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EduLinkMatch: A Virtual Lab-Integrated Smart E-Learning Model for Industry 4.0 and Society 5.0

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ABSTRACT

The transformation of higher education in the Industry 4.0 and Society 5.0 eras demands an intelligent learning model capable of dynamically aligning student competencies with the needs of the digital industry. This research develops EduLinkMatch, a web-based intelligent e-learning model integrated with a virtual laboratory using Cisco Packet Tracer in physical mode. The core technical innovation lies in the Learning Analytics Engine, which continuously collects and processes performance logs from virtual laboratory activities (e.g., configuration errors, task completion status, average completion time, and topology validation results). This data is analyzed through a rule-based diagnostic mechanism and threshold-based performance indicators, which drive an adaptive feedback module that recommends remedial tasks, additional simulations, or targeted resources through a competency dashboard. This research adopts a Research and Development (R&D) approach using the ADDIE framework, focusing on the Analysis, Design, and Development phases. System trials with 150 students in the Computer Networks course and validation by 10 experts have been conducted. The results showed that all modules functioned correctly based on Black Box Testing, the success rate of student assignments reached 92%, the average completion time was 24 minutes, and student satisfaction scores ranged from 4.3 to 4.5 (Likert 1–5). Expert validation yielded an average Aiken V = 0.875 and Fleiss κ = 0.91, indicating high interrater validity and reliability. The main contribution of this study is the presentation of an integrated intelligent e-learning model that combines virtual laboratories, learning analytics, and adaptive feedback in a single system, which provides a technical blueprint for competency-based vocational learning systems in developing countries.

1. INTRODUCTION

Technological developments in the Industry 4.0 era and the transition to Society 5.0 have had a broad impact on higher education. Industry 4.0 is characterized by the integration of digital technology, artificial intelligence, big data, the Internet of Things (IoT), and cyber-physical systems into business processes, which creates new competency demands for the modern workforce [1-3]. Meanwhile, Society 5.0 emphasizes the use of technology to improve the quality of life in a humanistic manner, so that the younger generation is required to have digital literacy as well as problem-solving, creativity, and collaboration skills [4, 5].

In the context of higher education, this paradigm shift poses challenges in preparing graduates with competencies aligned with global industry needs. Various findings indicate a competency gap between learning outcomes on campus and the actual skills required by the workplace [6, 7]. In Indonesia, including at the Universitas Teknologi Akba Makassar (UNITAMA), efforts to adapt the curriculum to industry needs continue to be encouraged; industry partnerships are seen as crucial for bridging academic learning and professional practice [8].

One area severely impacted is the computer networking curriculum. Students need to understand not only theoretical concepts but also technical skills such as device configuration, topology development, and troubleshooting. Lab work is a vital component for connecting theory to practice, but its implementation is often hampered by limited hardware (routers, switches, cables), laboratory space, and maintenance costs, reducing opportunities for intensive training and suboptimal technical competency achievement [9, 10].

In response to these constraints, simulation-based virtual laboratories have become a relevant alternative. One widely used tool is Cisco Packet Tracer, which enables network design, configuration, and testing in an interactive simulation environment. The physical mode feature provides a realistic representation of the hardware, bringing the practical experience closer to real-world laboratory conditions [11, 12].

Previous empirical evidence shows that using Packet Tracer can improve understanding of network concepts and reduce reliance on physical devices [13, 14]. Another study reported that virtual labs can improve students' motivation, creativity, and technical skills [15, 16], while providing learning flexibility without space and time limits and strengthening the learning process through virtual experiments [17, 18]. In fact, the integration of intelligent e-learning and virtual labs is associated with increased critical thinking and readiness to face the challenges of Industry 4.0 [19-21].

However, most research still positions Packet Tracer as a stand-alone simulation tool. Few studies have integrated it into an intelligent e-learning framework equipped with learning analytics and a competency dashboard. Yet, an adaptive data-driven learning approach is crucial to ensuring student competency outcomes align with industry standards. Thus, there is a research gap regarding learning models that connect virtual lab simulations with adaptive e-learning systems based on intelligent technology.

Existing smart learning environments and Learning Management Systems (LMS), such as Moodle or Canvas, equipped with virtual lab plugins, typically provide content delivery, assessment tools, and limited integration with external simulators. However, in most cases, virtual labs operate as add-on activities, without tightly integrated learning analytics pipelines or competency dashboards that translate lab performance into actionable feedback for students and instructors. Furthermore, previous studies of Packet Tracer-based environments have focused primarily on conceptual understanding or motivation, rather than fully integrated architectures that combine simulation logs, analytics, and adaptive recommendations. In contrast, EduLinkMatch is designed as a natively integrated virtual lab-centric e-learning model, where network simulation activities, performance tracking, and competency monitoring are orchestrated within a unified system.

Therefore, to address this gap, this study developed EduLinkMatch, an intelligent e-learning model that integrates virtual labs based on Cisco Packet Tracer physical mode. EduLinkMatch is designed to overcome the limitations of physical laboratories while providing a flexible, efficient, and representative practicum experience. Integration with learning analytics enables monitoring of competency achievement and the provision of data-based adaptive feedback, so that student competencies can be aligned with industry needs in the Industry 4.0 and Society 5.0 eras.

Specifically, this research aims to: (1) analyze the needs of computer network practicums at UNITAMA and their challenges; (2) design an EduLinkMatch model that integrates Cisco Packet Tracer physical mode with an intelligent e-learning system; and (3) develop an initial EduLinkMatch prototype that is ready to be tested in the next implementation stage.

This research contributes not only academically, enriching the literature on developing virtual lab-based learning systems, but also practically, offering concrete solutions to address the limitations of network laboratories in higher education. The novelty of this research lies in a tightly coupled architecture that integrates Cisco Packet Tracer physical mode network simulation with a learning analytics engine that processes detailed activity logs (task status, configuration errors, completion time) and provides an adaptive competency dashboard for continuous, data-driven monitoring and feedback. This integration enables realistic configuration practices as well as adaptive feedback based on individual performance, thus strengthening the theoretical foundation of smart technology-based educational information systems and increasing readiness for institutional-scale implementation.

2. LITERATURE REVIEW

The development of the virtual laboratory concept has made a significant contribution to education, particularly in the fields of science, technology, and engineering. A virtual lab is defined as a computer-based simulation environment that replicates real-life laboratory conditions, allowing students to conduct practical work without relying on physical equipment. Accordingly, the study [22, 23] emphasizes that virtual laboratories reduce costs, expand access, and offer greater flexibility than conventional laboratories, while supporting sustainable development goals.

In practice, virtual labs enable repeatable, low-risk experiments and reduce barriers caused by infrastructure limitations. References [24, 25] showed that virtual laboratory users had better conceptual understanding and learning motivation than students who only relied on physical laboratories. In other researched [26, 27], students also reported increased motivation, problem-solving skills, and the ability to connect theory to practical applications. Because of these advantages, virtual laboratories are seen as a strategic solution for enhancing practical learning, especially in institutions with limited facilities.

In the realm of computer networking, Cisco Packet Tracer is a widely used virtual lab application. Developed by Cisco Networking Academy, this tool facilitates learning network configuration through interactive visual simulations from topology design and device configuration (routers and switches), to online testing. Its main advantage lies in its physical mode feature, which realistically represents hardware (ports, cables, connections), thus bringing the learning experience closer to real-world laboratory conditions [28, 29].

The effectiveness of Packet Tracer is also supported by empirical evidence. Allison [30] reported an increase in conceptual understanding of up to 39% in students who learned using Packet Tracer, while Chang and Liu [31] added to the increase in motivation, creativity, and technical skills. Mwansa et al. [28] emphasized that physical mode accelerates the mastery of practical skills through visualization of physical devices during configuration. In addition, in the worked [32, 33], studies have shown that Packet Tracer effectively supports problem-solving-based learning because students can explore various scenarios, detect errors, and find solutions without risk on real devices. Thus, Packet Tracer is not just a simulation tool, but a strategic tool for strengthening networking competencies.

In line with technological advances, the concept of e-learning has evolved from simply distributing content to intelligent, adaptive, data-driven e-learning. This approach leverages artificial intelligence, big data, and adaptive algorithms to personalize the learning experience [34, 35]. The system is able to adjust the level of difficulty, content, and learning pace to suit individual needs. References [36, 37] showed higher learning outcomes in adaptive systems compared to non-adaptive ones. AI integration also enables learning recommendations that align with students' learning styles [38, 39], while content adaptation helps address competency heterogeneity providing additional support for low-ability students and more complex challenges for high-ability students [40].

A key component in intelligent e-learning is learning analytics, namely the process of collecting, analyzing, and interpreting learning data to understand and optimize the learning process [41]. Its implementation is often realized through a competency dashboard that presents a visualization of student progress, strengths, and areas of improvement. In references [42, 43], studies have shown that dashboards increase learning awareness and foster metacognitive skills. In the context of vocational education, dashboards are essential for ensuring student skills align with industry needs. Fitrihana and Nurdiyanto [44] emphasized that dashboard integration in competency-based learning strengthens the link between academic achievement and practical skills.

In general, the literature shows that each component of the virtual lab [45, 46], Cisco Packet Tracer [28, 47], as well as intelligent e-learning and learning analytics [48, 49] Individually, these components have a positive impact on learning quality. However, most research still positions these components separately. Studies integrating Packet Tracer (physical mode) into an intelligent e-learning framework equipped with learning analytics and a comprehensive competency dashboard are still limited, even though this integration is crucial for aligning learning outcomes with the competencies required in the Industry 4.0 and Society 5.0 eras.

Based on this gap, this research developed EduLinkMatch, an intelligent e-learning model that integrates Cisco Packet Tracer (physical mode) with learning analytics and a competency dashboard. This model is expected to not only address the limitations of physical laboratories but also become a strategic innovation that aligns student competencies with global industry needs, while simultaneously addressing the demands of higher education in the digital era.

3. METHODS

This research uses a Research and Development (R&D) approach with the ADDIE framework because it provides a systematic and structured workflow in developing technology-based learning systems [50, 51]. The focus of this research is on three initial stages, namely Analysis, Design, and Development, while the Implementation and Evaluation stages will be carried out in further research. The resulting product is EduLinkMatch, a web-based intelligent e-learning model integrated with a virtual lab Cisco Packet Tracer physical mode. This model was developed to support computer network practicum learning at the UNITAMA while aligning student competencies with industrial demands in the Industry 4.0 and Society 5.0 eras.

3.1 Research subjects

The system trial involved 150 active students at the UNITAMA who were currently or had completed a Computer Networks course. The sample was selected using a stratified sampling technique based on study program and year to ensure representativeness [52]. In addition, 10 experts participated in the validation, consisting of 5 computer network experts (material experts) and 5 educational technology/information systems experts (media experts). A panel of at least 5–10 experts is sufficient to produce a reliable validity assessment [53, 54].

3.2 Needs analysis

The analysis phase was conducted by identifying the network laboratory's condition, interviewing the lecturer, and reviewing literature related to computer network competency standards. The analysis revealed limited physical equipment, high maintenance costs, and limited laboratory space as the main obstacles to implementing the practicum. These conditions align with the findings of the study. References [19, 55] emphasize that limited facilities are a major obstacle in vocational education. Furthermore, international literature indicates that university graduates in the Industry 4.0 era are required to possess digital skills, communication skills, problem-solving skills, and data literacy. González-Pérez and Ramírez-Montoya [56] highlight that Education 4.0 frameworks strongly emphasize 21st-century competencies such as technological literacy, creativity, collaboration, and critical thinking as key components needed to adapt to rapid industrial changes. This view is reinforced by the findings of Ahmad Tajuddin and his colleagues [57], who revealed that communication and media industry players in Malaysia are increasingly demanding graduates who are able to adapt to technology-based work environments, have good digital communication skills, and can work effectively in teams. Meanwhile, the Society 5.0 framework expands these demands by encouraging the use of advanced technology to produce solutions that are not only efficient, but also oriented towards human values and improving the quality of life of the community [58].

3.3 Model design

Pada At the design stage, the EduLinkMatch blueprint was formulated, consisting of four core components: (1) a theory module in the form of text, illustrations, and learning videos; (2) a virtual practical module using Cisco Packet Tracer physical mode to provide a realistic network configuration experience [47, 59]; (3) competency dashboard that displays student achievement progress; and (4) learning analytics that analyzes student learning patterns and provides adaptive recommendations [60]. The system architecture is designed web-based with an interface that follows the principles of user-centered design [61-63]. On the user side, students and lecturers/admins access the system through a web browser that is directed to a reverse proxy (Nginx) for SSL/TLS and traffic management. The app server manages the frontend application logic (SPA React/Vue), backend APIs (Node/Java/Python), and middleware (authentication, routing, and Packet Tracer integration). The practicum module runs on a simulation host connected to Cisco Packet Tracer physical mode. Activities, materials, and competency achievements are stored in a database (PostgreSQL/MySQL). The analytics worker processes logs through a learning analytics engine and returns adaptive recommendations.

This diagram illustrates how students access theory modules, conduct virtual practicums, monitor competency achievement through a dashboard, and receive adaptive recommendations from learning analytics. Meanwhile, lecturers or administrators manage materials, monitor activities, and conduct assessments. This visualization helps ensure that the system design aligns with user needs.

3.4 Mapping of virtual lab tasks to learning outcomes

To ensure constructive alignment, each Packet Tracer-based lab assignment in EduLinkMatch is explicitly mapped to a course learning outcome (CLO) in the Computer Networks module. For example, the "construct a simple network topology" assignment targets CLO1: Describe and implement a basic network topology; the VLAN and routing configuration assignment addresses CLO2: Configure inter-network communication using VLAN and routing protocols; and the connectivity verification assignment addresses CLO3: Diagnose and troubleshoot basic network connectivity issues. This task-outcome mapping is documented in a course design matrix and implemented in the system so that a competency dashboard can incorporate performance indicators (e.g., success rate, number of errors, completion time) at the level of each learning outcome. This design ensures that virtual lab activities are not isolated exercises, but are directly linked to the intended competency-based curriculum.

3.5 Prototype development

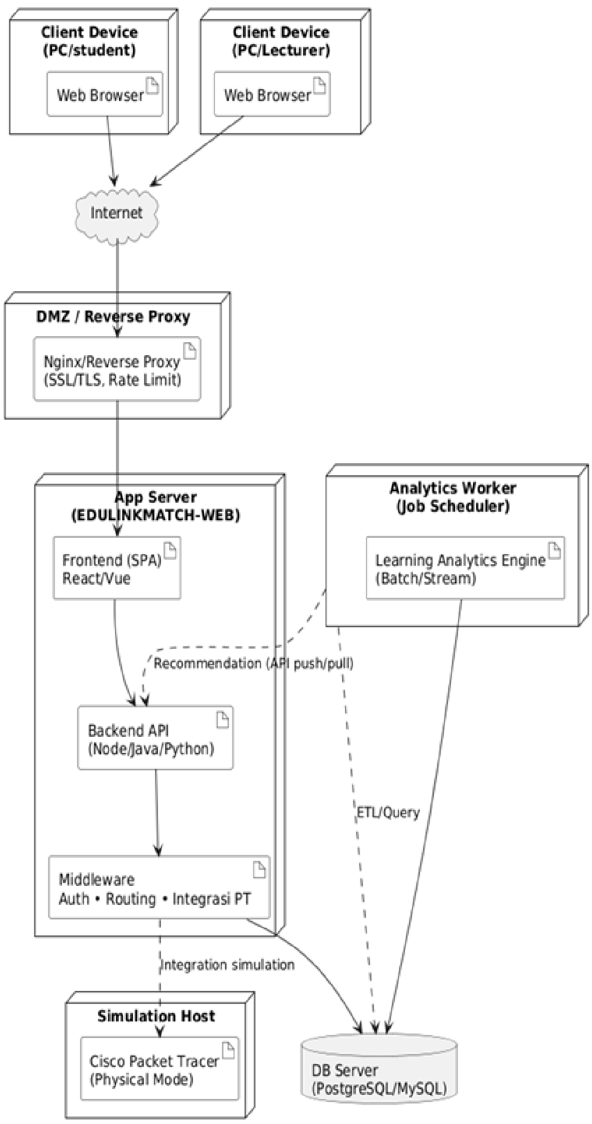

Figure 1. Overall EduLinkMatch system architecture

The EduLinkMatch prototype implements the design in Figure 1. This section focuses on the Packet Tracer integration mechanism (physical mode), the logging scheme for learning analytics, and the multimedia-based competency dashboard representation integrated with Cisco Packet Tracer physical mode for network simulation. The competency dashboard is graphical, and learning analytics features provide adaptive feedback. The prototype is then verified for functionality through Black Box Testing and evaluated through user trials and expert validation.

3.6 Black-Box validation

System testing is carried out using the Black Box Testing method which only focuses on the functional aspects of the system, without testing user performance [64-66]. Testing was conducted by the development team to verify that all modules ran according to specifications, including: accessibility of theoretical materials, execution of network simulations, accuracy of progress visualization on the dashboard, and reliability of the analysis process in learning analytics. The system testing instruments are shown in Table 1.

Table 1. Black box testing instruments

No.	Tested Modules	Test Scenario	Expected Results
1	Theory Module	Access text and video materials	The material appears without error
2	Practical Module	Network configuration simulation	Topology runs according to configuration
3	Competency Dashboard	Showing student progress	Progress data appears accurate
4	Learning Analytics	Processing student activity data	Adaptive recommendations appear

3.7 User trial

After the prototype was declared functional, a field trial was conducted involving 150 active UNITAMA students who were or had previously taken computer networking courses. The sample selection was stratified based on study program and year to increase representativeness. In the trial, students were asked to complete a series of practical tasks (e.g., building a network topology, configuring VLAN/Routing, and verifying connectivity) using EduLinkMatch. Afterward, they completed a questionnaire regarding ease of use, usability, and satisfaction with the system. Data collected included the success rate of the tasks, completion time, error frequency, and subjective student perceptions. Analysis was conducted descriptively, with the calculation of the average, median, and proportion of successes.

In addition to subjective perception data, the pilot was designed as a performance-based evaluation of practical skills, using three quantitative indicators: (1) task completion success rate, (2) average completion time, and (3) frequency of configuration errors per student. These indicators were used as proxies for practical competence in computer networking.

3.8 Validity and reliability

To assess the quality of the content and system, expert validation was conducted by 10 experts, consisting of 5 lecturers/practitioners in the field of computer networks (subject matter experts) and 5 lecturers in the field of educational technology/information systems (media experts). They assessed using a Likert scale instrument of 1–5, with indicators including: content relevance, clarity of material presentation, connection between theory and practice, system functionality, ease of navigation, and interface quality. Validation data were analyzed using Aiken's V [67, 68], with the formula Aiken's V:

$$V = \frac{\sum s}{n(c-1)}$$

where,
V = Aiken's validity index;
s = r − lo;
r = expert-given score;
lo = lowest score on the scale;
c= number of assessment categories;
n = number of experts.

The V value ranges from 0–1, with the following interpretations: V < 0.60 (less valid), 0.60 ≤ V < 0.80 (quite valid), and V ≥ 0.80 (very valid). In addition, inter-rater consistency was evaluated using Fleiss' kappa with a threshold of K ≥ 0.75 [69]. The validation instrument is presented in Table 2.

Table 2. Expert validation indicators

Rated Aspect	Assessment Indicators	Likert Scale (1–5)
Content	Relevance of material to industry standards	1–5
	Clarity of presentation of practical material	1–5
	The relationship between theory and practice	1–5
Media/System	System functionality	1–5
	Ease of interface navigation	1–5
	Visual design quality and UI consistency	1–5

3.9 Data analysis techniques

Data analysis was conducted in three stages. First, the results of Black Box Testing were analyzed descriptively based on the suitability of the system functions to the specifications. Second, student trial data (n = 150) were analyzed using descriptive statistics to describe success, completion time, and user perception. Third, expert validation data (n = 10) were calculated using Aiken's V to assess content validity, and Fleiss' kappa analysis for instrument reliability.

4. RESULT

4.1 Analysis

The analysis phase mapped the needs for computer network practicums at the UNITAMA. Observations revealed limited physical equipment such as routers, switches, and UTP cables, preventing all students from optimally practicing configurations in a single session. Interviews with lecturers also indicated relatively high maintenance costs and inadequate laboratory space. These findings are consistent with previous reports that limited practicum facilities are a significant barrier to vocational education [70].

From an industry perspective, a gap has been identified between classroom learning outcomes and the competencies required by the workplace. The industry emphasizes digital skills, data literacy, problem-solving, and the ability to adapt to new technologies [71, 72]. In line with the Society 5.0 paradigm, graduates are also expected to be able to integrate technology into humanistic solutions [3]. Thus, innovative learning media are needed that simultaneously address the limitations of physical laboratories and prepare students to face global challenges.

4.2 Design

Based on the analysis results, the design phase focused on developing the EduLinkMatch model as a technology-based learning solution. The core components include: (1) a network theory module in the form of text, illustrations, and interactive videos in accordance with multimedia learning principles; (2) a virtual practicum module based on Cisco Packet Tracer (physical mode) for a realistic network configuration simulation experience; (3) a competency dashboard to display student achievement progress in real-time; and (4) learning analytics to analyze activity data and generate adaptive learning recommendations.

The interaction model is visualized through a use-case diagram: students as the primary users who access materials, conduct lab work, and monitor progress; lecturers as facilitators who monitor achievement and provide feedback. The web-based system architecture is designed to be accessible anytime and anywhere and is integrated with the student achievement database. The user interface is developed following user-centered design principles to be simple, intuitive, and consistent.

This design is in line with previous research which emphasizes the importance of designing simulation-based learning systems to strengthen practical experiences [29-31]. The main advantage of EduLinkMatch lies in the integration of physical mode and learning analytics, a relatively unexplored approach in previous research. Thus, the design offers novelty in both the media and the approach to evaluating student achievement.

4.3 Development

The development phase resulted in a web-based EduLinkMatch prototype that integrates all components. The theoretical modules are presented in a multimedia format (text, illustrations, and videos). The practical modules are connected to Cisco Packet Tracer (physical mode) so students can configure networks visually and realistically. This feature allows for repeated practice without the risk of damaging physical devices, in line with findings that virtual laboratories can improve students' motivation and technical skills [27, 73].

The competency dashboard displays progress through interactive graphs, including the number of successful configurations, the success rate of exercises, and the average completion time. This component is enhanced by learning analytics, which logs student activity and generates adaptive recommendations based on individual performance, in line with data-driven e-learning literature [74, 75].

Next, to ensure reliability, functional testing (Black Box Testing) was conducted. The results showed that all modules operated according to specifications: theoretical materials were accessible, network simulations ran as configured, the dashboard displayed progress accurately, and learning analytics generated recommendations aligned with the data. Thus, EduLinkMatch met initial functional standards and was worthy of user testing (150 students) and expert validation. This supports the view that functional testing is a crucial step in ensuring software reliability before deployment to end users [76, 77] and in line with the recommendations for functional testing in virtual laboratories as a prerequisite for large-scale implementation [78, 79].

4.4 Student trial

The trial involved 150 UNITAMA students who were or had taken a computer networking course. Participants were asked to complete a series of practical tasks: (1) building a simple network topology, (2) configuring VLANs and routing, and (3) verifying connectivity. Afterward, students completed a questionnaire regarding the ease, usefulness, and satisfaction of learning using EduLinkMatch. A summary of the quantitative results is presented in Table 3.

Table 3 summarizes the results of the trial on 150 students. In terms of performance, the success rate of completing the practical assignments reached 92% with an average time of 24 minutes, faster than conventional practicals (±35–40 minutes). The frequency of configuration errors was relatively low (an average of 1.2 times/student). In terms of perception, students rated the system as easy to use (M = 4.3), highly useful for practicals (M = 4.4), and provided high satisfaction (M = 4.5) on a Likert scale of 1–5.

These findings indicate that EduLinkMatch is effective as an alternative practical medium. Overall, the high success rate, low error frequency, and reduced completion time provide quantitative evidence of improved practical performance, complementing subjective satisfaction measures and strengthening the rigor of the experimental evaluation. These results are in line with [32, 47] which reported the positive impact of Cisco Packet Tracer-based simulations on motivation and technical skills. A specific advantage of EduLinkMatch lies in its integration with a competency dashboard, which allows for real-time progress monitoring and encourages self-directed learning.

4.5 Expert validation

Validation involved 10 experts (5 subject matter experts; 5 media/system experts) using a Likert scale of 1–5. The Aiken's V index was used to analyze the assessments. The average Aiken's V value was 0.875, exceeding the threshold of 0.80, so all aspects were considered highly valid. Subject matter experts assessed the content as relevant to industrial computer networking competencies, clear presentation, and the link between theory and good practice. Media experts assessed the system as functional, easy to navigate, and consistent interface. These results are consistent with the findings of the study [80, 81] which emphasizes the importance of content quality and interface design for the effectiveness of virtual laboratories (see Table 4).

Based on Fleiss' kappa calculations, the inter-rater agreement, or reliability coefficient, was 0.91. This value indicates that the level of inter-rater agreement is in the very good category, indicating that the instrument used can be relied upon to consistently measure research variables. Figure 2 displays the login interface as the system's main gateway. Users select a role (student or lecturer/admin) and authenticate (email/password) while agreeing to the usage policy. Role selection determines access rights and interaction flow.

Figure 3 shows a lecturer dashboard that presents aggregated data for real-time achievement monitoring. Competency summaries (e.g., subnetting, VLAN, routing, troubleshooting) are displayed in a progress bar with measurable scores, facilitating evaluation and follow-up of learning.

The data displayed on the lecturer dashboard is generated from real student interaction records collected during the system trial, not simulated or manually generated scores, which ensures the visualization truly represents the students' practicum performance.

Figure 4 presents a student dashboard focused on individual progress. This dashboard provides a summary of individual learning outcomes, including overall progress, the number of successfully completed exercises, and the average completion time per assignment.

Table 3. Student trial results

Aspect	Indicator	Average Results	Interpretation
Task Performance	Successful completion of practical assignments	92%	Very good
	Average completion time (minutes)	24 minutes	Efficient
	Configuration error frequency (average)	1.2 times	Low
User Perception	Ease of use (Likert 1–5)	4.3	Tall
	Use of the system to support practicals	4.4	Very high
	Learning satisfaction with EduLinkMatch	4.5	Very high

Table 4. Expert validation results (Aiken's V)

Aspect	Indicator	Value	Interpretation
Content	Relevance of material to industry standards	0.87	Valid
	Clarity of presentation of practical material	0.85	Valid
	The relationship between theory and practice	0.90	Valid
Media / System	System functionality	0.88	Valid
	Ease of interface navigation	0.89	Valid
	Visual design quality & UI consistency	0.86	Valid

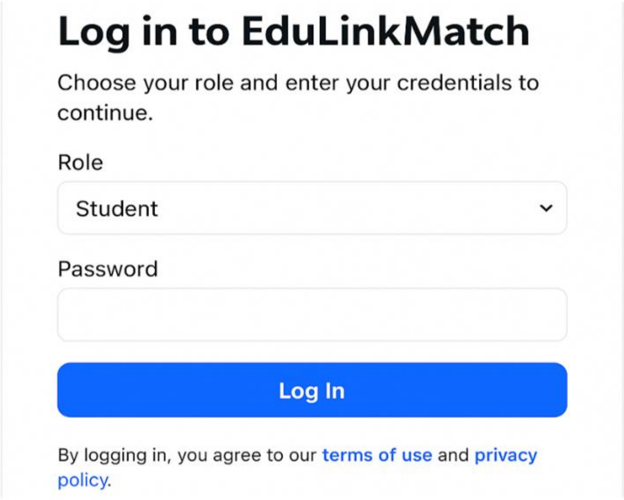

Figure 2. EduLinkMatch login display

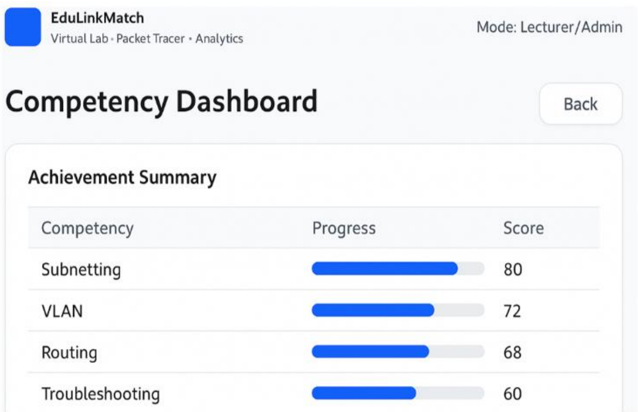

Figure 3. EduLinkMatch lecturer dashboard

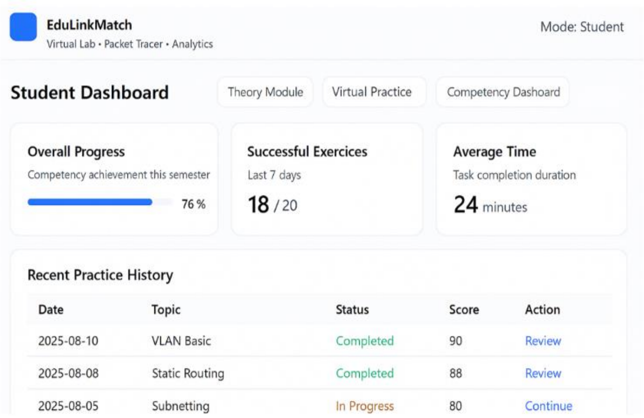

Figure 4. EduLinkMatch student dashboard

Additionally, students can view a history of their most recent practicums, complete with topics, status, scores, and follow-up actions such as review or continue. This feature helps students self-reflect on their learning outcomes while also providing motivation to improve competency in areas of weakness.

The data displayed on the lecturer dashboard is generated from real student interaction records collected during the system trial, not simulated or manually generated scores, which ensures the visualization truly represents the students' practicum performance.

5. DISCUSSION

The results of the study showed that the integration of a virtual lab based on Cisco Packet Tracer physical mode into the EduLinkMatch system was able to improve students' practical skills, with a success rate of 92%. This finding is consistent with research [32, 29], which states that using Cisco Packet Tracer improves students' motivation and technical skills. However, this research contributes further because EduLinkMatch not only provides network simulations but also integrates them with competency dashboards and learning analytics to monitor and personalize students' learning.

Expert validation yielded an average Aiken's V = 0.875, confirming that the content and system were highly valid. This result is in line with the study [19, 82, 83] which emphasizes the importance of content validity in virtual laboratory development. The difference is that this study used a multidisciplinary panel of experts (computer networks and educational technology), thus strengthening the objectivity of the validation.

The results of this study confirm that EduLinkMatch, as a web-based intelligent e-learning model that integrates a virtual lab in Cisco Packet Tracer physical mode, was successfully developed through the stages of Analysis, Design, and Development, then tested through functional testing, user testing, and expert validation. These findings provide a comprehensive overview that the system prototype is not only technically functional but also effectively improves the student learning experience.

5.1 Limitations and solutions

The analysis phase revealed limitations in physical equipment, laboratory space, and operational costs, which impacted the low intensity of student practicums. This aligns with the findings [19, 55, 70] which emphasizes that limited infrastructure is a serious obstacle in vocational education. EduLinkMatch addresses this issue by providing virtual laboratories that allow students to practice flexibly without the constraints of space and time. Thus, this system not only serves as a substitute for physical laboratories but also as an innovation that expands access to practical learning.

5.2 EduLinkMatch design

The EduLinkMatch design consists of multimedia-based theory modules, virtual practical modules with Cisco Packet Tracer physical mode, a competency dashboard, and learning analytics features. The theory modules, which present text, illustrations, and videos, align with multimedia learning principles proven to enhance student understanding. This is supported by Yan et al. [19], while Cisco Packet Tracer physical mode presents a realistic simulation of network configurations, providing an experience similar to a physical laboratory. The key innovation lies in the integration of competency dashboards and learning analytics, which enable real-time monitoring of student achievement and data-driven adaptive learning recommendations. These findings confirm that EduLinkMatch focuses not only on delivering content but also on supporting personalized and self-regulated learning.

5.3 Development and functionality verifications

The development phase resulted in a functional

EduLinkMatch prototype, as evidenced by Black Box Testing. All modules tested according to the material's accessible scenario, network simulations ran as configured, the dashboard accurately displayed progress, and learning analytics provided adaptive recommendations. These findings are consistent with the emphasis on the importance of functional testing to ensure software reliability before implementation, resulting in high-quality, well-tested, and ready-to-use software [76]. These results also support [84], which states that functional testing is an important prerequisite in the implementation of virtual laboratories.

5.4 Effectiveness of use for students

User trials with 150 students yielded positive findings. The success rate for completing lab assignments reached 92%, with an average completion time of 24 minutes, faster than conventional labs. Configuration error rates were low, and student perceptions of the system were very good (mean 4.3–4.5 for ease of use, usability, and satisfaction). These results are consistent with research [32] which shows that the use of network simulations improves student motivation and skills. However, EduLinkMatch's contribution goes further by providing a dashboard feature that strengthens student learning awareness, thus encouraging the development of sustainable, independent learning.

5.5 Expert validation: Content and media quality

Expert validation results with 10 experts showed an average Aiken's V value of 0.875, confirming that EduLinkMatch is highly valid from both content and technical aspects. Subject matter experts assessed that the content met industry standards and presented a clear connection between theory and practice. Media experts assessed that the system was functional, easy to use, and had good visual consistency. These results are in line with [80, 81] that the quality of content and interface design are important indicators in the effectiveness of virtual laboratories.

5.6 Novelty of EduLink match

In contrast to previous studies that treat virtual laboratories and learning analytics as separate components [18, 26], this study proposes an integrated architecture in which the physical mode of Packet Tracer is embedded as the core lab environment within a smart e-learning system. Technically, EduLinkMatch introduces a Learning Analytics Engine that continuously records and analyzes student actions (e.g., task completion, configuration errors, and task time) and maps them to predefined competency indicators. The resulting analytics are then visualized through a competency dashboard and used to trigger adaptive feedback in the form of remedial exercises, additional simulations, or targeted learning resources. This closed-loop path from simulation activities to analytics to adaptive interventions constitutes EduLinkMatch's key architectural and interactive innovation compared to conventional LMS-based solutions or the use of stand-alone Packet Tracer.

5.7 Theoretical and practical implications

Theoretically, this research enriches the literature on vocational e-learning by adding a new perspective in the form of integrating learning analytics and competency dashboards into a network simulation system. While previous research tends to focus on the technical aspects of simulation, EduLinkMatch combines it with analytical features to deliver adaptive, data-driven learning. Practically, this system provides a real-world solution for universities with limited physical laboratories, enabling students to practice flexibly, independently, and iteratively without relying on physical devices.

5.8 Limitations and directions for further research

Although the results of this study demonstrate the effectiveness of EduLinkMatch, there are several limitations. First, the pilot was only conducted on 150 students from a single institution, so the generalizability of the results is still limited. Second, this study only reports on three stages of ADDIE: Analysis, Design, and Development, while the Implementation and Evaluation stages will be conducted in subsequent studies. Therefore, further research is needed to involve more institutions and evaluate the long-term effectiveness of this system in improving student competency and its suitability to global industry needs.

6. CONCLUSION

This research resulted in EduLinkMatch, a web-based smart e-learning model that integrates a virtual lab in Cisco Packet Tracer physical mode with a competency dashboard and learning analytics. The development results showed that the system functioned as designed, as evidenced by functional testing using Black Box Testing. Trials on 150 students demonstrated the system's effectiveness in supporting network practicums, both in terms of configuration success, time efficiency, and user satisfaction. Validation by 10 experts through Aiken's V analysis also confirmed that the system's content and technical aspects were in the very valid category.

Thus, EduLinkMatch can be seen as an alternative solution to overcome the limitations of physical laboratories in higher education, while strengthening the achievement of student competencies according to the demands of the digital industry in the era of Industry 4.0 and Society 5.0. The main advantage of this system lies in the integration of network simulation with data-driven learning, so that EduLinkMatch not only acts as a medium for practical work, but also as an adaptive learning platform.

However, this study is still limited to a single institution and only covers the initial three stages of Analysis, Design, and Development (ADDIE). These limitations imply that the reported findings should be interpreted as preliminary evidence, rather than definitive proof of effectiveness across contexts. Therefore, future research should include multi-institutional implementation and longitudinal tracking of learning outcomes to provide stronger empirical support for the generalizability and long-term impact of EduLinkMatch. Therefore, further research is recommended involving cross-institutional samples, expanding implementation on a larger scale, and evaluating the system's impact on improving student competency and employability skills in the long term.

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