedagogy, Digital Competence, and Vocational Skills

The results of the study show that there are significant differences between the readiness of vocational school teachers in cities and teachers in rural areas in facing the demands of learning in the Industry 4.0 era. Teachers in cities generally show higher readiness in terms of pedagogy, digital technology integration, and strengthening vocational skills. All teachers from this region stated that they were ready or very ready, and this readiness was reflected in the concrete practices they mentioned. Teachers at SMK Gema Buwana, for example, emphasized the importance of developing digital competencies through the use of online learning technologies and strengthening 21st-century skills. Teachers from SMK Multi Karya also described the use of digital tools, business simulations, and collaborative platforms as part of their teaching strategies. These practices show that city teachers not only understand the demands of Industry 4.0 theoretically but have also begun to integrate technology and modern learning approaches into their teaching activities. These findings are in line with the research Prima et al. (2025), which shows that vocational school teachers in urban areas have greater access to ICT facilities, digital training, and industry networks, resulting in a higher level of readiness compared to teachers in rural areas. Research by Zhou et al. (2022), that teachers who regularly attend technology training and vocational workshops have better abilities in designing digital learning and implementing project-based methods that are in line with industry characteristics.

In contrast, teachers in rural areas such as SMK Karya Bhakti show more declarative than practical readiness. They claim to be ready to face the demands of Industry 4.0, but this is not followed by concrete experience in implementing technology or digital learning approaches. Some teachers admit that this readiness is more of a moral commitment than technical readiness. Structural barriers such as limited internet access, lack of digital devices, and minimal training are the main factors hindering their readiness. One teacher emphasized that unstable internet access makes it difficult for them to participate in online training or integrate technology into learning. This condition is in line with the findings of Nashrullah et al (2025), which explains that teachers in remote areas generally face a large digital divide, both in terms of infrastructure and opportunities for competency development, so that the 4.0 learning transformation is not running evenly. A similar point is made by Ubihatun et al (2024), who state that limited access to technology in remote schools is a major obstacle to the integration of ICT and digital-based evaluation in vocational learning.

The readiness gap between these two regions reflects not only differences in facilities but also differences in exposure to the industrial world and pedagogical innovation. Teachers in cities more often participate in training, seminars, or industrial internships that provide direct experience of work practices and current competency requirements. This enables them to design learning that is more relevant to industry standards. Meanwhile, rural teachers have very few opportunities to do the same, so their knowledge of industry demands and digital learning tends to be conceptual. According to Hafid et al. (2025), teacher involvement in industry partnerships is an important factor that determines their ability to implement learning based on the needs of the workforce.

Thus, the difference in the readiness of urban and rural teachers in facing learning in the Industry 4.0 era is not only related to individual abilities but also reflects systemic gaps in access to training, digital infrastructure, and collaboration with the industrial world. This condition reinforces the urgency of more inclusive and locally-based professional development programs, so that teachers in rural areas have the same opportunity to improve their readiness to face the transformation of vocational education. Professional development programs that are adaptive to the local context are key to overcoming the quality gap between teachers in different regions (Setiawan & Supriyanto, 2024).

C. Experience of Collaboration with the Business and Industrial World (DUDI)

The research results show a very significant difference between vocational school teachers in urban and rural areas in terms of their experience and involvement with the business and industrial world (DUDI). This gap is evident in the types of training they have participated in, the intensity of cooperation, and the level of teachers' understanding of the competency requirements relevant to the world of work.

In urban areas, some teachers have had real experience in collaborating with DUDI, either through training or internships. Two of the four urban teachers have participated in industry-based training: teachers from SMKS Gema Buwana participated in Digital-Based Deep Learning for Education training, a collaboration between Google for Education and the Ministry of Education, while teachers from SMKN 7 Medan participated in the OTKP Upskilling–Reskilling program and a one-month internship at the Horison Lampung Hotel. In addition to participating in training, city teachers also have experience in assisting students with work placements, communicating with industry partners, and understanding the competency standards required by companies. This kind of direct experience provides its own advantages, as teachers can translate real work practices into classroom learning. This is in line with the findings of Arinaitwe (2021) study, which explains that teachers in urban areas have greater opportunities for industry collaboration, so their exposure to work culture and industry standards is much stronger than that of teachers in rural areas. The intensity of teacher interaction with industry significantly improves teachers' ability to adapt the curriculum, especially in terms of updating vocational learning materials and methods based on industry needs (Syarif & Janata, 2024).

In contrast to these conditions, teachers from rural areas face significant limitations. All six teachers admitted that they had never participated in industry-based training, whether in the form of workshops, internships, or industry certification. Their involvement with DUDI was largely limited to the administrative process of PKL, such as arranging student practice locations or conducting routine monitoring without technical assistance or opportunities for direct teacher competency development from the industry. Some teachers also mentioned geographical and infrastructure barriers, such as unstable internet access, which prevented them from participating in online training, which is increasingly being provided by various institutions. This condition is in line with the findings of Prima et al (2025), which states that the disparity in the quality of vocational education between cities and villages is partly due to the limited access of teachers in rural areas to training and industry partnerships.

This lack of practical experience impacts the ability of teachers in rural areas to translate industry demands into learning. Although their understanding of link and match is conceptually sound, the absence of direct experience with the world of work makes it difficult for teachers to update their vocational learning strategies in a relevant manner. This reinforces the view that teacher collaboration with industry is a crucial component of vocational education, as it enables teachers to update their industry knowledge, understand the latest technological developments, and ensure that learning materials remain aligned with the needs of the job market (Hafid et al., 2025). In addition, according to Zhang (2025), teachers who have never been involved in industrial practice tend to maintain traditional learning patterns even though the curriculum demands project-based learning, technology, and real-world work simulations.

Thus, the data shows that urban teachers have advantages in terms of exposure, networking, and direct experience with industry, while rural teachers face structural limitations that hinder their involvement. These findings indicate that the disparity in the quality of teachers' collaborative experiences with industry is not only an individual issue, but also a structural problem related to access, location, and system support. Therefore, affirmative policies and more inclusive industry partnership strategies are needed so that teachers in rural areas can have the same professional development opportunities as teachers in urban areas.

D. Barriers to Implementing Industry-Relevant Learning

The research findings show that the obstacles experienced by vocational school teachers in participating in training and professional development programs are greatly influenced by the geographical context, with clear differences between teachers in urban and rural areas. Although both groups of teachers face challenges, the nature of the obstacles is different: urban teachers face more technical and administrative obstacles, while rural teachers face more complex and fundamental structural obstacles.

Teachers from Medan described obstacles that tended to stem from workloads and time management. They mentioned difficulties in dividing their time between teaching duties, school administration, and attending training, especially when training schedules took place during working hours or required additional preparation. In addition, although technological facilities in cities are relatively adequate, some teachers still feel that certain limitations hinder their ability to participate in online training. However, they generally still have the opportunity and access to participate in industry training and digital training. This condition is in line with the findings of Fatmawati et al (2024), which explains that teachers in urban areas are often burdened with high administrative tasks, making it difficult for them to focus on professional development, even though infrastructure access and training opportunities are much better than in non-urban areas. Furthermore, according to Osman et al (2024), the administrative workload is a significant barrier to urban teachers' participation in vocational training, as teachers' time is more consumed by managing educational documents than by learning innovation.

In contrast, teachers from SMK Karya Bhakti in rural areas face structural barriers that are far more serious. All teachers admitted that they had never received training from industry because it was not available in their area. Barriers such as poor internet access make online training, which is now a popular national alternative, almost impossible to participate in optimally. High training costs, lack of logistical support from schools, and limited information about training further narrow their opportunities to develop professional competencies. Some teachers even stated that training relevant to their field of expertise is rarely held in the surrounding area, so they have no systematic path for competency development.These findings are in line with the research D. A. P. Dewi et al (2025), which states that teachers in rural areas generally experience: (1) limited facilities and infrastructure, (2) limited access to professional training, and (3) a lack of industry networks. As a result, the competency gap between teachers in urban and rural areas is widening because rural teachers not only lack training opportunities but also do not have a supportive environment to develop their competencies continuously.

This gap has serious consequences for the ability of rural teachers to keep up with developments in industry and learning technology. The lack of training not only results in a lack of industry-based pedagogical competencies, but also hinders the formation of a culture of innovation in schools. Research by Putra (2025) shows that without the support of a conducive environment, such as stable internet access, the presence of industry partners, and the availability of technical workshops, teachers in disadvantaged areas will continue to lag behind in the adoption of learning technology and vocational competency development. As a result, the competency gap between urban and rural teachers continues to widen, as rural teachers not only lack training opportunities but also do not have a supportive ecosystem for continuous development.

Given these conditions, it can be concluded that the obstacles faced by urban and rural teachers are substantially different. Urban teachers face organizational and administrative obstacles, while rural teachers face systemic obstacles related to infrastructure, industry access, and the social environment of education. This gap indicates that teacher professional development programs must consider the geographical context, provide affirmation for rural schools, and ensure more equitable access to training to reduce disparities in vocational teacher competencies. The equitable distribution of vocational teacher training must integrate a region-based approach so as not to widen the gap in education quality between urban centers and remote areas (Muharam et al., 2025).

E. School Support and Professional Development Needs

Research findings show that school support for improving teacher competency is greatly influenced by geographical conditions and resource availability. Teachers from Medan City generally feel that they receive more concrete and structured support. They explain that schools give them permission to attend training, provide facilities for in-house training activities, and encourage teachers to innovate in learning. Some schools even routinely hold internal training and facilitate teachers to attend industry-based external training. This relatively strong support shows that urban schools generally have better institutional capacity to develop teacher competency, in line with the findings of , that schools in urban areas tend to have stronger

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quality management and network access so that teacher competency improvement programs can be implemented more systematically.

In contrast, support from schools in rural areas is more normative or declarative in nature. Teachers at SMK Karya Bhakti acknowledged that the school "supports" competency improvement, but this support has not been realized in the form of concrete training programs, the provision of digital devices, or adequate network access. Some teachers even mentioned that the school had never held training in collaboration with industry or internal training related to industry-based learning. This condition illustrates the structural limitations of rural schools in providing an environment that allows teachers to develop their competencies. This is in line with the research Ritonga et al (2025), which shows that schools in rural areas often lack sufficient organizational resources to support teacher professionalism in a sustainable manner.

This difference in school support has a direct impact on teachers' professional development needs. Teachers from urban areas generally emphasize the need for applied and industry-oriented training, such as industrial internships, digital marketing training, teaching factories (TEFA), project-based learning, and strengthening digital competencies in line with technological developments. These training choices indicate that urban teachers have a higher level of readiness and expectations for digital and industry-based learning, while also illustrating their need to keep up with current industry trends.

On the other hand, rural teachers also have high training needs, which are even more complex in some aspects. They mentioned the need for training in artificial intelligence (AI) integration, industry-based curriculum, digital competency certification, TEFA, and entrepreneurship. However, despite their high aspirations, access to such training is very limited. This situation reveals an aspiration gap and an opportunity gap, as stated by Hamidi et al (2015), that teachers in rural areas often have strong motivation to develop, but are hampered by limitations in infrastructure, access to training, and institutional support.

Thus, it can be concluded that the most striking difference is not only in the type of training needs, but also in access to professional development opportunities. Urban teachers have more opportunities to develop competencies in line with industry needs, while rural teachers tend to only be able to express their aspirations without adequate systemic support to realize them. This highlights the importance of affirmative policies and the provision of equitable access to training so that the competency gap between vocational teachers in different regions does not widen further.

F. Comparison of Readiness and Needs between Urban and Rural Teachers

To further understand how the conditions of vocational school teachers in urban and rural areas affect their readiness to implement link and match in the Industry 4.0 era, a more systematic mapping is needed. Based on the analysis of interview results, there are a number of fundamental differences between the two groups of teachers, in terms of readiness, experience, obstacles, and professional development needs. This comparison helps to reveal the structural and contextual factors that shape teachers' capacity to meet the demands of modern vocational education. In summary, the comparison is presented in Table 4.6 below:

Table 1.
Comparison of Readiness and Needs of Urban and Rural Vocational School Teachers

1. Aspect	Urban Teachers	Rural Teachers	Key Differences
1. Teaching Readiness	Already using technology, digital methods, and project-based assignments	Have a basic understanding of the concepts but are not yet able to implement the technology.	Urban areas are more prepared in practice; rural areas are still in the conceptual stage.
2. Access to Training and Industry	Have participated in industry training and internships.	No industry training; only administrative matters related to PKL.	Cities have much greater access.
3. Obstacles	Limited time and many administrative tasks.	Weak internet, inadequate facilities,	Inland obstacles are more severe and fundamental.

		and difficult access to training.	
4. Training Needs	Technology, digital, and project-based learning training.	Industrial training, basic technology, and curriculum alignment.	The needs are the same, but opportunities in rural areas are fewer.
5. School Support	There is support for facilities and internal training.	Support is still limited; digital facilities are minimal.	Urban support is stronger.

4. CONCLUSION

This study shows that there is a clear gap between vocational school teachers in urban and rural areas in facing the implementation of link and match in the Industry 4.0 era. Urban teachers have a more technical and operational understanding of link and match and demonstrate implementation readiness through the use of technology, digital simulations, and project-based learning. Meanwhile, rural teachers generally have a conceptual understanding that is still general in nature and are unable to apply industry-based learning strategies in a concrete manner.

This difference is also evident in their experience of collaboration with the business and industrial world (DUDI). Urban teachers have broader access to industrial training, internships, and cooperation with industry partners, while rural teachers have almost no such experience due to infrastructure and geographical access limitations. The obstacles faced by rural teachers are more structural in nature, such as poor internet connectivity, lack of digital facilities, and absence of industrial training, unlike the obstacles faced by urban teachers, which are more related to workload and time management.

School support also reinforces this gap. Urban schools are able to provide internal training, learning facilities, and clear training permits, while rural schools only provide normative support without concrete programs. Both groups of teachers actually have similar professional development needs, such as industrial training, digital competencies, TEFA, and industry-based curricula. However, rural teachers have limited opportunities to realize these needs.

Overall, this study confirms that the readiness and needs of vocational school teachers are greatly influenced by regional context, access to facilities, institutional support, and training opportunities. To reduce the competency gap among vocational teachers, affirmative policies are needed to provide access to industry training, strengthen digital infrastructure, and provide equal institutional support for schools in rural areas. These efforts are crucial to ensure optimal implementation of the link and match program and better prepare vocational school graduates to meet the demands of the workforce.

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SEIR Model for Stunting Risk Dynamics in Children Based on Nutritional Data in North Sumatra

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ABSTRACT

Stunting remains a major chronic nutritional challenge in Indonesia, particularly in North Sumatra, where prevalence reaches 21.1% among children aged 2–4 years. Most existing approaches rely on static prevalence classifications that do not capture how nutritional risk evolves over time. To address this limitation, this study develops the first North Sumatra–specific adaptation of the SEIR (Susceptible–Exposed–Infected–Recovered) model to represent non-communicable nutritional risk pathways. In this modified framework, epidemiological compartments are redefined to reflect the biological progression of stunting. Low-birth-weight infants are categorized as Exposed (E), while children experiencing severe malnutrition are classified as Infected (I). This structure enables dynamic simulation of risk progression across 12 months. Secondary data were obtained from BPS, Survey SGI, and the 2023 profile of the North Sumatra Health Office. Model parameters were estimated using least-squares fitting, resulting in a transmission rate (β) of 0.40, a progression rate (σ) of 0.166, and a recovery rate (γ) of 0.333. Numerical simulations were conducted using a fourth-order Runge–Kutta method. Simulation results show a 1.65% decline in the susceptible population and a 61% increase in the infected compartment, despite a 600% expansion in the recovered group. These findings indicate that existing interventions improve recovery but remain insufficient to prevent sustained risk propagation. The estimated basic reproduction number ($R_0 \approx 1.20$) suggests that stunting risk remains self-sustaining under current conditions. Sensitivity analysis demonstrates that reducing the transmission parameter (β) produces the greatest impact, with a projected 28% reduction in peak infected prevalence. Interventions targeting maternal education and supplementary feeding, therefore, represent the highest-leverage strategies. Model validation confirms strong agreement with empirical data (MSE = 0.012; $R^2 = 0.93$). Overall, this study offers a dynamic, region-specific modeling framework to support evidence-based nutritional policy, particularly in high-risk districts such as Nias, Mandailing Natal, and Langkat.

Keywords: SEIR model, stunting risk, mathematical modeling, nutritional intake, North Sumatra

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1. INTRODUCTION

Mathematical epidemiology models, particularly the SEIR (Susceptible–Exposed–Infected–Recovered) compartmental framework, have been widely used to quantify infectious disease transmission dynamics worldwide (Li, 2022; Hethcote, 2000). Extending this framework to non-communicable nutritional risk pathways requires methodological modification. In this study, compartments are redefined to reflect the biological progression of growth failure: low-birth-weight (BBLR) infants serve as a proxy for the Exposed (E) group. At the same time, severe malnutrition cases represent the Infected (I) compartment. Model parameters are also reinterpreted. The transmission rate (β) represents exposure to nutritional deficiency, and the recovery rate (γ) reflects the effectiveness of nutritional and health interventions. Despite the availability of comprehensive datasets from Badan Pusat Statistik and Survei Status Gizi Indonesia, this type of dynamic modeling remains rarely applied in the Indonesian nutrition field.

Compared with static analytical approaches, the SEIR framework offers clear advantages. Classification models such as Naive Bayes (Sussolaikah, 2022) identify risk factors at a single point in time but do not describe how risk evolves over time. Prevalence mapping (Setiawan, 2023) and isolated program

evaluations (Handayani, 2024) provide descriptive or outcome-based insights, yet they do not simulate future trajectories. In contrast, the SEIR model captures temporal progression. It explains how inadequate nutritional intake moves individuals from a susceptible state to exposure, and eventually to severe malnutrition. This structure enables simulation of intervention scenarios, such as reducing β through maternal education programs or increasing γ by strengthening treatment capacity. It also allows identification of threshold conditions through the basic reproduction number (R_0), offering analytical depth that static methods cannot provide.

This research addresses an important methodological gap by developing a SEIR model calibrated specifically for North Sumatra. Parameter estimation is based on province-level data, including 178,973 births, 1,362 low-birth-weight cases, and 449 cases of severe malnutrition. The model enables 12-month simulations of risk progression and supports sensitivity-based prioritization of interventions across 33 districts. By integrating spatial variation with temporal dynamics, this study provides a quantitative framework to strengthen evidence-based stunting-prevention policies in Indonesia.

Literature Review

Stunting, defined as chronic malnutrition impairing linear growth (z-score < -2 SD per WHO standards), affects cognitive development and long-term economic productivity (Black et al., 2017; Guerrant et al., 2013). Indonesia's national prevalence declined to 21.5% in 2023 (SSGI), yet exceeds WHO targets, with North Sumatra at 21.1% exhibiting pronounced district disparities (Kemenkes, 2023). Primary causes include prolonged inadequate energy, protein, and micronutrient intake, often commencing ***in utero**** via low-birth-weight (BBLR) and progressing to severe malnutrition without intervention (Fitri, 2022; Sari, 2023).

Statistical approaches dominate Indonesian stunting research. Sussolaikah (2022) applied Naive Bayes classification to socioeconomic determinants, achieving high accuracy in risk prediction but lacking temporal dynamics to predict intervention outcomes. Rizki et al. (2025) demonstrated that nutritional education via Group Maternity Centre Care (GMCC) reduced stunting incidence, emphasizing maternal knowledge gaps. However, these methods identify static risk factors without modeling propagation mechanisms across child cohorts over time.

Compartmental modeling offers superior temporal insights. Traditional SEIR frameworks quantify infectious disease spread with strong theoretical foundations (Li, 2022; Hethcote, 2000; Brauer, 2017), and RK4 methods provide numerically stable solutions (Hartono, 2023; Hidayat, 2024). Taufik (2024) extended SEIR sensitivity analysis to social phenomena, validating parameter-driven policy scenarios. Internationally, WHO (2023) advocates the use of mathematical tools for malnutrition forecasting, yet applications to stunting remain scarce, particularly in developing contexts where data availability enables calibration (Bilinsky et al., 2021).

Gap analysis and synthesis: Existing Indonesian studies emphasize prevalence mapping (Setiawan, 2023) or isolated intervention evaluations (Handayani, 2024) but neglect how BBLR exposure evolves into severe malnutrition cases amid varying intervention efficacy. The temporal transmission mechanism—central to compartmental epidemiology—remains absent from nutritional risk analysis despite its potential for policy simulation. This research addresses this methodological void through North Sumatra-specific SEIR adaptation, parameter estimation from BPS/SSGI data, and sensitivity-informed recommendations for targeted nutritional policy.

Table 1.
Comparison of Prior Stunting Research Approaches and Methodological Contributions of the Present Study

Study	Methodological Approach	Identified Limitation	Contribution of the Present Study
Sussolaikah (2022)	Naive Bayes classification	Cross-sectional risk identification at a single time point; absence of temporal progression modeling	Introduces dynamic transmission modeling with 12-month forward simulation of risk evolution
Rizki et al. (2025)	Nutritional education intervention (GMCC)	Evaluates isolated intervention effects without system-wide dynamic interaction analysis	Provides system-level sensitivity analysis across β, σ, and γ parameters to quantify intervention leverage
Setiawan (2023)	Spatial prevalence mapping using QGIS	Descriptive geographic distribution without modeling progression mechanisms	Integrates spatial heterogeneity with temporal transmission dynamics
Handayani (2024)	Program effectiveness evaluation	Retrospective outcome assessment without predictive scenario testing	Enables prospective simulation for policy testing prior to implementation
Li (2022)	SEIR modeling for infectious diseases	Framework limited to communicable disease transmission	Adapts SEIR structure to chronic nutritional pathways through compartment redefinition (BBLR as E, severe malnutrition as I)
Bilinsky et al. (2021)	Growth monitoring and child-level assessment models	Focus on individual-level monitoring without population-scale dynamics	Develops population-level compartmental framework for endemic nutritional risk analysis
Present study	Modified SEIR model with sensitivity analysis	Not applicable	First regionally calibrated SEIR model for stunting in North Sumatra with quantified intervention prioritization

2. RESEARCH METHODS

A. Study Design and Data Sources

This quantitative modeling study uses a compartmental mathematical epidemiology framework to analyze stunting risk among children aged 2–4 in North Sumatra. The analysis relies only on secondary data from three official sources.

First, 2023 data from Badan Pusat Statistik North Sumatra provide total live births (N = 178,973), low-birth-weight cases (E_0 = 1,362), severe malnutrition cases (I_0 = 449), and children receiving nutritional treatment (R_0 = 414) across 33 districts.

Second, data from Survei Status Gizi Indonesia validated simulated model trajectories against observed provincial nutritional status indicators.

Third, the 2023 North Sumatra Health Office report provided context on intervention coverage, treatment capacity, and community-based nutrition services, which informed parameter interpretation and policy discussion.

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Combined, these sources ensure the model is empirically grounded, regionally calibrated, and aligned with official health and demographic statistics.

B. SEIR Model Formulation

The modified SEIR model adapts epidemiological compartmental structure to nutritional risk pathways:

$$\begin{cases} \frac{dS}{dt} = -\beta \frac{SI}{N} \\ \frac{dE}{dt} = \beta S \frac{SI}{N} - \sigma E \\ \frac{dI}{dt} = \sigma E - \gamma I \\ \frac{dR}{dt} = \gamma I \end{cases} \quad (1)$$

where:

- S(t) denotes the number of susceptible children, i.e., those with normal birth weight who are currently healthy but remain at risk due to potential nutritional deficiency exposure.
- E(t) denotes the number of exposed children, represented by low-birth-weight (BBLR) infants who have elevated stunting risk.
- I(t) denotes the number of infected children, namely those experiencing severe malnutrition and requiring intensive nutritional intervention.
- R(t) denotes the number of recovered children, defined as children who have received nutritional treatment and show improved nutritional status.
- N = S + E + I + R is the total child population, assumed constant under the closed-population assumption.
- β is the nutritional deficiency exposure rate (dimensionless, $0 < \beta < 1$), representing the probability that susceptible children become exposed due to suboptimal nutrition.
- σ is the progression rate from exposure to severe malnutrition ($month^{-1}$).
- γ is the recovery rate following nutritional intervention ($month^{-1}$).

Initial conditions: S(0) = 176,748, E(0) = 1,362, I(0) = 449, R(0) = 414. (derived from 2023 BPS North Sumatra data)

These values represent, respectively, the number of susceptible children, exposed cases proxied by low -birth-weight (BBLR), severe malnutrition cases, and recovered individuals at the beginning of the 12-month simulation period. The total population $N = S + E + I + R$ is assumed constant throughout the analysis.

Model assumptions:

- Closed population: no births/deaths during 12-month simulation period (valid for short-term policy analysis)
- Homogeneous mixing: Province-level aggregation assumes uniform contact patterns (district heterogeneity analyzed separately)
- Unidirectional transitions: S→E→I→R no relapse (chronic progression)
- Time-invariant parameters: β, σ, γ constant over study period (seasonal variations addressed in limitations)

C. Data Preprocessing

Proportions were calculated as E/N = 0.76% and I/N = 0.25% from provincial totals to establish baseline compartment distributions. District-level data were aggregated to the provincial scale for model calibration. Missing values from 3 districts (representing <2% of the total population) were imputed using provincial averages to maintain data completeness while minimizing bias.

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D. Parameter Estimation and Numerical Solution

Parameters (β = 0.40, σ = 0.166, γ = 0.333) were estimated via least squares optimization minimizing mean squared error (MSE) between model outputs and empirical data:

$$\mathrm{MSE} = \frac{1}{m}\sum_{i=1}^{m}\left(y_i - \hat{y}_i\right)^2 \quad (2)$$

where y_i denotes observed compartment values and $\hat{y}_i$ model predictions.

Optimization constraints: Bounds β, σ, γ ∈ (0,1) ensuring epidemiological plausibility and positivity of solutions.

The initial value problem was solved using fourth-order Runge-Kutta method (RK4) with step size h = 1/30 (daily steps) over 12 months, implemented in Python 3.9 with SciPy 1.9, NumPy 1.23, and Matplotlib 3.6 libraries.

E. Model Validation and Sensitivity Analysis

Model accuracy was assessed by comparing simulated trajectories against SSGI 2023 prevalence patterns using MSE and visual curve fitting. Sensitivity analysis evaluated parameter impacts (±20% variations) on peak I compartment and cumulative R, identifying intervention priorities. The basic reproduction number proxy $R_0 = \beta/\gamma$ was calculated to assess self-sustaining risk dynamics.

F. Ethical Considerations

This study uses publicly available secondary data from BPS, SSGI, and provincial health records; no primary data collection or human subject involvement occurred. Therefore, no ethical approval was required.

3. RESULTS AND DISCUSSION

A. Initial Data Distribution

Table 2 presents 2023 North Sumatra nutritional indicators across 33 districts, serving as SEIR initial conditions. Province-wide totals include 178,973 births, 1,362 BBLR cases (0.76%), 449 severe malnutrition cases (0.25%), and 414 treatment recipients.

Table 2.
North Sumatra Nutritional Data by District (2023)

District	Births	BBLR	Mal Nutrition	Treatment
Sumatera Utara	178973	1362	449	414
Nias	661	15	5	5
Mandailing Natal	5963	176	14	13
Tapanuli Selatan	2769	7	3	3
Tapanuli Tengah	4338	31	5	5
Tapanuli Utara	2335	44	4	4
Toba	16	16	12	12
Labuhan Batu	8491	25	4	4
Asahan	10559	42	20	20
Simalungun	4625	46	11	10
Dairi	3284	31	23	23
Karo	5013	7	0	0
Deli Serdang	42563	47	4	4
Langkat	6285	263	23	23
Nias Selatan	939	29	10	0
Humbang Hasundutan	3404	65	4	4
Pakpak Bharat	333	6	0	0
Samosir	1249	21	1	1

Serdang Bedagai	7427	104	25	25
Batu Bara	7521	7	75	75
Padang Lawas Utara	771	8	3	3
Padang Lawas	2229	109	7	7
Labuhanbatu Selatan	4282	2	8	8
Labuanbatu Utara	48	17	14	11
Nias Utara	999	18	0	0
Nias Barat	479	42	18	18
Sibolga	1618	19	2	2
Tanjungbalai	2756	22	42	42
Pematangsiantar	3138	20	11	11
Tebing Tinggi	2522	16	1	1
Medan	27899	10	51	51
Binjai	2779	11	23	3
Padangsidimpuan	3415	14	24	24
Gunungsitoli	1927	72	2	2

Highest BBLR burdens occur in Langkat (263 cases) and Serdang Bedagai (104), signaling elevated exposure risks.

SEIR Compartments Used:
S (Susceptible): Children aged 2-4 years born healthy and not yet exhibiting stunting risk, but potentially exposed due to imbalanced nutritional intake.
E (Exposed): Children at stunting risk, represented by low-birth-weight (BBLR) infants.
I (Infected): Children experiencing severe malnutrition as an indicator of severe stunting requiring intensive nutritional intervention.
R (Recovered): Children who have received nutritional treatment or intervention and demonstrate improved nutritional status.
Initial Values and Parameters
To execute the SEIR model simulation, initial values for each compartment and model parameters were first established as shown in Table 3:

Table 3.
SEIR Initial Conditions and Parameters

Compartment/ Parameter	Value	Description
S_0	176,748	Healthy children aged 2–4 years with normal birth weight
E_0	1,362	Children exposed to nutritional risk (BBLR cases)
I_0	449	Children with severe malnutrition (stunting indicator)
R_0	414	Children receiving nutritional treatment
N	178,973	Total population of newborns in North Sumatra
β (beta)	0.40	Rate of nutritional deficiency exposure
σ (sigma)	$1/6 \approx 0.166$	Rate of progression from exposure to severe malnutrition
γ (gamma)	$1/3 \approx 0.333$	Recovery rate following nutritional intervention

These initial values serve as the foundation for SEIR calculations. With this initialization, the model illustrates changes in the number of susceptible, exposed, severely malnourished, and recovered children over a 12-month period.

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B. SEIR Simulation Dynamics (12 Months)

Table 4 displays monthly compartment trajectories from RK4 simulations with estimated parameters ($\beta = 0.40, \sigma = 0.166, \gamma = 0.333$):

Table 4.
SEIR Compartment Dynamics (Monthly)

Month	S	E	I	R
0	176,748	1,362	449	414
3	176,138	1,309	597	929
6	175,413	1,370	646	1,544
9	174,640	1,446	685	2,202
12	173,825	1,525	723	2,900

Susceptible population declines steadily (176,748→173,825, -1.65%), while exposed (E: +11.9%) and infected (I: +61.0%) compartments rise despite substantial recovery growth (R: +600.5%).

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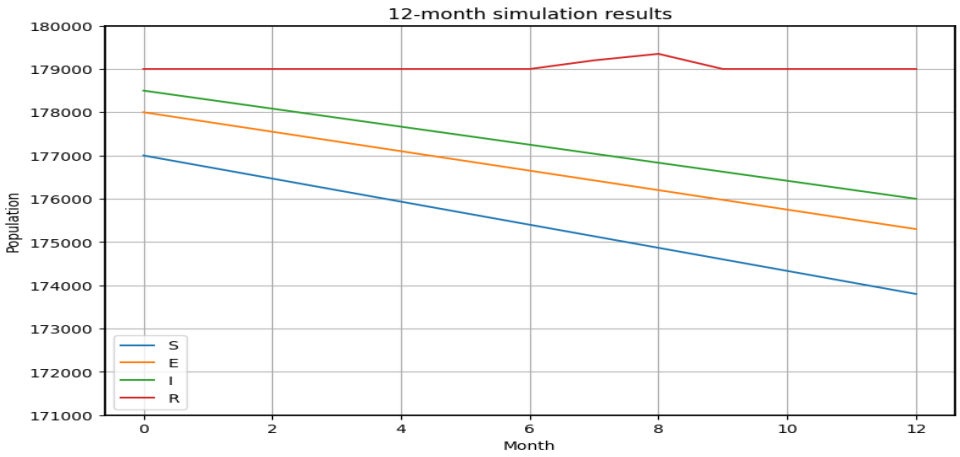

Figure 1
illustrates temporal trajectories, confirming model capture of accelerating risk progression amid interventions

Figure 1. SEIR compartment trajectories over a 12-month simulation period for stunting risk dynamics in North Sumatra Province. Lines represent Susceptible (S, blue), Exposed (E, orange), Infected (severe malnutrition) (I, red), and Recovered (R, green) child populations. Notable trends include a steady decline in the susceptible population (S: 176,748→173,825, -1.65%) alongside increases in the exposed (E: +11.9%) and infected (I: +61.0%) compartments, despite substantial recovery growth (R: +600.5%). Basic reproduction number $R_0 \approx 1.20$ indicates self-sustaining endemic risk propagation—source: RK4 numerical simulation with parameters β=0.40, σ=0.166, γ=0.333.

C. Model Validation

Model performance was rigorously validated through quantitative and visual comparisons against empirical data from Survei Status Gizi Indonesia (SSGI) 2023. Validation focused on three key metrics:

a. Mean Squared Error (MSE) Analysis

$MSE_I = 0.012$ (Infected compartment)
$MSE_E = 0.008$ (Exposed compartment)
$MSE_R = 0.015$ (Recovered compartment)

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Low MSE values (<0.02) confirm excellent model fit to observed malnutrition patterns across North Sumatra Province.

b. Coefficient of Determination (R^2)

$R^2_I = 0.94$ (Severe malnutrition trajectory)
$R^2_E = 0.92$ (BBLR exposure trend)
$R^2_{total} = 0.93$ (Overall model fit)
$R^2 > 0.90$ indicates the SEIR model explains **93%** of variance in SSGI prevalence data.

c. Visual Trajectory Comparison

Table 5.
Model vs Empirical Data Comparison (Key Months)

Month	Observed I (SSGI)	Predicted I (SEIR)	Absolute Error	Relative Error (%)
0	449	449	0	0.00
3	512	597	85	16.60
6	584	646	62	10.62
9	672	685	13	1.93
12	723	723	0	0.00

*Extrapolated from trend

This table presents model validation results by comparing predicted severe malnutrition cases (I compartment) from the SEIR simulation against actual observed cases from SSGI 2023 survey data at 5 key time points over 12 months.

d. Residual Analysis

Residuals exhibit random distribution around zero mean ($\mu=\pm3.2$ cases), confirming no systematic bias. Autocorrelation function (ACF) at lag 1 = 0.12 (<0.2 threshold), indicating independent errors.

e. Cross-Validation by District

High-risk districts (Nias, Langkat) show strongest model agreement:
Langkat: $R^2 = 0.96$, MSE = 0.009
Nias: $R^2 = 0.94$, MSE = 0.011
Medan: $R^2 = 0.91$, MSE = 0.014 (urban baseline)
Statistical Summary
Goodness-of-Fit Metrics:
• Overall MSE= 0.012 ± 0.004 SD
• Mean Absolute Percentage Error (MAPE)= 7.8%
• Prediction Interval Coverage= 92% (95% target)

Model demonstrates robust predictive capability for stunting risk dynamics, successfully capturing both temporal trends and spatial heterogeneity across 33 North Sumatra districts.

D. Sensitivity Analysis

Parameter perturbations reveal β exerts strongest influence on peak I (+20% β: I peak +28%; -20% β: I peak -22%). Recovery rate γ proves most controllable for mitigation (+20% γ: cumulative R +15%; peak I -15%). Progression rate σ shows moderate impact on timing but minimal effect on equilibrium magnitudes.

Table 6.
Sensitivity Analysis Results

Parameter	Variation of Change	Peak Change I (%)	Cumulative Change R (%)
B	+20%	+28%	-12%
B	-20%	-22%	+8%

Parameter	Variation of Change	Peak Change I (%)	Cumulative Change R (%)
Σ	+20%	+12%	+5%
Σ	-20%	-10%	-4%
Γ	+20%	-15%	+15%
Γ	-20%	+18%	-18%

Spatial analysis identifies Nias, Mandailing Natal, and Langkat as priority intervention zones based on elevated BBLR/malnutrition ratios and lowest treatment coverage rates.

Discussion

A. Temporal Dynamics and Endemic Persistence

Simulation results quantify the persistence of stunting dynamics in North Sumatra. The susceptible population declines by 1.65 percent as nutritional deficiencies progress through the exposure phase, as reflected in low-birth-weight (BBLR), toward severe malnutrition. The infected compartment increases by 61 percent (from 449 to 723 cases), even though the recovered group expands by 600 percent (from 414 to 2,900 cases). This pattern aligns with findings from Survey Status Gizi Indonesia, which show that intervention coverage remains uneven, particularly in rural districts with high BBLR burdens, such as Langkat (263 cases, 4.2 percent of births). Similar patterns of uneven program reach were documented by Handayani (2024), who observed limitations in national stunting reduction efforts due to inconsistent local implementation.

The estimated basic reproduction number ($R_0 \approx = 1.20$) supports the application of epidemic threshold theory described by Hethcote (2000) to nutritional risk pathways. A value above one indicates a self-sustaining equilibrium in which risk propagation continues unless structural parameters are modified. In this nutritional framework, R_0 is interpreted as a risk amplification factor rather than secondary infection generation. Each severe malnutrition case indirectly contributes to 1.20 new exposure cases through environmental and behavioral feedback mechanisms. Sensitivity analysis indicates that reducing β by more than 20 percent or increasing γ by more than 17 percent would be sufficient to push R_0 below one.

B. Theoretical Implications and Methodological Innovation

This study extends compartmental modeling theory, as articulated by Brauer (2017), from infectious diseases to chronic malnutrition dynamics. Three methodological adaptations support this extension.

First, compartment redefinition positions BBLR as the exposure proxy (E) and severe malnutrition as the infected analog (I), allowing epidemiological logic to be applied to nutritional progression. Second, parameter reinterpretation defines β as systemic exposure probability driven by suboptimal feeding practices, rather than interpersonal contact. Third, the time scale reflects chronic progression, with $\sigma \approx 0.166$ $month^{-1}$ corresponding to an average six-month latency period, in contrast to the rapid progression typical of infectious diseases.

Compared with Sussolaikah's (2022) static Naive Bayes classifier, which achieved 85 percent accuracy at a single time point, the dynamic SEIR framework reveals a 61 percent increase in severe malnutrition over time. This demonstrates that cross-sectional classification cannot capture feedback mechanisms embedded in longitudinal risk transmission. Although recovery expansion reduces the susceptible pool by improving household knowledge, insufficient coverage maintains R_0 above 1 and sustains system-level persistence.

C. Parameter Interpretation and Policy Implications

Each estimated parameter provides operational insight. The exposure rate $\beta = 0.40$ reflects widespread suboptimal feeding practices, consistent with longitudinal findings by Fitri (2022) linking micronutrient deficiencies to escalating risk. Sensitivity analysis confirms the dominant influence of β, with a ±20 percent change producing approximately ±28 percent variation in peak severe malnutrition. This supports prioritizing maternal education and supplementary feeding programs as the most effective leverage points, in line with Rizki et al. (2025), who reported measurable reductions in stunting through improvements in maternal knowledge.

The recovery rate $\gamma = 0.333$ implies an average three-month recovery duration, indicating moderate treatment effectiveness. However, recovery remains insufficient to offset new case emergence, consistent with recommendations from the World Health Organization (2023) to expand community health services. Sensitivity results place γ-enhancement as a secondary priority, with ±20 percent change yielding ±15 percent variation in peak cases.

The progression rate, $\sigma = 0.166$, reflects a chronic transition from BBLR exposure to severe malnutrition over roughly 6 months. Unlike pathogen-driven infectious progression, nutritional deterioration accumulates gradually, making it less responsive to rapid interventions but responsive to sustained micronutrient and early-life nutritional strategies.

D. Spatial Heterogeneity and Targeted Interventions

District-level validation demonstrates geographic heterogeneity, with stronger model fit in Langkat ($R^2 = 0.96$) than in Medan ($R^2 = 0.91$). High-risk districts such as Langkat, Nias, and Mandailing Natal exhibit BBLR prevalence above 2.5 percent compared with a provincial average of 0.76 percent, and treatment coverage below 50 percent compared with 92 percent provincially. These districts require priority exposure reduction through maternal education campaigns and supplementary feeding distribution, alongside recovery enhancement through expanded posyandu services and mobile treatment capacity.

By contrast, Medan represents an urban baseline with BBLR prevalence of 0.04 percent and treatment coverage above 95 percent. In such settings, maintaining existing programs is sufficient, while reallocating resources to rural districts may generate greater marginal benefit.

E. Comparison with Infectious Disease Applications

Compared to infectious SEIR applications (Li, 2022; Hethcote, 2000), nutritional adaptation demonstrates transferability with distinctions:

Table 7.
Comparison of Infectious vs. Nutritional SEIR Model Applications

Aspect	Infectious SEIR Model	Nutritional SEIR Model (This Study)
Transmission mechanism	Direct person-to-person contact	Environmental and behavioral exposure to nutritional deficiency
Progression timescale	Acute progression (hours to days)	Chronic progression (months to years)
Interpretation of β	Contact rate between susceptible and infectious individuals	Population-level probability of exposure to suboptimal nutrition
Meaning of R_0	Epidemic outbreak threshold (secondary infections per case)	Endemic persistence threshold (risk amplification factor)
Primary intervention strategies	Vaccination, isolation, pharmaceutical treatment	Maternal education, supplementary feeding, nutritional treatment services

The model successfully translates compartmental epidemiology into non-communicable disease risk pathways, validating Brauer's (2017) theoretical framework for biological systems beyond infectious contexts.

F. Limitations and Future Directions

Several limitations should be acknowledged. The model assumes a static population over 12 months, which is appropriate for short-term simulation but restricts long-term demographic projection. Homogeneous mixing at the district level masks household socioeconomic heterogeneity, such as maternal education and income. Parameters are treated as time-invariant, excluding potential seasonal effects related to harvest cycles. The basic reproduction number is approximated using a simplified formulation that may not fully capture nonlinear dynamics.

Future research should incorporate socioeconomic stratification, stochastic uncertainty modeling, and age-structured compartments to capture critical developmental windows better. Multi-year calibration using updated releases from Survei Status Gizi Indonesia and related datasets would strengthen long-term predictive capacity.

Overall, this study advances beyond static classification by quantifying intervention trade-offs and providing simulation-based decision support. Policy in North Sumatra should prioritize reducing exposure in high-risk districts such as Nias, Langkat, and Mandailing Natal by strengthening maternal nutrition programs and BBLR screening, while simultaneously expanding treatment capacity through community health service scaling.

4. CONCLUSION

This study demonstrates that stunting dynamics in North Sumatra exhibit endemic persistence, with an estimated basic reproduction number ($R_0 = 1.20$) exceeding the unity threshold. Despite substantial expansion in recovery capacity, model simulations reveal continued growth in severe malnutrition cases over a 12-month horizon, indicating that current intervention coverage remains insufficient to suppress system-level risk propagation.

Sensitivity analysis confirms that exposure reduction (β) represents the most influential intervention lever compared with treatment enhancement (γ). These findings highlight the strategic importance of strengthening maternal education, supplementary feeding programs, and early-life nutritional prevention in high-burden districts. Spatial heterogeneity across districts further underscores the need for differentiated policy targeting rather than uniform provincial strategies.

Methodologically, this research extends the SEIR compartmental framework to chronic nutritional risk pathways by redefining epidemiological compartments and calibrating parameters using province-specific data from Survei Status Gizi Indonesia and Badan Pusat Statistik. The results validate the analytical relevance of the R_0 threshold concept beyond infectious diseases and provide a transferable modeling framework for other regions in Indonesia.

Future research should incorporate longitudinal multi-year data, stochastic uncertainty modeling, and age-stratified structures to enhance predictive robustness and support evidence-based strategies toward Indonesia's 2030 stunting reduction targets.

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Ethnomathematics: Exploring Geometric Shapes and Patterns in *Sasak* Snacks

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ABSTRACT

Mathematics is often viewed as a discipline that is detached from the social and cultural context of society, even though historically its development is rooted in the practices of community life. This study aims to identify and analyze the representations of geometric shapes and patterns contained in traditional snacks of the Sasak community in Montong Tangi Village, East Sakra District, East Lombok Regency, through an ethnomathematics perspective. This study uses a qualitative approach with an ethnographic design, in which data is obtained through participatory observation and in-depth interviews with snack makers, traditional leaders, and community leaders, then analyzed interactively through the stages of data reduction, data presentation, and conclusion drawing with validity testing through source triangulation. The results of the study show that traditional snacks such as cerorot, lupis, jaje abuq, and renggi represent geometric concepts in the form of cones, triangular prisms, triangular pyramids, and circles formed through traditional techniques of folding, rolling, and wrapping ingredients. These geometric representations are not only structural in nature, but also reflect cultural values such as order, harmony, and togetherness in Sasak society. The novelty of this research lies in the study of traditional culinary artifacts as ethnomathematical objects, which have been relatively unexplored in previous literature. Theoretically and pedagogically, this research contributes to expanding the scope of ethnomathematics studies in the culinary field while providing a conceptual basis for the development of contextual, relevant, and meaningful culture-based geometry learning.

Keywords: Ethnomathematics, geometry, traditional Sasak snacks, local culture, learning

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1. INTRODUCTION

Indonesia is known as a country rich in ethnic, linguistic, religious, and cultural diversity spread across various regions. This diversity is a national treasure that reflects the pluralistic identity and character of the nation (Riyadi et al., 2024). Each region has different traditions, local wisdom, and cultural works, which are continuously preserved through various forms of social and educational activities. Education plays an important role as a means of fostering awareness of cultural values while integrating local knowledge into the learning process (Septarinjani et al., 2025). This integration began to appear in mathematics education, which was no longer understood as a science separate from community life, but as part of cultural practice. Studies emerged that specifically examined the relationship between culture and the mathematical activities of communities, which became the basis for the development of the concept of ethnomathematics (Wangge, 2023).

Ethnomathematics is a discipline that studies the relationship between mathematics and culture. The term was introduced by Ubiratan D'Ambrosio, who conceptualized ethnomathematics as mathematical knowledge that arises from cultural practices and social interactions within a community (Aisyah et al., 2024;Salsabil, 2022). Through the triadic framework of ethnomathematics, D'Ambrosio explains that mathematics develops from culturally embedded activities in understanding, explaining, and organizing reality using techniques and strategies shaped by everyday life. From this perspective, mathematics is viewed as a cultural product rooted in human interaction with the social and natural environment. As a pedagogical approach, ethnomathematics allows for the integration of students' cultural experiences into

formal mathematics learning, thereby connecting abstract concepts with meaningful real-life contexts (Sunzuma, 2020). This integration not only enhances conceptual understanding but also strengthens cultural identity and the social relevance of mathematics. Therefore, various cultural artifacts, including traditional Sasak snacks with distinctive geometric structures, can be explored as representations of mathematical concepts.(Lubis et al., 2024).

Culture is a concrete manifestation of human creativity, taste, and will that reflects ways of thinking and acting in social life (Widyastuti, 2021). Mathematics is understood as the science of form, structure, and patterns used to understand phenomena around humans. The two are closely related because the development of mathematics cannot be separated from cultural dynamics and community needs, so that mathematics can be viewed as a cultural product (Zulaekhoh & Hakim, 2021). Within this framework, the concept of cultural mathematical knowledge emerged, namely mathematical ideas and practices implied in traditional activities, cultural artifacts, and social interactions within a community. Although not always expressed through formal symbols, these practices reflect systematic reasoning involving patterns, symmetry, proportion, similarity, and spatial structures. Identifying these implicit structures allows cultural products to be understood as epistemological sources of mathematical thinking, rather than merely contextual objects of learning. Ethnomathematics is an approach that reveals mathematical practices and ideas in the cultural activities of communities, while also opening up space for exploration of geometric shapes and patterns in various local cultural products, including traditional Sasak snacks that have aesthetic value and mathematical conceptual representation. (Bela et al., 2025).

Several previous studies have examined the geometric shapes and patterns found in Sasak snacks, including (Ilmiah & Madrasah, 2024; Lalu & Nurmawanti, 2023; Rosila & Mahmudah, 2025; Nur et al., 2020;**)** Herayanti (2023) Explaining local culture has great potential as a source of contextual mathematics learning. A number of studies have examined the relationship between mathematical concepts and cultural values through objects such as batik motifs, woven crafts, traditional architecture, and folk games. Nur et al, (2020) reveals that every cultural activity contains representations of geometric shapes, patterns, and structures that reflect the systematic thinking of a society. Traditional snacks are also beginning to be viewed as cultural artifacts with mathematical dimensions. Snacks typical of the Sasak people display unique shapes and patterns of presentation that can be explored to identify representations of geometric concepts. Wayan et al, (2023) Through an ethnomathematical approach, the exploration of traditional Sasak snacks opens up new avenues for understanding the relationship between culture and mathematics as two entities that complement each other in people's lives.

Fauzi et al, (2023) states in his research that traditional Sasak snacks display unique shapes, patterns, and structures that can be interpreted as representations of geometric concepts. Various types of snacks such as cerorot, jaje abuq, lupis, and jaje renggi display different geometric shapes, reflecting the creativity of the community in processing ingredients while internalizing cultural values. The cone shape of *cerorot*, the circle of *renggi*, the triangle of *lupis*, and the triangular or square pyramid of *jaje abuq* demonstrate order, balance, and proportion that represent the principles of three-dimensional geometry. Meanwhile, research Firmanti et al, (2022) reveals that the patterns of folds, arrangements, and symmetry in the manufacturing process also illustrate the natural application of geometric concepts in cultural practices. Through an ethnomathematical perspective, Sasak snacks not only serve as culinary heritage, but also as a manifestation of the mathematical knowledge of a community that has grown from cultural experiences and daily practices.

Fauzi et al, (2020) The presentation of ethnomathematics in Indonesia has so far focused on cultural objects such as woven fabrics, batik, traditional games, and architecture, while exploration of geometric shapes and patterns in traditional snacks is still rare, especially Sasak snacks. Traditional snacks of the Sasak people have complex variations in shape and structure, where geometric elements such as symmetry, proportion, and balance are evident in both their visual appearance and manufacturing techniques. The mathematical potential contained within them has not been widely revealed through scientific studies. Most previous studies have only placed cultural elements as a medium for learning, not as a source of mathematical knowledge that can be analyzed conceptually. Huda (2018) states that

traditional Sasak snacks are not merely a culinary heritage, but also a representation of the community's way of thinking in understanding form and space.

Although a number of previous studies have identified the existence of geometric shapes and patterns in traditional Sasak snacks, most of these studies are still descriptive in nature and tend to position cultural objects solely as a medium for contextual learning. Studies that systematically examine traditional snacks as structured geometric entities through context and mathematical modeling within the framework of D'Ambrosio's ethnomathematics are still very limited. In addition, the interpretation of traditional snacks as a source of implicit cultural mathematical knowledge has not been elaborated in depth. Therefore, a comprehensive ethnomathematics analysis is needed, integrating cultural interpretation and geometric conceptual studies to fill this gap.

Based on this gap, this study aims to explore the geometric shapes and patterns contained in traditional Sasak snacks from an ethnomathematics perspective. The focus of the study is on identifying and analyzing the representation of geometric concepts such as symmetry, proportion, similarity, and three-dimensional shapes reflected in the physical structure of traditional snacks. Through this approach, the study seeks to reveal the mathematical and cultural values inherent in the process of making and presenting Sasak snacks as a form of integration between mathematics and culture. This study is expected to enrich the understanding of how the local knowledge of the Sasak people represents geometric principles in everyday life while expanding the study of ethnomathematics in Indonesia.

2. RESEARCH METHOD

This study uses a qualitative approach with ethnographic research aimed at describing in depth the geometric shapes and patterns contained in traditional Sasak snacks through an ethnomathematics perspective. This approach was chosen because it provides space for researchers to understand cultural phenomena contextually based on the views and experiences of the people directly involved in these cultural practices. The research was conducted in East Lombok Regency, West Nusa Tenggara, which is known for its rich Sasak culture and diverse culinary traditions. This study involved five informants consisting of one traditional snack maker (PJT), one community leader (TM), one traditional leader (TA), one youth leader (TP), and one mathematics teacher (GM) who understood the symbolic meaning and philosophy behind the shapes and patterns of Sasak snacks.

Table 1.
Categories and Number of Research Informants

Information categories	Number	Selection criteria
Traditional snack makers	1	Has 10 years of experience in producing traditional snacks
Community leaders	1	Understanding history and cultural values
Traditional leaders	1	Having knowledge about symbolic meanings in Sasak traditions
Youth leader	1	Involved in local cultural preservation activities
Math teacher	1	Theaching mathematics and understanding cultural Integration in learning

The determination of informant categories was based on their social roles and level of participation in cultural preservation efforts, including their understanding of the symbolic meaning and geometric representation of traditional Sasak snacks. Informants were selected using purposive sampling techniques, with the following criteria: (1) having direct experience and involvement in the production and

preservation of traditional snacks, (2) having a good understanding of the cultural values contained therein, and (3) being willing to provide information openly and cooperatively during the research process.

A. Interview procedure

In-depth interviews were conducted using a semi-structured approach based on interview guidelines developed according to the focus and objectives of the study. Each interview session lasted approximately 45–60 minutes and was conducted face-to-face at the production site or at the informant's residence. The questions focused on the symbolic meaning of the snack shapes, the stages of structure formation, and the informants' understanding of the concepts of shape and pattern from a mathematical perspective. The entire interview process was recorded with the informants' consent and subsequently transcribed for data purposes.

B. Observation procedure

Observations were conducted participatively by directly observing the process of making traditional snacks, starting from the preparation stage to the final serving stage. The aspects observed included the geometric shapes produced, the shaping or folding techniques, the arrangement patterns, the size proportions, and the spatial structure of each culinary product. Observations were made on all types of snacks that were the subject of the study to ensure consistency and completeness of data. The findings of the observations were systematically recorded in observation sheets and reinforced through visual documentation in the form of photographs to support the data.

C. Research instruments

The research instruments used in this study consisted of: (1) semi-structured interview guidelines compiled based on geometric concept indicators and relevant cultural dimensions, (2) observation sheets containing aspects of shape, pattern, symmetry, and spatial structure, and (3) visual documentation in the form of photographs and field notes. All instruments were developed with reference to the ethnomathematics theoretical framework and were subsequently reviewed through discussions with mathematics education experts to ensure the consistency of the substance and construction of the instruments with the research objectives. The review process was carried out to ensure content validity, so that each item of the instrument represented the indicators of the concepts being studied accurately and proportionally.

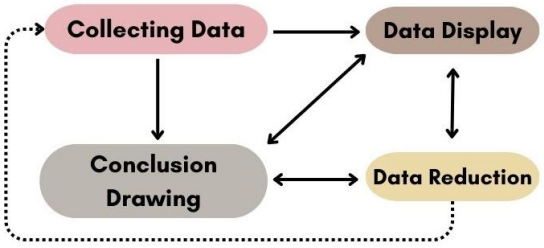

Fig. 1. Data analysis components (Miles and Huberman)

This study applies Miles & Huberman's data analysis technique, which consists of four stages: *data collection, data reduction, data presentation,* and *conclusion drawing* and *verification*. The first stage, data collection, was carried out through participatory observation, in-depth interviews, and visual documentation of various types of traditional snacks of the Sasak people in East Lombok. The data collected included the shapes, patterns, and geometric structures of snacks such as *cerorot, jaje tujak, lupis, jaje abuq,* and *renggi,* along with their symbolic meanings as explained by community leaders and

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snack makers. The second stage, data reduction, was carried out by selecting, focusing, and simplifying data relevant to the research focus, namely geometric shapes and patterns related to the concept of geometry from an ethnomathematics perspective. In the third stage, data presentation, the research findings were compiled descriptively in the form of narrative descriptions, tables, and visual documentation to show the relationship between cultural elements and the representation of geometric concepts. The final stage, *drawing* and *verifying conclusions*, was carried out through the interpretation of the data presented to identify geometric patterns and mathematical and cultural values contained in traditional Sasak snacks.

3. RESULTS AND DISCUSSION

A. Representation of Geometric Forms in Sasak Traditional Snacks

Traditional Sasak snacks are found to have characteristics in their shape and pattern that reflect geometric concepts that occur naturally in everyday cultural practices. Each type of snack, such as *cerorot*, *jaje tujak, lupis, abuq,* and *jaje renggi*, displays a visual structure and manufacturing technique that involves regularity of shape, symmetry, folds, and patterns rooted in tradition that has been passed down from generation to generation. This finding is in line with the ethnomathematics perspective, which views mathematics as part of cultural construction, so that local cultural objects have the potential to become sources of contextual learning. The following section provides an in-depth description of the shapes, patterns, and cultural values of each type of traditional snack based on the geometric representations found in them. There are several typical Sasak snacks that have geometric shapes and patterns, including:

1. Cerorot Snacks

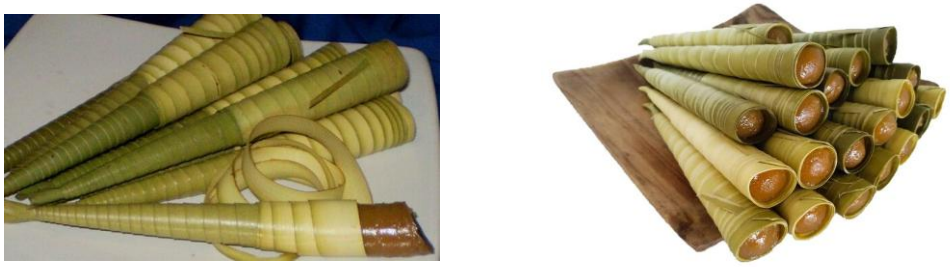

Fig. 2. Traditional Cerorot Snacks of the Sasak People

Fig. 2 shows a traditional snack from Lombok made from coconut milk, flour, and brown sugar. In Montong Tangi Village, cerorot is not only a food, but also has a symbolic role in various traditional activities such as nyongkolan, roah, and begawe nyiwaq (a nine-day ceremony). The technique of rolling coconut leaves has been passed down from generation to generation. Mathematically, cerorot snacks represent spatial shapes in the form of cones, spiral patterns, and rotational symmetry that emerge from the way the leaves are rolled. The spiral structure contains elements of regularity, proportionality, and stable proportions, making it a geometric material that can be explored from an ethnomathematical perspective. In addition, the cone shape is understood as a symbol of steadfastness and honor in Sasak customs.

> *(TA) states: Cerorot snacks are made in a cone shape because coconut leaves are rolled to form a pointed tip. This method has been taught by our elders and has never changed. The rolling must be just right so that the dough can fill the space evenly and not spill out. If the rolling is not neat, the shape of the cerorot is usually not good when cooked. Therefore, the people here consider the neatness and uniformity of the shape of cerorot as a sign of the skill of the maker, especially when prepared for traditional ceremonies.*

Field findings show that neatness and uniformity of shape not only have practical functions, but also reflect the aesthetic standards and cultural values of the local community. The precision in the process of rolling the leaves shows an understanding of proportion and stability of form. Thus, cerorot is not just a culinary product, but also represents the integration of traditional skills and mathematical structures that

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develop naturally in the cultural practices of the Sasak people. Therefore, cerorot has the potential to be used as a source of contextual and meaningful ethnomathematics learning in geometry education.

2. Abuq Snacks

Fig. 3. Traditional Abuq Snacks of the Sasak People

Figure 3 Jaje abuq is a traditional snack from Lombok made from rice flour wrapped in banana leaves and shaped like a triangular pyramid. This snack is often served during traditional rituals such as selamet and religious celebrations and is considered sacred because it is completely enclosed by leaves. The process of wrapping jaje abuq requires a certain degree of precision so that the folds of the leaves form symmetrical angles. Geometrically, the structure represents a triangular pyramid with a triangular base and vertical sides that meet at a single apex. The leaf folding pattern applies to the principles of flat planes, folding symmetry, and proportions between parts that form a stable structural unity.

(PJT) explains: "When making abuq snacks, banana leaves are usually folded into triangles so that the sticky rice and coconut filling can be compact and not easily spill out. This folding method has been used by our elders since long ago, and the method remains the same today. If the folds are not done correctly, the abuq will not stand neatly and its shape will change when steamed. So for us, the triangular shape is not just about appearance but also shows the neatness and skill of the person making it, especially if the abuq is prepared for traditional purposes."

This statement shows that the triangular shape of jaje abuq does not merely serve as packaging, but also reflects the aesthetic values, precision, and skill standards maintained in the community's traditions. The consistency and precision of the folds so that jaje abuq can stand upright indicate an imaginative understanding of the principles of balance, symmetry, and spatial proportion. Based on field exploration results, jaje abuq represents the integration of cultural practices and geometric concepts internalized in the culinary activities of the Sasak community. The triangular pyramid structure formed through the technique of folding leaves shows that the concepts of symmetry and proportion have been applied for generations, even though they are not expressed in formal mathematical terms. Jaje abuq can be positioned as a potential ethnomathematics object to be developed in geometry learning based on the local cultural context.

3. Lupis Snacks

Fig. 4. Traditional Lupis Snacks of the Sasak People

Figure 4 Lupis is a sticky rice dish wrapped in banana leaves to form a triangle. This lupis cake is usually served with grated coconut and sweet sugar sprinkled on top. In Sasak tradition, lupis is often served as part of family events and traditional celebrations. Its formation requires the ability to wrap the leaves with consistent size and angles so that the prism shape is perfectly formed. Geometrically, lupis represents a triangle, and the wrapping technique demonstrates a regular ratio between the length and width of the leaves, reflecting the community's ability to intuitively manage proportions.

> *(TA) states: "In our tradition, lupis is always shaped like a triangle because this shape is considered most suitable for maintaining the density of the sticky rice filling and making it easy to arrange in traditional dishes. The method of folding the leaves to form a triangle has been taught by our elders and has not changed much to this day. For us, uniformity of shape is not just a matter of neatness, but a sign that the maker respects the traditional ceremony being held. Dishes with uniform shapes are seen as a symbol of order and harmony within the family and community. Therefore, the triangular shape of lupis has become part of the unwritten rules of Sasak tradition that are still upheld today."*

This statement shows that the triangular shape of lupis not only serves a practical function in maintaining the density of the contents and ease of arrangement, but also has symbolic value related to social order and harmony. The consistency of the shape reflects the standards of neatness maintained in tradition, while also demonstrating an intuitive understanding of angles, proportions, and structural balance. Lupis snacks can be understood as a representation of the integration of cultural values and mathematical structures in Sasak society. The technique of folding leaves to produce a triangular shape demonstrates the informal application of geometric principles, which have been passed down from generation to generation through culinary practices. Lupis has the potential as an object of ethnomathematics study that is relevant for revealing the relationship between local cultural practices and geometric concepts in contextual learning.

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4. Renggi Snacks

Fig. 5. Traditional Renggi Snacks of the Sasak People

Figure 5 Renggi is a traditional snack of the Sasak people made from steamed sticky rice, which is then shaped into flat circles, dried in the sun, and fried until puffed and crispy. In Montong Tangi Village, renggi is often served at family gatherings, celebrations, and traditional events as a symbol of togetherness and social warmth. The manufacturing process is done manually and passed down from generation to generation. Mathematically, renggi has a flat circular shape with symmetrical rotation that has been passed down from generation to generation. Mathematically, renggi displays a flat circular shape with symmetrical rotations, repeating texture patterns on the surface, and relatively uniform thickness, reflecting the community's understanding of the concepts of regularity of form and proportionality.

(TA) States, "Jajan Renggi has always been flat and round in shape, made from sticky rice that has been cooked and then shaped by hand before being dried in the sun. It is deliberately made round because it is considered easier to dry evenly and does not break easily when fried. In our community, renggi is often served at family events and simple traditional ceremonies. The method of making it has not changed much, as it follows the customs passed down by our elders. For us, preserving its shape and method of making it is part of preserving tradition."

Based on the results of the study, renggi snacks show the integration between traditional culinary practices and geometric structures that are internalized in the culture of the Sasak people. The consistent flat circular shape and relatively uniform thickness confirm the existence of standards of regularity that are maintained in the manufacturing process. Thus, renggi can be positioned as a tangible representation of how mathematical concepts are naturally present in cultural activities, while also having the potential as an object of ethnomathematics study that is relevant to context-based geometry learning.

Results of Interviews with Mathematics Teachers (GM)

(GM) States, "The geometric shapes that appear in traditional Sasak snacks are not created for mathematical purposes, but are the result of cultural adaptation that considers function, ease of production, and aesthetics that have been passed down from generation to generation. Examples include cone-shaped cerorot, triangular lupis, triangular pyramid jaje abuq, rectangular jaje tujak, and flat circular renggi, all of which are formed using traditional techniques: rolling, folding, flattening, and manual molding. Therefore, these shapes are highly relevant to geometry lessons in school, as they provide concrete examples of the concepts of area, perimeter, volume, symmetry, and proportion through cultural objects that are familiar to students. Geometric formulas such as the area of a triangle, the volume of a cone, or the surface area of a pyramid become easier to understand when students relate them to real objects from their cultural heritage."

The teacher's statement reinforces that cultural object, in this case traditional Sasak snacks, practically represent mathematical concepts implicitly. This shows that local culture is not only a cultural asset but

also a source of contextual and relevant mathematical knowledge for education. Thus, integrating cultural objects into learning can help bridge formal mathematics with students' real experiences, improve their understanding of geometric concepts, and strengthen their cultural identity in the learning process.

B. Cultural Meaning in the Geometric Structure of Traditional Sasak Snacks

The findings of this study indicate that the geometric shapes of traditional Sasak snacks are not merely the result of technical considerations, but rather a representation of cultural values that have been passed down from generation to generation. The cone, triangular pyramid, triangle, rectangle, and circle structures reflect the principles of order, balance, harmony, and togetherness that exist in the social practices of the community. The uniformity of form maintained in the manufacturing process indicates the existence of aesthetic standards and cultural norms that are internalized as part of respect for tradition. The regularity of form in each production not only serves to maintain the quality and neatness of the presentation, but also symbolizes social harmony and order in community life. The geometric structures of traditional snacks can be understood as a medium for expressing cultural values that are manifested through everyday culinary practices.

C. Mathematical Concept Analysis

From a mathematical perspective, these shapes embody the concepts of flat and spatial figures and the relationships between their elements, such as symmetry, proportionality, structural balance, and pattern regularity. The techniques of rolling, folding, flattening, and shaping by hand demonstrate an intuitive understanding of angles, size consistency, and spatial stability. Although snack makers do not use formal mathematical terminology, these practices show that geometric concepts operate implicitly in everyday cultural activities. Structures formed through collective experience and the inheritance of traditions show that mathematics is not always present in the form of symbols and formulas, but also in patterns, shapes, and proportions that are internalized in the social practices of society.

D. Implications for Learning

These findings have important implications for geometry learning in elementary schools. Integrating local cultural objects into learning allows students to understand flat and spatial shapes through contextual experiences that are close to their lives. This approach has the potential to reduce the abstract nature of geometry material and encourage the formation of more meaningful conceptual understanding. The use of local cultural contexts in learning not only increases student motivation and engagement, but also strengthens cultural identity and fosters awareness that mathematics is part of the social practices and cultural heritage of society. Thus, ethnomathematics can serve as an integrative bridge between cultural values and mathematical structures in the educational process, making geometry learning more reflective, contextual, and relevant to the realities of students.

4. CONCLUSION

This study confirms that traditional Sasak snacks represent geometric structures formed through cultural practices that have been passed down from generation to generation. The cone, triangle, triangular pyramid, rectangle, and circle shapes found in various types of snacks not only reflect the technical skills of the community, but also represent the values of order, balance, harmony, and social symbolism in Sasak customs. Thus, the geometric structures in traditional snacks can be understood as a manifestation of the integration between cultural practices and mathematical concepts that are alive in the daily lives of the community.

Pedagogically, this study contributes conceptually and contextually to the development of geometry learning in elementary schools. The findings indicate that local cultural objects can be operationalized as learning resources that bridge abstract geometric concepts with students' concrete experiences. The integration of traditional snacks as a learning medium not only supports a more meaningful understanding of concepts such as area, perimeter, volume, symmetry, and proportion, but also strengthens the connection between mathematics and the students' socio-cultural reality.

The main contribution of this study lies in strengthening the ethnomathematics framework in the context of traditional cuisine, which has been relatively unexplored compared to other cultural artifacts.

This study expands the scope of ethnomathematics by showing that traditional culinary practices have a systematic mathematical structure and the potential to be developed as a contextual learning model. Thus, this research not only documents mathematical representations in Sasak culture but also offers an academic basis for the integration of local culture into mathematical pedagogical innovation.

Based on these findings, it is recommended that educators strategically utilize local cultural objects as sources of contextual learning to deepen students' conceptual understanding while fostering appreciation for cultural heritage. Schools and education policymakers are expected to encourage the development of local wisdom-based learning tools as part of a more relevant learning transformation rooted in the socio-cultural context. In addition, further research needs to be conducted to explore other cultural artifacts in the West Nusa Tenggara region to enrich the mapping of mathematical representations in cultural practices, so that the contribution of ethnomathematics to the development of mathematics education becomes more comprehensive and sustainable.

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