From Simulation to Pedagogy: Implementing the Haida Virtual Lab Model in Computer Network Learning

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Abstract. The advancement of digital technology and the Industry 4.0 era has transformed vocational education, especially in computer network learning. Many vocational schools (SMK) in Indonesia rely on simulation tools such as Cisco Packet Tracer, yet learning often remains procedural and teacher-centered. This study introduces the HAIDA Virtual Lab Learning Model, integrating virtual simulation, Learning Management System (LMS), and authentic digital assessment to enhance students' cognitive, technical, and reflective abilities. Developed through a Design-Based Research (DBR) approach, the model underwent expert validation and field implementation at SMK Multi Karya Medan. The HAIDA syntax: Highlight, Analyze, Integrate, Do, and Assess guides learners from conceptual exploration to reflective practice. Results indicate that the model is feasible, practical, and effective in improving network understanding, problem-solving, and collaborative learning. This study contributes theoretically by bridging simulation practice with pedagogy and practically by supporting Indonesia's *Merdeka Belajar* initiative. Unlike previous models that focus on simulation usage, HAIDA explicitly integrates reflective assessment and LMS-mediated collaboration into a structured pedagogical syntax, which has not been systematically addressed in prior vocational simulation studies.

Keywords: vocational education, virtual lab learning, HAIDA model, digital pedagogy, computer networks, reflective learning.

1 Introduction

The rapid advancement of digital technology and the transformation driven by the Fourth Industrial Revolution (Industry 4.0) have fundamentally redefined the paradigm of vocational education worldwide. Vocational learning is no longer confined to technical skill acquisition but must also cultivate higher-order competencies such as critical thinking, collaboration, adaptability, and lifelong learning to meet the demands of the evolving digital workforce [1].

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In Indonesia, Sekolah Menengah Kejuruan (SMK) plays a strategic role as the backbone of technical and vocational education, supplying skilled human resources for the industrial sector. According to the Ministry of Education, Culture, Research, and Technology, more than 14,000 SMKs operate nationwide, with approximately 5,000 focused on Information and Communication Technology (ICT), including Teknik Komputer dan Jaringan (TKJ), which is critical in the digital economy [2].

Despite these advancements, empirical studies reveal that computer network learning in vocational education still encounters substantial pedagogical and infrastructural constraints. Instructional practices are often dominated by procedural and teacher-centered approaches, reducing opportunities for active inquiry, collaborative learning, and reflective engagement. Moreover, inadequate access to laboratory facilities and networking devices limits students' hands-on experience and technical skill acquisition [3].

To address these limitations, virtual simulation tools such as Cisco Packet Tracer, GNS3, and NetSim have been widely adopted. These tools provide flexible and cost-effective environments for practicing networking skills and visualizing complex systems [4]. However, studies indicate that such tools are often used primarily as instructional media rather than being integrated into a comprehensive pedagogical framework [5]. Consequently, students may focus on completing technical procedures without engaging in authentic learning processes, critical reflection, and meaningful knowledge construction [6].

A review of recent studies (2018–2025) indicates that most innovations in vocational education primarily emphasize technological integration rather than the development of comprehensive pedagogical models. Although virtual laboratories have demonstrated positive impacts on students' conceptual understanding and practical engagement, many implementations still lack structured instructional syntax that systematically integrates simulation activities with reflective and collaborative learning processes [7]. Similarly, simulation-based learning has been shown to enhance procedural competence; however, it often provides limited support for the development of higher-order thinking skills, such as critical analysis, problem-solving, and reflective reasoning [8]. Although Learning Management Systems (LMS) have been introduced to support collaboration and feedback, their pedagogical integration remains limited [5]. These findings highlight a critical research gap: existing approaches emphasize virtual labs as tools rather than as components of a structured pedagogical model. Therefore, there is a need for a theoretically grounded framework that integrates simulation, collaboration, and reflective learning [5].

The novelty of this study lies in the development of the HAIDA Virtual Lab Learning Model, which moves beyond tool-based simulation toward a model-based pedagogical framework. Unlike prior approaches, the HAIDA model integrates virtual simulation, Learning Management Systems (LMS), and reflective assessment into a structured five-phase learning cycle: Highlight, Analyze, Integrate, Do, and Assess. This integration supports not only technical skill development but also higher-order thinking, metacognitive reflection, and collaborative learning, which are often underrepresented in existing virtual lab implementations.

In response to this gap, this study develops and validates the HAIDA Virtual Lab Learning Model using a Design-Based Research (DBR) approach [9], combining theoretical design, expert validation, and classroom implementation. The objectives of this study are to:

- Design a theoretically grounded digital learning model (HAIDA) that integrates virtual simulation, LMS, and reflective pedagogy.

- Validate the feasibility and practicality of the HAIDA model through expert judgment and pilot implementation.
- Examine the effectiveness of the model in improving students' conceptual understanding, technical performance, and reflective competence in network learning.

Theoretically, this study contributes to bridging the gap between simulation and pedagogy. Practically, it offers a scalable and replicable digital learning model aligned with Indonesia's *Merdeka Belajar* and SMK *Pusat Keunggulan* initiatives. Furthermore, this study shifts the focus from technology utilization toward pedagogical model development, addressing a critical limitation in current virtual laboratory research.

2 Method

2.1 Research Design

This study employed a Design-Based Research (DBR) approach, which integrates theory-driven design, expert validation, and iterative field testing to develop and refine educational innovations [9]. DBR was selected because it aligns with the dual objectives of this study: (1) to design a pedagogical model that addresses authentic problems in computer network learning, and (2) to validate its feasibility, practicality, and effectiveness in real educational settings.

The DBR approach is widely recognized for its capacity to bridge theory and practice through iterative cycles of design, implementation, analysis, and refinement, making it particularly suitable for developing technology-enhanced learning models in vocational education contexts [9].

The study was conducted in four main stages:

- **Preliminary Research**, identifying problems and analyzing learning needs in network learning at vocational schools (SMKs).
- **Model Design**, constructing the conceptual framework and syntactic structure of the HAIDA Virtual Lab Learning Model.
- **Model Validation and Revision**, conducting expert assessments on content, learning design, and media feasibility.
- **Implementation and Evaluation**, applying the model in classroom settings and measuring its practicality and effectiveness.

This iterative process ensured continuous refinement between theory and practice, enabling the HAIDA model to evolve into a pedagogically robust and contextually relevant framework for digital vocational learning [9].

2.2 Participants and Setting

The study was conducted at SMK Multi Karya Medan, one of the vocational schools in North Sumatra specializing in *Teknik Komputer dan Jaringan (TKJ)*. The participants consisted of:

1. Experts: three subject matter experts (computer network specialists), two instructional design experts, and one media expert for validation purposes.
2. Teachers: two network instructors teaching *Administrasi Infrastruktur Jaringan (AIJ)*.
3. Students: 60 students enrolled in the TKJ program (Grade XI).

The selection of participants used purposive sampling, considering their direct involvement in computer network learning and familiarity with simulation-based environments (Cisco Packet Tracer, LMS, etc.).

2.3 Model Development Procedure

The development of the HAIDA Virtual Lab Learning Model followed the Design-Based Research (DBR) frameworks proposed by Plomp and Reeves [9], consisting of iterative and systematic stages that integrate design, validation, and implementation processes. This approach ensures that the resulting model is both theoretically grounded and empirically tested in real educational settings [9]. The development procedure consisted of the following stages:

a) Preliminary Investigation

This stage involved a needs analysis based on classroom observations, teacher interviews, and student questionnaires. The investigation identified key issues in computer network learning, including limited access to physical laboratory facilities, teacher-centered instructional practices, and the lack of reflective digital pedagogy. These findings served as the foundation for designing a relevant and context-sensitive learning model.

b) Design and Construction

At this stage, the core components of the HAIDA model were developed, including syntax, social system, reaction principles, and support systems. The instructional syntax was structured into five sequential phases: *Highlight, Analyze, Integrate, Do,* and *Assess*, each aligned with specific learning objectives and digital learning activities. The model integrates Learning Management Systems (LMS) and Cisco Packet Tracer to facilitate simulation-based and collaborative learning environments.

c) Expert Validation

The developed model was evaluated by experts using validation instruments that assessed content relevance, instructional design, and media feasibility. The level of agreement among experts was measured using Aiken’s V coefficient [1]. A validity score of $V \geq 0.85$ was used as the threshold to indicate high validity, ensuring that the model meets academic and practical standards.

d) Prototype Testing (Pilot Study)

The initial prototype was implemented in one class ($n = 30$) to examine its practicality and usability. Data were collected through observation checklists, teacher reflective journals, and student response questionnaires. This stage aimed to identify implementation challenges and gather feedback for model refinement.

e) Field Implementation and Evaluation

The revised model was implemented in two classes involving 60 students. Students' cognitive achievement, technical skills, collaborative abilities, and reflective behaviors were evaluated through achievement tests, performance-based assessments, and classroom observations. The effectiveness of the implementation was determined by comparing pre-test and post-test outcomes to identify improvements in students' learning performance.

This multi-phase DBR process ensured that the HAIDA Virtual Lab Learning Model evolved through iterative validation, refinement, and implementation cycles. Such an approach strengthens the reliability and applicability of the model in real classroom contexts [9]. The complete research and development process is illustrated in Figure 1, which presents the integration of DBR stages with the HAIDA instructional syntax.

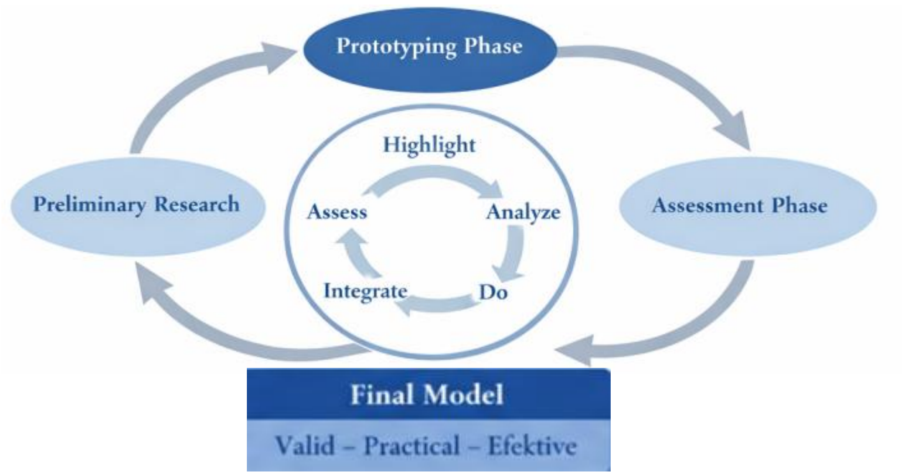

Figure 1. Research and development stages of the HAIDA Virtual Lab Learning Model based on the Design-Based Research (DBR) framework (adapted from Plomp, 2013)

2.4 Data Collection Instruments

Four instruments were developed to collect both quantitative and qualitative data as shown in Table 1.

Table 1. Data Collection Instruments and Their Purposes

Type	Instrument	Purpose
Expert Validation	Validation sheets for content, design, and media	Measure model feasibility
Practicality	Teacher & student response questionnaires	Assess usability and clarity
Effectiveness	Cognitive and performance-based tests	Evaluate learning outcomes
Qualitative	Observation sheets & interviews	Capture implementation insights

Each instrument underwent reliability testing using Cronbach's Alpha ($\alpha \geq 0.80$), ensuring internal consistency. Validity was confirmed through expert judgment and item analysis before field deployment.

2.5 Data Analysis Techniques

The data were analyzed through both quantitative and qualitative approaches:

a) **Quantitative Analysis**
Expert validation data were analyzed using *Aiken's V* to determine the validity level of each component. Effectiveness data (pre- and post-tests) were analyzed using paired-sample t-tests and N-Gain calculations to measure the improvement in student learning outcomes. Criteria for interpretation followed Hake (1999): *High (≥ 0.7)*, *Medium (0.3–0.7)*, *Low (< 0.3)*.

b) **Qualitative Analysis**
Observations and interview transcripts were analyzed using thematic coding to identify recurring patterns related to engagement, reflection, and collaboration. The analysis aimed to reveal how students' learning behavior transformed through the application of the HAIDA Virtual Lab Learning Model.

The DBR process allowed the researcher to iteratively bridge theory and practice in the context of digital vocational learning. By combining simulation-based environments (Cisco Packet Tracer), reflective tasks, and LMS-supported learning, the HAIDA Virtual Lab Model was refined into a validated and empirically tested pedagogical framework. This design approach ensured that the model was not only *technologically feasible* but also *pedagogically grounded* in the principles of constructivism, experiential learning, and socio-constructivism.

3 Results and Discussion

3.1 Results

3.1.1 Validation Result

The validation results presented in Table 2 indicate that all evaluated aspects of the HAIDA model achieved high validity scores, with Aiken's V values ranging from 0.87 to 0.91. These values exceed the commonly accepted threshold ($V \geq 0.85$), confirming that the model is conceptually sound and appropriate for implementation in vocational learning contexts. The highest score was obtained in content validity (0.91), suggesting strong alignment between the model components and the curriculum requirements of computer network learning. Meanwhile, instructional design (0.87) and media feasibility (0.88) also demonstrate that the model is structurally well-designed and supported by appropriate digital tools.

Table 2. Expert Validation Results of the HAIDA Model Feasibility

Aspect	Mean Score	Category
Content validity	0.91	Highly valid

Aspect	Mean Score	Category
Instructional design	0.87	Very valid
Media feasibility	0.88	Very valid
Average Aiken's V	0.89	Very valid

The experts also provided qualitative feedback indicating that the HAIDA model has a clear and systematic syntax consisting of five phases: Highlight, Analyze, Integrate, Do, and Assess. The model was considered appropriate for supporting computer network learning activities in vocational education.

3.1.2 Practicality

As shown in Table 3, the practicality test results indicate that the HAIDA model is highly usable in classroom settings, with an average score of 88% from teachers and 86% from students, both categorized as very practical. The highest teacher rating was observed in the "ease of use" indicator (90%), reflecting that the model is easy to implement within existing instructional practices. Similarly, students rated "clarity of syntax" highest (88%), suggesting that the structured learning phases of HAIDA are easily understood and followed. However, slightly lower scores in LMS integration (84% from students) indicate that technical factors, such as internet stability or platform familiarity, may influence user experience. Despite this, the overall findings demonstrate that the HAIDA model is practical, user-friendly, and adaptable to vocational learning environments. These results confirm that the integration of structured pedagogy with digital tools can enhance usability without increasing instructional complexity.

Table 3. Practicality Test Results of the HAIDA Model Based on Teacher and Student Responses

Indicators	Teacher (%)	Student (%)
Ease of use	90	85
Clarity of syntax	87	88
LMS integration	89	84
Reflection and feedback	86	87
Collaboration support	88	86
Average Practicality	88%	86%

Qualitative feedback from teachers indicated that the HAIDA model helped organize digital learning activities more systematically. Students reported that the learning phases supported independent exploration, collaboration, and reflection during the learning process.

3.1.3 Effectiveness

The effectiveness results presented in Table 4 demonstrate a significant improvement in student learning outcomes after the implementation of the HAIDA model. Cognitive achievement increased from a pre-test mean of 62.4 to a post-test mean of 84.5, with an N-Gain score of 0.68 (medium–high category). Similarly, practical performance showed a substantial improvement (N-Gain = 0.71), indicating that the model effectively enhances students' hands-on technical skills. Reflective competence also improved (N-Gain = 0.67), suggesting that the model supports not only procedural learning but also higher-order thinking skills.

Table 4. Effectiveness Test Results of the HAIDA Model on Student Learning Outcomes

Variable	Pre-test Mean	Post-test Mean	N-Gain	Category
Cognitive achievement	62.4	84.5	0.68	Medium–High
Practical performance	65.1	87.2	0.71	High
Reflective competence	58.7	82.3	0.67	Medium–High

The paired-sample t-test results ($t = 8.45$, $p < 0.001$) further confirm that these improvements are statistically significant. This indicates that the HAIDA model has a meaningful impact on both conceptual understanding and practical application in computer networking. Overall, these findings suggest that the integration of structured learning phases, virtual simulation, and reflective activities contributes to more comprehensive and effective learning outcomes. The results of the paired-sample t-test ($p < 0.05$) indicated a statistically significant difference between pre-test and post-test scores. Qualitative observations showed increased student engagement in collaborative activities, particularly during the Integrate and Do phases. Students were observed working in teams to solve network configuration problems and documenting their learning processes through the LMS.

3.2 Discussion

3.2.1 Reflection on Model Implementation

The integration of Learning Management Systems (LMS), virtual laboratories, and reflective pedagogy created a more transformative learning environment. The findings indicate that students not only developed technical skills in network configuration but also demonstrated improved reflective thinking through digital journals and peer evaluation activities. These results support prior studies emphasizing that technology-enhanced learning environments can foster both cognitive and metacognitive development when supported by appropriate pedagogical structures [9].

Several pedagogical strengths of the HAIDA model were identified. First, the model provides a systematic learning flow, where the HAIDA syntax (*Highlight–Analyze–Integrate–Do–Assess*) structures the learning process from conceptual understanding to reflective evaluation. Second, the model promotes collaborative and self-regulated learning, as students engage in group problem-solving while monitoring their individual progress through the LMS, aligning with socio-constructivist learning principles [10]. Third, the use of authentic assessment enables students to work on real-world digital tasks, consistent with the principles of authentic vocational learning [11].

Despite these strengths, several challenges emerged during implementation. Limited internet connectivity occasionally disrupted LMS access, while variations in teachers' digital competence affected the consistency of instructional delivery. These constraints highlight the importance of institutional support, particularly in terms of infrastructure development and teacher capacity building, to ensure the sustainable implementation of digital learning models in vocational education. Previous studies on digital learning adoption in vocational contexts have similarly emphasized the need for adequate technological resources, pedagogical readiness, and continuous professional development [12].

From a theoretical perspective, the HAIDA model reflects a progressive cognitive learning process grounded in established learning theories. The *Highlight* phase aligns with Bruner's constructivist approach in activating prior knowledge [13], the *Do* phase reflects Kolb's experiential learning cycle through hands-on practice [14], and the *Assess* phase corresponds to Vygotsky's concept of guided reflection within the Zone of Proximal Development [10]. This integration demonstrates how the HAIDA model connects conceptual understanding, experiential learning, and reflective practice within a coherent instructional framework.

The overall structure of the HAIDA Virtual Lab Learning Model is illustrated in Figure 2.

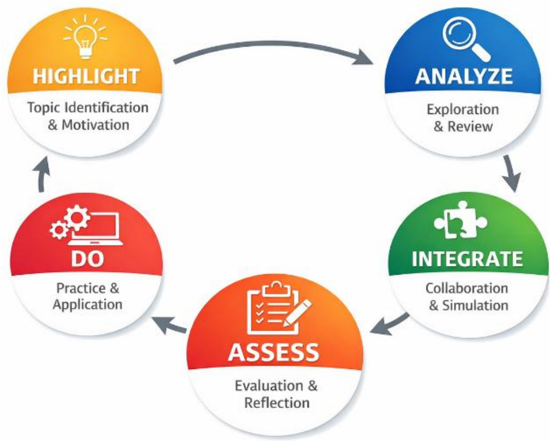

Figure 2. The HAIDA Virtual Lab Learning Model integrates constructivist, experiential, and socio-constructivist principles into five cyclical learning phases: Highlight, Analyze, Integrate, Do, and Assess. Each phase is supported by a digital ecosystem (LMS, virtual lab, and authentic assessment) that enables reflective and collaborative learning in vocational education contexts.

Figure 2 shows that the learning process begins with the Highlight phase to activate prior knowledge, followed by Analyze for collaborative problem identification. The Integrate phase links theoretical understanding with simulation-based practice, while the Do phase emphasizes hands-on experimentation. Finally, the Assess phase facilitates reflection and peer feedback. The cyclical relationship among these phases supports continuous knowledge construction, while the LMS and virtual laboratory function as digital scaffolding throughout the learning process.

3.2.2 Comparative Discussion with Prior Studies

This study advances previous research by shifting the focus from tool-based simulation to model-based pedagogy. Earlier studies demonstrated that virtual simulation tools such as Cisco Packet Tracer improve students' procedural and conceptual understanding [4]. However, these studies primarily emphasized task execution rather than the underlying cognitive and reflective processes. In contrast, the HAIDA model embeds simulation within a structured pedagogical framework that integrates cognitive activation, collaborative problem-solving, and reflective assessment.

In particular, the Integrate and Assess phases incorporate structured reflective practices that are frequently underrepresented in conventional simulation-based learning approaches. Previous studies have indicated that reflection within digital laboratory environments is often limited and relies heavily on teacher guidance [15]. By embedding reflection systematically into the instructional cycle, the HAIDA model facilitates deeper metacognitive engagement and promotes greater learner autonomy.

Furthermore, this study supports and extends recent research highlighting that effective digital learning requires not only technological tools but also clearly defined pedagogical structures [5]. While prior studies have explored the integration of Learning Management Systems (LMS) and simulation tools, their implementation often remains fragmented and lacks instructional coherence. The HAIDA model addresses this gap by systematically integrating simulation, LMS-based interaction, and reflective activities into a unified and cyclical learning process.

Empirical observations during implementation further reinforce these findings. Initially, students tended to follow procedural steps without conceptual reasoning, consistent with earlier reports in simulation-based vocational learning [4]. However, during the *Integrate* and *Do* phases, students began engaging in collaborative problem-solving and conceptual discussions. For instance, students were able to identify and correct network configuration errors, such as subnetting issues, through peer interaction and LMS-supported reflection. Their reflective outputs evolved from descriptive accounts to analytical explanations, indicating the development of metacognitive awareness.

These findings align with the social constructivist perspective, which emphasizes that knowledge is constructed through social interaction and guided reflection [10]. Additionally, the structured sequence of the HAIDA model supports not only technical skill acquisition but also the development of self-regulated learning, which is essential in digital and vocational education contexts [4].

Overall, the HAIDA Virtual Lab Learning Model not only confirms the effectiveness of virtual simulation for skill development but also extends existing literature by demonstrating that pedagogical structure plays a critical role in fostering higher-order thinking, metacognitive skills, and reflective learning in vocational education.

3.2.3 Limitations

Despite the positive outcomes of the HAIDA Virtual Lab Learning Model, several limitations should be acknowledged.

First, this study was conducted in a single vocational school (SMK Multi Karya Medan) with a relatively limited sample size (n = 60), which may restrict the generalizability of the findings. Future research is therefore recommended to involve multiple institutions with diverse characteristics to enhance external validity and broader applicability.

Second, the implementation of the HAIDA model depended on stable internet connectivity and adequate digital infrastructure. Occasional connectivity issues during LMS access and simulation activities may have influenced student engagement and learning continuity. This suggests that infrastructure readiness remains a critical factor in the successful adoption of digital learning models in vocational education contexts.

Third, teacher readiness was identified as an important factor affecting implementation. Variations in digital literacy and pedagogical adaptation influenced the consistency of instructional delivery, indicating the need for targeted professional development programs to support teachers in integrating digital pedagogy effectively.

Finally, this study did not examine long-term learning retention or the transferability of skills beyond the instructional setting. Future studies are encouraged to explore the long-term impact of the HAIDA model on student performance, employability, and real-world problem-solving abilities.

In addition, the absence of a control group limits the ability to draw strong causal inferences regarding the effectiveness of the model. Future research should consider employing experimental or quasi-experimental designs with comparison groups to strengthen internal validity and provide more robust evidence of effectiveness.

Overall, these limitations provide important directions for future research and highlight key considerations for the broader implementation of the HAIDA Virtual Lab Learning Model in vocational education.

3.2.4 Theoretical and Practical Implications

From a theoretical perspective, the HAIDA Virtual Lab Learning Model contributes to the development of digital pedagogy in vocational education by integrating constructivist, experiential, and socio-constructivist learning principles into a unified framework [10]. The five learning phases (Highlight, Analyze, Integrate, Do, and Assess) represent a structured cognitive cycle that connects knowledge activation, experiential learning, and reflective practice. This model extends existing simulation-based learning approaches by demonstrating how pedagogical structure can facilitate higher-order thinking and reflective competencies [5].

From a practical perspective, the HAIDA model offers a scalable and adaptable framework for vocational schools seeking to transition from teacher-centered instruction to student-centered digital learning environments. The model can be implemented through three main components: (1) virtual simulation tools such as Cisco Packet Tracer, (2) a Learning Management System (LMS) to facilitate collaboration and reflective activities, and (3) a structured instructional sequence based on the HAIDA syntax [5].

In addition, the model aligns with national educational initiatives such as *Merdeka Belajar* and SMK Pusat Keunggulan, supporting the development of adaptive and technology-enhanced learning environments [2]. Its implementation can inform curriculum design by integrating simulation-based practice with reflective digital assessment [5].

In the long term, the HAIDA model provides a foundation for the integration of learning analytics, where data generated from LMS interactions and virtual laboratory activities can be utilized to support instructional decision-making and personalized learning in vocational education.

4. Conclusion

The HAIDA Virtual Lab Learning Model effectively bridges the gap between simulation-based practice and digital pedagogy in vocational education. Validation and field implementation confirm that the model is feasible, practical, and effective in enhancing students' conceptual understanding, technical proficiency, and reflective learning skills in computer network courses. Its five integrated phases: Highlight, Analyze, Integrate, Do, and Assess provide a coherent instructional framework that supports the development of critical thinking, collaboration, and authentic assessment in digital learning environments. The model contributes theoretically by extending constructivist and experiential learning frameworks into virtual learning contexts, and practically by offering a scalable digital pedagogy aligned with Indonesia's Merdeka Belajar and SMK Pusat Keunggulan initiatives. Overall, the HAIDA Virtual Lab Learning Model represents a strategic shift from simulation as a tool toward simulation as a structured pedagogical model for the digital transformation of vocational education. Furthermore, this model has strong potential for broader implementation in diverse vocational and technical education settings beyond Indonesia, particularly in resource-limited environments.

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