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Development of an integrative learning model based on artificial intelligence and digital literacy for prospective vocational teachers

Sapto Haryoko [1], Hendra Jaya [2,*], Ahmad Risal [2] and Muhammad Mahdinul Bahar [2]

[1] *Department of Electronics Engineering and Information Technology,*
[2] *Department of Automotive Engineering, Universitas Negeri Makassar.*

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Abstract

This study aims to develop an integrative learning model based on Artificial Intelligence (AI) and digital literacy to enhance the competencies of prospective vocational teachers, particularly in Statistics learning. The research employed a Research and Development (R&D) approach adapted from the Lee and Owens model, consisting of five stages: needs assessment, front-end analysis, design, development and implementation, and evaluation. The study involved students of the Electronics Engineering Education Study Program at Universitas Negeri Makassar. Data were collected through tests and non-test instruments, including questionnaires, interviews, and expert validation sheets, and analyzed using qualitative and quantitative descriptive techniques. The findings revealed that students' initial competencies in Statistics were relatively low, indicating a significant gap between actual and expected learning outcomes. The developed learning model integrates AI-based adaptive features, interactive multimedia, and digital learning resources to support personalized and flexible learning. Validation results from media, instructional design, and subject matter experts showed that the model is categorized as "very good," with average scores above 89%. Furthermore, empirical testing demonstrated a significant improvement in student learning outcomes, as indicated by the increase in post-test scores compared to pre-test results, as well as highly positive student responses. The study concludes that the AI-based integrative learning model with digital literacy is effective in improving students' conceptual understanding, engagement, and digital competencies. This model also contributes to preparing prospective vocational teachers to meet the demands of technology-driven education in the era of the Industrial Revolution 4.0 and Society 5.0.

Keywords: Artificial Intelligence; Digital Literacy; Integrative Learning Model; Vocational Education; Statistics Learning

1. Introduction

The rapid development of digital technology, particularly artificial intelligence (AI), has brought significant changes to various aspects of life, including the education sector. This technology is capable of mimicking human cognitive functions and enhancing the efficiency of various data-driven activities and automated systems [1][2]. The utilization of AI in education is not limited to the automation of administrative tasks but also encompasses support for the learning process through intelligent tutoring systems, learning data analysis, and the development of more effective technology-based learning methods [3][4]. Furthermore, AI technology enables the implementation of adaptive learning systems that can adjust learning materials, pace, and individual learner needs based on the analysis of their learning behavior data [5][6]. The use of AI also plays a role in developing more personalized and interactive learning media, which can increase student engagement and help educators identify learning difficulties more quickly and accurately [7][2]. Therefore, the digital transformation driven by AI advancements requires the education sector to prepare human resources with high technological literacy and adaptability in order to face the challenges and opportunities in the era of technology-based education [8][4].

* Corresponding author: Hendra Jaya

One of the competencies that is becoming increasingly important in the digital era is AI literacy, which refers to the ability to understand the basic concepts of artificial intelligence, the working principles of algorithms, and the application of AI technology in various aspects of life and education [9][10]. AI literacy is not only related to technical skills in using digital technology, but also encompasses an understanding of how AI systems work, data analysis, and the ability to critically evaluate the reliability and limitations of the technology [11][12]. In addition, AI literacy also involves awareness of the social, legal, and ethical implications arising from the use of AI technology, such as data privacy issues, algorithmic bias, and its impact on professions and societal life [13][14]. Various studies have shown that the level of AI literacy among university students still varies and is often at a low to moderate level, thus requiring the systematic integration of AI learning into higher education curricula [15][16]. Therefore, strengthening AI literacy has become an essential need in the modern education system so that learners can utilize AI technology critically, ethically, and productively in facing the increasingly rapid digital transformation [17][18].

In the context of vocational education, the need for artificial intelligence (AI) literacy is becoming increasingly important because vocational education focuses on the development of practical skills that align with industrial needs and continuously evolving digital technology [19][20]. Prospective vocational education teachers are not only required to possess pedagogical and professional competencies, but must also have digital literacy and AI literacy in order to effectively utilize intelligent technologies in designing, implementing, and evaluating the learning process [21][22]. The integration of AI literacy into vocational education also enables educators to align the curriculum with the demands of the workforce, enhance human–machine collaboration, and create more adaptive and relevant learning experiences that correspond with industrial developments [23][24]. Therefore, strengthening AI literacy among prospective vocational education teachers is a crucial strategy in preparing graduates who are capable of equipping learners with 21st-century skills relevant to the needs of the workforce in the era of the Industrial Revolution 4.0 and Society 5.0 [25][26].

However, in reality, the level of understanding among prospective teacher students regarding the concepts and utilization of AI in learning is still relatively limited. Many students only recognize AI as a technology used in certain applications, without understanding its basic principles, its potential applications in education, or the ethical implications of using the technology. In addition, teacher education curricula in several vocational education programs have not yet systematically integrated the development of AI literacy competencies.

These limitations highlight the need for a structured and systematic training approach to enhance AI literacy among prospective teacher students. One effort that can be undertaken is through the development of an AI Literacy Training model specifically designed to support the needs of students in vocational education, so that they are able to understand the basic concepts of artificial intelligence and its implications in modern learning processes [27][28]. This training model is expected to help students understand AI concepts and its working principles, enabling them to have sufficient understanding to interact effectively with AI technology in both academic and professional environments [29][28]. Furthermore, AI literacy training also aims to introduce various AI applications in education, including their use in supporting the learning process, learning data analysis, and the development of technology-based teaching materials [29][30]. Through this approach, students are expected to be able to utilize AI technology critically, creatively, and responsibly in learning practices, so that they do not merely become technology users but are also capable of evaluating the ethical, social, and academic impacts of AI use in education [31][28].

Based on the above description, the development of an integrative learning model based on Artificial Intelligence and digital literacy that is suitable for prospective vocational teacher students is important to undertake. This model is expected to serve as an innovation in strengthening the digital competencies of prospective teachers, while also supporting the improvement of adaptive learning quality in response to the development of artificial intelligence technology.

2. Research Methodology

This research adopted a Research and Development (R&D) methodology, drawing on the framework introduced by Lee and Owens. The model is structured into five main phases, namely needs assessment, front-end analysis, design, development and implementation, and evaluation.

The research process begins with a comprehensive needs analysis. Termed needs assessment, this initial stage systematically identifies the gap between the present condition and the desired outcome. It further encompasses the formulation of objectives, the identification of discrepancies between actual and expected conditions, and the prioritization of required interventions.

Media analysis in the development of an integrative learning model based on AI and digital literacy for prospective vocational teacher students involves identifying various types of media that can support effective learning, with a focus on integrating AI technology to enhance the learning experience and develop digital literacy. Media such as e-books, interactive modules, instructional videos, AI-based applications, and digital learning platforms are carefully selected to facilitate students' understanding of vocational concepts and digital literacy through text, images, videos, animations, and engaging AI-based interactions that are easy to comprehend.

Subsequently, external data analysis is conducted by examining trends in technology and AI in education to provide insights into the learning needs of prospective vocational teachers, including the identification of digital literacy skills that must be acquired and their readiness to integrate AI into learning, supported by relevant literature and studies. A cost-benefit analysis is then performed by assessing development costs such as AI-based content creation, software procurement, and user training, as well as the benefits gained by students.

Course Design Specification (CDS) includes determining learning media specifications, structuring the curriculum that integrates digital literacy and AI, and periodic management and review of the configuration cycle to ensure continued relevance. The development and implementation stage involves creating and distributing AI-based learning media through digital platforms. Finally, evaluation is carried out through the assessment of learning strategies, lesson plans, the development of evaluation instruments, and the analysis of results to determine the impact of AI-based learning on the improvement of students' skills as a basis for continuous improvement in technology-based vocational education.

2.1. Student Activities in the Research Subjects

The subjects of this study were students of the Electronics Engineering Education Study Program at the Faculty of Engineering, Universitas Negeri Makassar, in the 2025/2026 academic year. The research subjects consisted of students who had completed the Statistics course and students who were currently taking the Statistics course. In this study, student activities focused on student engagement in the Artificial Intelligence (AI)-based and digital literacy learning process, including: 1) Interaction with AI-based digital materials, such as interactive modules, simulations, and adaptive learning platforms; 2) Solving statistical problems through case studies relevant to the electronics engineering context; 3) Collaboration and online discussions using digital learning forums or applications to share solutions and analyze statistical data; 4) Self-reflection and evaluation through online quizzes and automatic feedback from AI-based systems.

These activities aimed to observe how the integration of AI and digital literacy influences students' understanding of statistical concepts and their application skills in the context of electronics engineering vocational education. The informants in this study consisted of: 1) One instructional design expert, to provide input regarding AI-based learning strategies; 2) One learning media expert, to assess the effectiveness of digital media use; 3) Two statistics experts, to validate the test instruments and learning materials.

2.2. Data Collection Techniques

Data collection in this study employed two main types of instruments, namely test and non-test tools, both of which were specifically designed and adapted for the Statistics course context. The non-test instruments comprised an interview protocol aimed at gathering qualitative insights into students' experiences with AI-supported and digital literacy-based learning, as well as a questionnaire used to assess students' perceptions regarding the effectiveness of the integrative learning model. In contrast, the test instrument consisted of a set of Statistics assessment items that had undergone expert validation. The content validity of the instrument was ensured through evaluations conducted by experts in statistics and instructional design. Furthermore, empirical validation was carried out through a pilot study involving a group of students, which confirmed that the instrument effectively measured students' statistical competencies.

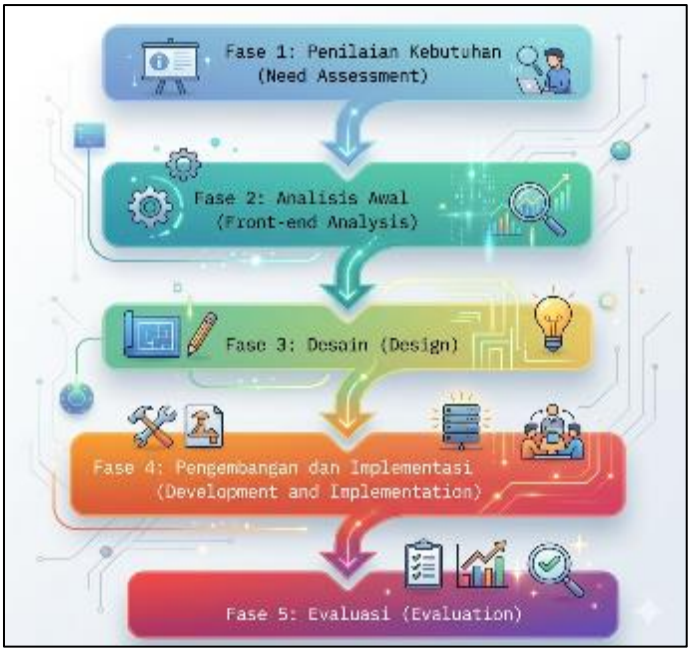

Figure 1 The Five Phases of Learning Development Process

2.3. Data Analysis Techniques

Qualitative descriptive analysis was conducted on data obtained from the input, criticism, and suggestions of the experts (instructional design expert, learning media expert, and statistics experts), as well as from the results of interviews and observations during the field trial. These qualitative data were processed through the stages of data reduction, data presentation, and conclusion drawing to revise and refine the integrative learning model based on AI and digital literacy. Quantitative descriptive analysis was performed on data collected from the feasibility assessment questionnaire completed by the experts and students during the field trial stage. This technique involved calculating the mean score, percentage, maximum score, minimum score, and standard deviation. The results of these calculations were then converted into feasibility categories (very feasible, feasible, moderately feasible, or not feasible) to determine the feasibility level of the developed model. The results of both analyses were subsequently used as the basis for revising the product, evaluating the success of the model implementation during the field trial, and providing recommendations for further improvement.

3. Research Results

The findings of this study on the development of digital-based learning materials for the Statistics course are presented in two main sections. The first section provides a detailed description of the development process, which involved the creation of an e-book and an interactive digital platform specifically designed to enhance students' comprehension of statistical concepts. These materials were developed with the primary aim of increasing learning effectiveness by offering students greater flexibility and interactivity in accessing and engaging with the content. Second, the description of the feasibility test of the digital-based learning materials development, which involves an evaluation of the quality and success of the implementation of the materials. This feasibility test was conducted through assessments by experts and students, with the aim of ensuring that the developed materials meet learning needs and can be accessed easily and effectively in achieving educational objectives.

3.1. Development of Digital-Based Learning Materials

3.1.1. Needs Assessment (Need Assessment)

Digital instructional materials for the Statistics course were designed using the stages of the Lee and Owens development model. The needs assessment stage was conducted to determine students' current level of competence in Statistics and to define the expected competencies to be achieved after the instructional process. Information on students' abilities was collected through questionnaires and interviews involving students who had already taken the Statistics course.

The results of the questionnaire revealed that students' competencies in Statistics were still relatively low. These findings were based on responses from both the students and the lecturer responsible for the course. A summary of students' competency levels prior to the development of the digital instructional materials is presented in the following table 1.

Table 1 Student Competencies in the Statistics Course in the Electronics Engineering Education Study Program, Faculty of Engineering, Universitas Negeri Makassar (FT UNM Makassar)

No	Competency	% Result 1	% Result 2	% Result 3	% Result 4
1	Determining the mean, median, and mode of data	11.5	26.9	46.2	15.4
2	Calculating variance and standard deviation	19.2	34.6	30.8	15.4
3	Drawing and interpreting bar charts, pie charts, and histograms	53.9	30.8	7.6	7.6
4	Using frequency tables and distributions	46.1	23.1	15.4	15.4
5	Calculating probability in discrete distributions	61.5	19.2	11.5	7.7
6	Calculating probability in continuous distributions	46.2	19.2	23.0	11.5
7	Using basic probability theorems	42.3	23.1	23.1	11.5
8	Calculating and interpreting simple correlation and regression	46.2	19.2	26.9	26.9
9	Determining the expected value and variance of random variables	34.6	34.6	26.9	3.85
10	Using sampling and calculating parameter estimation	53.8	19.2	15.4	11.5
11	Calculating cumulative probability	53.8	19.2	19.2	7.7
12	Using binomial and normal distributions	50.0	19.2	26.9	3.8
13	Interpreting data based on distribution curves	53.9	26.9	11.5	7.7
14	Calculating and analyzing confidence intervals	53.9	26.9	11.5	7.7
15	Testing simple hypotheses	57.7	23.1	11.5	7.7
16	Using statistical software for simple data analysis	53.8	23.1	19.2	3.9

The results presented in Table 2 indicate that students' competencies in the statistics course are still relatively low. This can be seen from the dominance of percentages in Result 1 and Result 2 categories across most competency indicators, while higher-level achievement categories (Result 3 and Result 4) tend to have significantly lower percentages. For example, competencies such as calculating probability in discrete distributions (61.5%), testing simple hypotheses (57.7%), and interpreting data based on distribution curves (53.9%) are largely concentrated in the lower achievement levels. Only a small proportion of students demonstrate higher-order competencies, as reflected in relatively low percentages in Result 4 across almost all indicators. This pattern suggests that students have not yet achieved optimal mastery, particularly in more complex statistical concepts such as regression analysis, confidence intervals, and probability distributions.

The needs assessment results provide a more detailed picture: out of the sixteen basic competencies that students must master, only two competencies are categorized as good, namely the ability to calculate measures of central tendency (mean, median, mode) and the ability to calculate variance and standard deviation. Two other competencies are categorized as moderate, namely the ability to draw and interpret diagrams as well as to use frequency tables and distributions. The remaining twelve competencies fall into the low category.

This condition underscores the need to develop an integrative learning model that utilizes artificial intelligence technology and digital literacy to improve students' statistical competencies, while also supporting their readiness as prospective vocational teachers in effectively managing learning data.

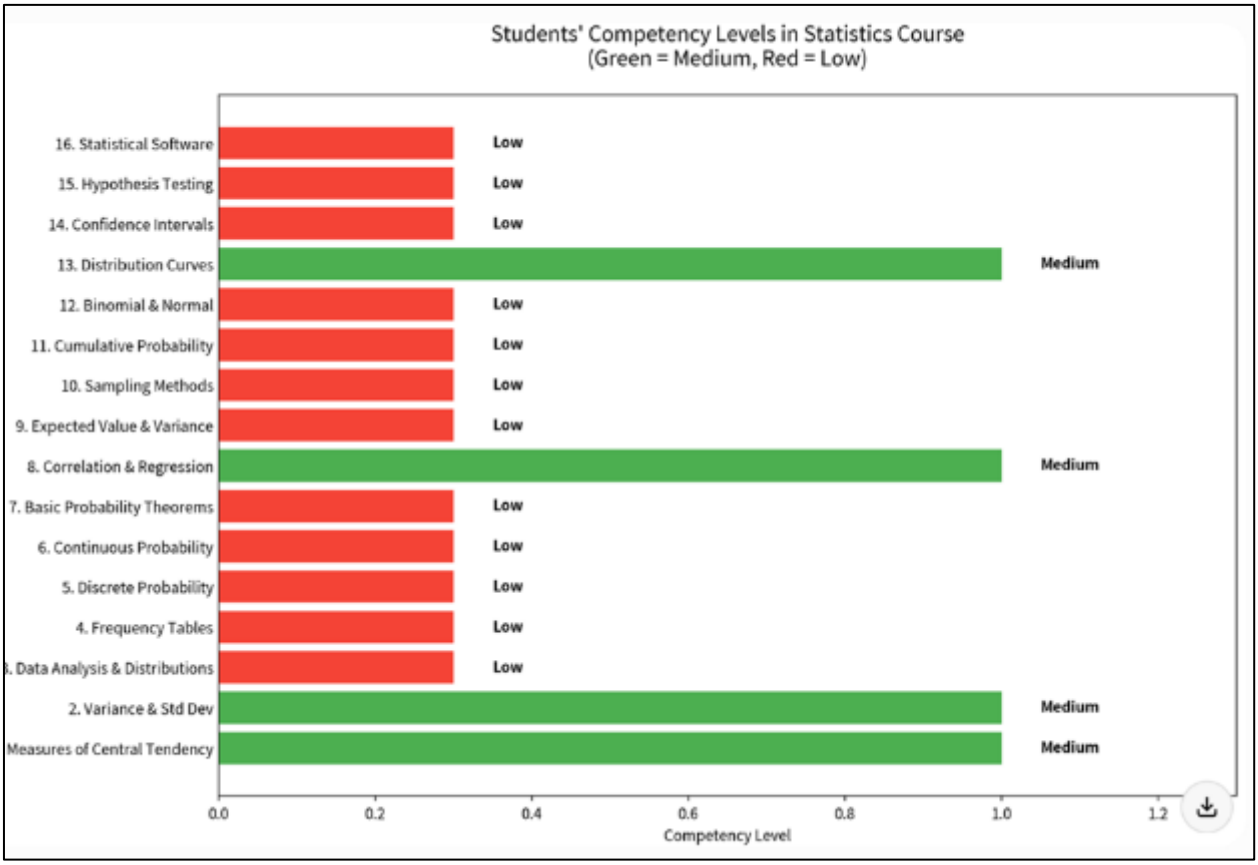

Figure 2 Graphics Students' Competency Levels in the Statistics Course

Based on the lecturer's evaluation, it was identified that among the sixteen fundamental competencies required in the Statistics course, only four competencies have been adequately mastered, whereas the remaining twelve competencies are still insufficiently developed. This finding highlights a substantial discrepancy between the students' existing competency levels and the expected learning outcomes. To address this issue, a front-end analysis was undertaken as an initial phase in the development of the instructional model. This analysis includes several key components, namely audience analysis, technology analysis, task analysis, critical incident analysis, goal analysis, and available data analysis. The primary objective of this process is to bridge the gap between the students' current competencies and the targeted competencies, while simultaneously ensuring the development of a relevant and effective instructional design.

The audience analysis was conducted to examine students' learning characteristics as well as their prior knowledge and prerequisite competencies. Based on the research findings, these student characteristics are further illustrated in the following graph.

Figure 3 Graph of Student Characteristics

The majority of students in the Electronics Engineering Education Study Program are graduates of Senior High School (SMA) and have acquired basic knowledge of statistical concepts. Nevertheless, they still encounter difficulties in understanding more complex statistical concepts. On the other hand, the students demonstrate a positive attitude and high motivation to learn Statistics. In addition, the students possess strong abilities in understanding visual information, such as graphs, as well as material presented through videos and animations. This indicates the potential for utilizing interactive and digital media in the learning strategy. Based on SIAKAD data for the 2016/2017 academic year, the pass rate for the Statistics course reached 78.18%. This figure suggests that although most students passed the course, there remains considerable room for improvement in deepening their conceptual understanding and statistical competencies.

Technology analysis was conducted to evaluate the availability of technological facilities that support the use of digital learning resources, including e-books, in Statistics instruction. The results of the analysis revealed that the Electronics Engineering Education Study Program at Universitas Negeri Makassar has a computer laboratory that can be used by students. Moreover, the majority of students also own personal computing devices, such as PCs or notebooks, and can access e-books and learning materials via smartphones.

These findings indicate that the available technological infrastructure is sufficiently adequate to support the implementation of an integrative learning model based on artificial intelligence and digital literacy. Accordingly, the learning strategy can leverage a combination of laboratory facilities, students' personal devices, and interactive digital media to enhance understanding of statistical concepts.

Task analysis was performed to break down students' work into more specific tasks and responsibilities, as well as to determine the knowledge, skills, and attitudes that need to be mastered so that students can perform their roles effectively. The process began by defining the students' position or role as prospective vocational teachers, particularly in the field of mathematics or statistics education. Subsequently, all tasks related to this role were identified, encompassing the activities that students must undertake to achieve the desired competencies. Each task was then identified and organized according to its priority and level of complexity. Thus, task analysis ensures that students have a clear understanding of their responsibilities and the steps required to achieve the learning objectives.

The expected tasks for students in this context include mastery of basic statistical concepts such as mean, median, mode, variance, and distribution. Students are expected to be able to clearly explain measures of central tendency and data variability, as well as interpret data distributions and probabilities. In addition, the ability to present and interpret information in the form of graphs and tables is also part of their responsibilities. Students must be able to apply these statistical concepts in both learning contexts and real-life cases, enabling them to solve everyday problems using appropriate statistical approaches.

The results of this task analysis provide a clear foundation for designing an integrative learning model based on artificial intelligence and digital literacy, ensuring that every student can systematically master the relevant competencies. The results of the task analysis can be visualized in the following figure:

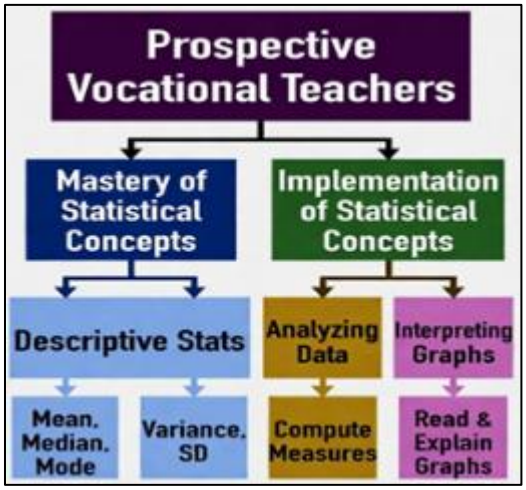

Figure 4 Statistical Concepts for Prospective Vocational Teachers

As shown in Figure 1, mastery of statistical concepts involves a solid understanding of both descriptive and inferential statistics. In descriptive statistics, students are expected to master the calculation of mean, median, mode, variance, and standard deviation to describe data as a whole. In inferential statistics, the required skills include an understanding of probability and distribution to make predictions or generalizations from sample data to the population. Furthermore, the application of statistical concepts also encompasses the ability to analyze real data, such as calculating measures of central tendency and variability, as well as performing estimations based on available data. Finally, the ability to read and interpret statistical graphs and tables is crucial for communicating information and drawing valid conclusions from the data.

3.1.2. Goals Analysis:

Specific learning objectives in instructional planning must address several essential elements. First, the domains of learning objectives — cognitive, affective, and psychomotor — need to be clearly determined, as each domain plays a vital role in developing students' competencies. Next, it is important to specify the level or degree of mastery desired within each domain, such as remembering, understanding, applying, analyzing, evaluating, or creating in the cognitive domain, along with relevant skills and attitudes in the psychomotor and affective domains. General learning objectives should then be formulated as the primary guide and further broken down into specific, measurable, and focused learning objectives that can be clearly evaluated to achieve optimal outcomes. In this study, the measured learning objective domain for the Statistics course was the cognitive domain. The cognitive levels consist of: remembering, understanding, applying, analyzing, evaluating, and creating.

Available Data Analysis (Extant Data Analysis): In the **Available Data Analysis (Extant Data Analysis)** phase, the developers examined existing instructional resources to support the design of an integrative learning model grounded in Artificial Intelligence and digital literacy. The preliminary findings indicated that lecturers had already developed teaching materials for the Statistics course; however, these resources required further adaptation and refinement to effectively align with a digital and adaptive learning environment. Consequently, the developers curated and integrated additional relevant sources to enrich the instructional content. These included statistics textbooks, interactive digital materials such as hypermedia-based e-books, and AI-supported instructional videos equipped with adaptive exercises, personalized feedback mechanisms, and learning analytics features. Collectively, these resources facilitate a more effective, engaging, and individualized learning experience, allowing students to progress according to their own learning pace..

Design Phase: The design phase involves the systematic planning of the integrative learning model based on Artificial Intelligence and digital literacy. Thorough planning is critical to the success of the learning product development process. The primary output of this phase is the Digital Learning Design Plan (DLDP). In preparing the Digital Learning Design Plan, the first step is to determine the specifications of the media and technology to be used. This includes selecting appropriate digital platforms, implementing AI features that support interaction, and incorporating interactive

elements that enhance students' digital literacy. Subsequently, the development of learning materials must include clear specifications and structure, encompassing the grouping of relevant topics, systematic linking of statistical concepts, and the integration of interactive or adaptive activities. This approach aims to facilitate personalized and collaborative learning, thereby optimizing students' conceptual understanding.

3.1.3. Design of the AI-Based Integrative Learning Model with Digital Literacy

The design of this learning model produces specifications and content structures that support interactive and adaptive learning of statistics. Based on the media analysis results, the materials for the Statistics course were designed to be accessible across various digital devices, including notebooks, personal computers (PCs), and smartphones, while ensuring compatibility with interactive content. The materials integrate text, graphics, videos, animations, and AI features such as adaptive feedback and interactive simulations. Multimedia content was created with relatively small file sizes to ensure smooth access without compromising learning quality. This approach enables students to learn flexibly (anytime and anywhere) while simultaneously developing digital literacy and the ability to utilize AI technology in statistics learning.

3.1.4. Multimedia Design in the Integrative Learning Model

Multimedia design, which includes images, animations, and videos, was aligned with learning theories and AI-based instructional strategies to enhance student understanding. Images are used to visualize statistical concepts clearly, helping students comprehend complex material. Videos provide focused instruction on data analysis processes, supplemented with AI features such as guided walkthroughs or adaptive hints that support more personalized and interactive learning. Meanwhile, animations serve to explain concepts such as area measurement, data distribution, probability, and graph interpretation in a dynamic manner. These animations also allow students to interact with the content through simulations or adaptive exercises, thereby strengthening their engagement in the learning process.

3.1.5. Content Structure of the AI-Based Integrative Learning Model with Digital Literacy

The content structure was developed in alignment with the existing curriculum and designed to support interactive and adaptive learning of statistics. The content consists of the following components:

- **Introduction** – This section includes learning objectives, an overview of the material, and guidelines for using the digital learning media.
- **Core Materials** – This component contains text, graphics, animations, videos, and interactive modules equipped with AI features, such as adaptive feedback and simulations, to facilitate personalized learning.
- **Interactive Activities** – These include exercises, quizzes, and simulations that enable students to test their understanding and receive automatic feedback.
- **Conclusion and Evaluation** – This section provides a summary of the material, learning reflections, and evaluation mechanisms to measure competency achievement as well as the development of digital literacy.

Table 2 Content Structure of the AI-Based Integrative Learning Model with Digital Literacy

No	Learning Model Component	Specifications
1	Unit	Measures of central tendency (mean, median, mode), variance and standard deviation, probability, and data distribution. The material is presented through interactive modules equipped with AI-based simulations and adaptive exercises.
2	Introduction / Digital Cover	Main display color: Denim Blue; Title: Interactive Statistics; Title color: Yellow (Segoe UI Black, font size 74); Developer name: Arial 30, Yellow color; Visual: Interactive graphs or diagrams; Orientation: Portrait; Content size: A4; Institutional logo and publisher information; Introductory page: Summary of learning objectives.
3	Front Section / Navigation	Title page, navigation buttons to the table of contents or modules, equipped with interactive instructions for students.
4	Core Materials	Each unit includes: chapter title, brief description, learning objectives, theory, sample problems, summary, interactive exercises, and AI-based adaptive evaluation.
5	Final Section	Glossary, index, answer key, digital references, and links to additional learning resources to support students' digital literacy.

3.2. Development and Implementation

The development of the integrative learning model based on Artificial Intelligence and digital literacy was carried out through several stages, including:

- Compiling learning materials based on the curriculum and instructional objectives.
- Designing interactive multimedia components, including images, animations, videos, and adaptive AI modules.
- Integrating all multimedia components and AI features into the digital learning model.
- Conducting formative evaluation to assess the effectiveness of the content and interactivity.
- Implementing the integrative learning model in the Statistics course classroom.

The materials were developed based on the learning objectives, content structure, and instructional strategies designed to support adaptive and interactive statistics learning. The content covers basic statistical concepts, data analysis principles, and relevant facts, presented through interactive multimedia modules.

The learning components include animations, videos, images, audio, and adaptive AI modules, which are integrated to support interactive learning activities, provide automatic formative feedback, and strengthen theoretical understanding. This approach simultaneously develops students' digital literacy, as they are actively engaged in navigating, evaluating, and utilizing AI technology in the learning process.

3.3. Formative Evaluation

Formative evaluation was conducted to assess the feasibility and effectiveness of the developed integrative learning model based on Artificial Intelligence (AI) and digital literacy. The evaluation process began with a one-to-one expert review involving media experts, design experts, and statistics teaching experts to assess the quality of the content, structure, and AI integration within the learning model. Subsequently, the model was evaluated with students to examine readability, interactivity, and the overall digital learning experience. This was followed by a small-group implementation to observe learning effectiveness, student interaction with the content, and the use of adaptive AI features. The final stage involved large-group implementation, aimed at evaluating acceptance, engagement, and the impact of the learning model on students' competency achievement.

This evaluation not only assessed the feasibility of the content but also examined the effectiveness of AI integration and interactive elements in supporting personalized learning, improving statistical understanding, and developing students' digital literacy.

Table 3 Evaluation conducted by experts

Validator	Component	Aspect of Evaluation	Result (%)
Media Expert	Media	Learning model display	93.3
		Module / digital content size	73.0
		Multimedia content composition	93.3
		Ease of use of interactive features	93.3
		Application / AI integration	95.5
Average			89.68
Instructional Design Expert	Learning Model Design	Formulation of learning objectives	95.0
		Material organization strategy	91.7
		Material delivery strategy & interactivity	93.8
Average			93.5
Statistics Teaching Expert	Instructional Material	Alignment of material with learning objectives	90.0
		Accuracy of statistical content	85.7
		Language use / delivery	86.0

		Material organization	97.5
		Learning assessment / evaluation	92.0
Average			90.24

The validity results presented in Table 6 indicate that the media expert evaluation yielded the following scores: learning model display (93.3%), digital module size (73%), multimedia content composition (93.3%), usability of interactive features (93.3%), and application/program/AI integration (95.5%), resulting in an overall average of 89.68%. These findings suggest that the developed model falls within the "very good" category. Furthermore, the instructional design expert assessment demonstrated high levels of validity, with scores of 95% for the formulation of learning objectives, 91.7% for the material organization strategy, and 93.8% for both material delivery strategy and interactivity, yielding an average of 93.5%. Accordingly, the learning model is classified as "very good" from an instructional design perspective. The evaluation conducted by the statistics education expert showed scores of 90% for alignment between content and learning objectives, 85.7% for the accuracy of statistical material, 86% for language clarity and delivery, 97.5% for material organization, and 92% for assessment design, with an overall average of 90.24%. These results confirm that the AI-based integrative learning model with digital literacy is categorized as "very good" as instructional material.

3.4. One-on-Individual Assessment

The one-to-one formative evaluation was conducted with three students who represented varying levels of ability, namely high, moderate, and low.. Participants were asked to review the revised version of the learning model and provide feedback through a questionnaire. The results revealed scores of 85.8% for the presentation of the learning model, 87.4% for material quality, and 96.7% for the usability of interactive features and digital navigation. With an average score of 89.9%, the model is categorized as "very good." These findings indicate that students were able to access the material easily, comprehend the content effectively, and actively engage in adaptive digital learning activities.

3.5. Small-Group Evaluation

The small-group trial involved ten students and employed questionnaires to collect data. The results showed that the average pre-test score was 42.4%, which increased to 72.8% in the post-test. This improvement indicates a substantial enhancement in students' learning outcomes following the implementation of the AI-based integrative learning model with digital literacy. The model facilitates adaptive and interactive learning, thereby promoting a deeper understanding of statistical concepts.

3.5.1. Field Trial (Large-Group Tryout)

The field trial aimed to evaluate both the effectiveness of the integrative learning model and user responses at a larger scale. The questionnaire results yielded an average score of 94.11%, which falls within the "very good" category. This reflects a highly positive student response toward the interactive and adaptive learning experience provided by the model.

4. Findings

4.1. Development and Evaluation of the AI-Based Integrative Learning Model with Digital Literacy

The high expert ratings of the integrative learning model based on AI and digital literacy in this study indicate that aspects such as display quality, module size, multimedia composition, and ease of interactive features play a crucial role in enhancing learning quality. These findings align with previous research, which states that multimodal design, readability, and cross-device accessibility are critical factors in improving students' understanding of statistical concepts and digital literacy, as reported by [33], and [34]. Furthermore, the integration of various multimedia elements — including text, graphics, video, audio, animation, and AI-based interactive features — designed according to the principles of Cognitive Theory of Multimedia Learning, has proven effective in increasing student engagement, clarifying material structure, and supporting a more personalized learning experience, as suggested by [33].

In addition, the results of this study are supported by findings that computational and interactive e-learning environments equipped with analytics and real-time interaction features can enhance collaboration, data exploration, and students' communication skills. This has implications for improving understanding of statistical concepts as well as strengthening statistical and digital literacy, as revealed by [34]. The consistency between instructional objectives,

intuitive navigation, and automatic feedback support in the AI-based system also contributes positively to the learning experience and optimization of students' knowledge acquisition process, as reported in research.

The evaluation results in this study demonstrate that students were able to access and utilize the learning materials effectively and experienced an improvement in their understanding of statistical concepts through the use of AI-based interactive modules and multimedia. These findings are consistent with research stating that AI algorithms in e-learning can personalize learning pathways, optimize engagement, and improve students' academic performance through content adaptation and data-driven adaptive feedback, as reported by Gligorea et al. [35]. In the context of statistics learning at the university level, the results of this study are also consistent with findings showing that the implementation of adaptive learning can improve learning outcomes and student satisfaction, both in face-to-face and online settings. This confirms that learning designs enriched with adaptive features are effective in supporting the mastery of statistical concepts and creating a more positive learning experience, as stated by Contrino et al. [36]. Furthermore, this study is strengthened by a systematic review indicating that the integration of machine learning techniques and multimodal analytics in adaptive learning can support real-time personalization, increase student engagement, and expand learning access. This approach not only strengthens knowledge transfer in mathematics and statistics but also contributes to the development of digital literacy through intensive interaction with digital platforms and the provision of continuous automatic feedback, as reported by Xaveria et al. [37].

4.2. Interactivity and Multimedia in the AI-Based Integrative Learning Model with Digital Literacy

The AI-based integrative learning model with digital literacy for Statistics instruction in this study receives strong support from various previous research findings. The results of this study align with investigations showing that the utilization of AI, interactive multimedia, videos, and animations can enhance conceptual understanding, motivation, and student learning achievement. This is consistent with a systematic review which states that the use of AI tools, such as machine learning-based simulations and generative language models, can deepen conceptual understanding, improve data analysis skills, and develop students' critical thinking abilities and collaborative engagement [38].

The findings of this study are also consistent with literature reviews on adaptive e-learning, which demonstrate that AI and machine learning algorithms that personalize learning pathways can optimize academic performance, increase learning retention, and enrich the learning experience in digital environments, as reported by [39]. In the context of interactive multimedia use, the results of this study are strengthened by findings showing that the integration of AI-based multimedia significantly improves conceptual understanding and student participation. This is due to the presence of interactive simulations and instant feedback, which make the learning material easier to understand and more engaging, as revealed in research by [40].

More specifically in Statistics education, the results of this study are supported by findings indicating that the development of digital modules and instructional videos as teaching materials can overcome the limitations of conventional resources. These modules were judged to be valid, adaptive, and helpful for students in understanding the material, thereby leading to improved learning outcomes, as reported by [41]. Furthermore, the effectiveness of a micro-learning approach through short animated videos also reinforces the findings of this study. This method has been proven more effective than text or comic media in enhancing the understanding of basic statistical concepts and fostering positive attitudes toward statistics learning, as demonstrated in research by [42].

5. Conclusion

This study demonstrates that the development of an integrative learning model based on Artificial Intelligence (AI) and digital literacy is both necessary and effective in enhancing the competencies of prospective vocational teachers, particularly in the context of Statistics learning. The initial findings revealed a significant gap between students' existing competencies and the expected learning outcomes, with the majority of statistical competencies still categorized at a low level. Through the systematic application of the Research and Development (R&D) approach, the resulting learning model successfully integrates AI-driven adaptive features, interactive multimedia, and digital learning resources into a coherent instructional design. The model is structured to support personalized, flexible, and engaging learning experiences, enabling students to better understand complex statistical concepts while simultaneously developing their digital and AI literacy skills. The validation results from experts in media, instructional design, and statistics education consistently indicate that the developed model is categorized as "very good," confirming its feasibility in terms of content quality, instructional design, and technological integration. Furthermore, empirical testing through one-to-one evaluation, small-group trials, and large-scale field implementation shows a significant improvement in student learning outcomes, as reflected in the increase from pre-test to post-test scores, as well as highly positive student responses toward the learning experience. These findings affirm that the integration of AI and digital literacy within an

adaptive and interactive learning framework not only enhances students' conceptual understanding but also fosters higher engagement, motivation, and independent learning. Moreover, the model contributes to preparing prospective vocational teachers with the necessary competencies to effectively utilize AI technologies in educational settings, aligning with the demands of the Industrial Revolution 4.0 and Society 5.0. In conclusion, the AI-based integrative learning model with digital literacy represents a viable and innovative solution for improving the quality of vocational education. It is recommended that future research expand the implementation of this model across different disciplines and educational contexts, as well as further explore its long-term impact on teaching effectiveness and professional competency development.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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