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Development and Validation of the Integrated Inquiry Blended Learning (IIBL) Model Supported by Smart Learning to Support 21st-Century Skills in Vocational Engineering Education: A Design-Based Research Study

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ABSTRACT

Background. The learning process in vocational engineering electronics still faces challenges such as low student literacy, limited face-to-face learning time, and the need for experiment-based instruction. Previous studies have generally examined inquiry-based learning, blended learning, and digital learning separately, with limited integration into a structured Smart Learning–supported instructional model. Smart Learning facilitates digital resources, online discussions, assignment management, and flexible blended learning activities.

Purpose. This study aims to develop and validate the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning in vocational engineering education.

Method. A Design-Based Research approach was employed through iterative processes of analysis, design, development, implementation, and evaluation, including expert validation, practicality testing, and effectiveness testing. Validation instruments were analyzed using SEM-PLS to ensure construct validity, while practicality was measured through student and lecturer perception surveys. Effectiveness was evaluated across three implementation cycles through analyses of cognitive, psychomotor, affective, and 21st-century skills, supported by paired sample t-tests comparing pre- and post-test scores in control and experimental groups.

Results. The IIBL model was construct-valid, with outer loadings above 0.70, AVE above 0.50, CR above 0.70, and HTMT below 0.90. Practicality evaluations by lecturers and students reached a very high category, while effectiveness testing showed significant improvements in students' cognitive, psychomotor, affective, and 21st-century skills.

Conclusion. The developed IIBL model provides a validated instructional framework integrating inquiry-based learning, blended learning, and Smart Learning support, contributing a structured IIBL syntax empirically validated through SEM-PLS and demonstrating potential to enhance students' engagement, practical competencies, and 21st-century skills.

KEYWORDS

21st Century Skills, Engineering Education, Smart Learning, Vocational Education, Integrated Inquiry Blended Learning (IIBL)

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INTRODUCTION

The Fourth Industrial Revolution has brought significant transformations across various sectors of life, including education. In this era, higher education is expected not only to produce graduates with strong theoretical knowledge but also to equip them with 21st-century competencies such as critical thinking, collaboration, digital literacy, effective communication, adaptability, and lifelong learning (Saihi et al., 2024). In the context of engineering and vocational education, these challenges are even more complex, as students must be able to integrate cognitive, affective, and psychomotor domains to meet the demands of an increasingly dynamic workforce. However, the current reality shows that the learning process, particularly in electronics, still faces several challenges. Students demonstrate low levels of literacy, limited participation in online learning, and inadequate mastery of basic concepts (Maloney et al., 2022). Meanwhile, the existing Learning Management System (LMS) has not been able to effectively manage learning interactions, particularly in monitoring students' activities in real time (Furqon et al., 2023). These limitations have resulted in low learning achievement and hindered the development of essential 21st-century competencies, including critical thinking, collaboration, communication, creativity, and digital literacy.

Various learning models, such as inquiry learning, blended learning, and project-based learning, have been widely implemented in engineering education. Nevertheless, previous studies have generally applied these approaches separately and have rarely integrated inquiry learning syntax, blended learning activities, and Smart Learning support into a single structured instructional framework empirically validated in vocational engineering education contexts (Park & Doo, 2024; Shakeel et al., 2023). Previous studies have also rarely conducted syntax validation of learning models using Structural Equation Modeling (SEM) approaches such as SEM-PLS, nor have they examined the contribution of each syntax stage to students' readiness for the challenges of the Fourth Industrial Revolution. Recent systematic reviews further highlighted that although blended learning models in higher education have evolved, few studies have systematically validated both their pedagogical structure and technological integration, particularly in engineering education contexts (Dewi et al., 2024; McCarthy & Palmer, 2023).

To address this gap, the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning was developed. The model consists of five structured learning syntaxes supported by digital resources such as e-books, animated videos, automated notifications, discussion forums, online assignment submission, and interactive chatbot assistance to support students during independent and blended learning activities (Saihi et al., 2024). The platform also enables lecturers to monitor student participation and learning progress throughout the learning process. The IIBL model not only combines the strengths of inquiry and blended learning but also integrates interactive digital learning features to support guided and independent student engagement. Therefore, this study aims to develop and validate the IIBL model supported by Smart Learning in vocational engineering education through a Design-Based Research (DBR) approach (Van Zyl & Karsten, 2022; Wei et al., 2023).

The Smart Learning platform was designed as a solution to the limitations of the Moodle-based LMS at Universitas Negeri Padang. The platform integrates automated notifications, online assessments, communication tools, and interactive chatbot assistance to support both online and face-to-face learning activities while facilitating assignment management, learning flexibility, and monitoring of student participation during blended learning processes (Basri et al., 2025; Regmi et al., 2024). The Smart Learning platform was designed to address limitations of conventional LMS usage in vocational education. The platform supports adaptive and interactive learning through features such as online assessments, real-time monitoring, automated notifications, and communication tools that facilitate both online and face-to-face learning activities (Basri et al., 2025) highlighted that smart learning supports personalized learning experiences.

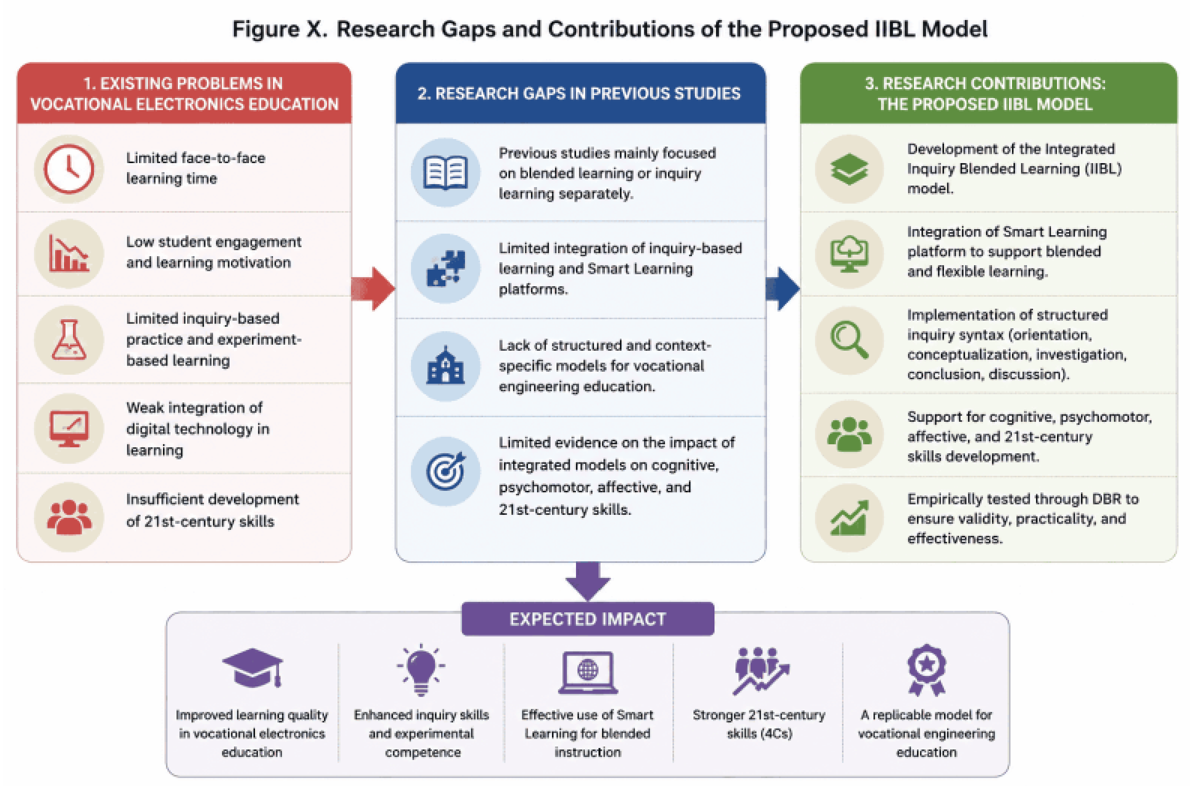

Figure 1. Research Gaps and Contributions of the Proposed IIBL Model

Digital technologies play a crucial role in strengthening inquiry-based learning through interactivity and adaptivity. A meta-review also reported that 86% of studies demonstrated positive effects of adaptive learning systems on student achievement (Geeta, 2025). In vocational education contexts, the sustainability of innovative digital learning platforms is influenced by factors such as usability, well-being, and functional value (Mehta et al., 2021; Rodríguez & Pulido-Montes, 2022). These insights emphasize the importance of designing user-centered platforms such as Smart Learning to optimize student engagement and learning outcomes. According to (Park & Doo, 2024), smart learning ecosystems are characterized by adaptivity, interactivity, and data-driven personalization, which support students' autonomy and engagement key components also embedded within the IIBL design.

The Integrated Inquiry Blended Learning (IIBL) model was developed by integrating inquiry-based learning and blended learning into five systematic learning syntaxes. The model is designed to promote active student engagement through problem exploration, experimentation, data analysis, and reflection activities, supported by the Smart Learning platform as an adaptive and interactive digital tool (Ahmed et al., 2022; Hussain et al., 2023; Santosa et al., 2025). Inquiry-Based Learning (IBL) emphasizes students' active involvement in the process of knowledge construction through exploration, question formulation, experimentation, data analysis, and conclusion drawing. According to (Pedaste et al., 2015), IBL typically consists of five stages: orientation, conceptualization, investigation, conclusion, and discussion. In engineering and vocational education contexts, inquiry-based approaches are highly relevant because students are required to understand and validate theoretical concepts through practical laboratory activities. Recent evidence by (Corral-Barraza et al., 2024) demonstrated that applying IBL in electronics engineering classrooms enhanced students' motivation and conceptual understanding in designing technological solutions. This finding highlights the effectiveness of IBL in fostering critical and analytical thinking skills in technical education.

The IIBL model was developed to address challenges in engineering education, particularly in electronics, which requires students not only to understand theoretical concepts but also to validate them through experimentation. While inquiry learning provides a scientific framework, laboratory implementation often faces barriers such as students' low literacy, limited face-to-face time, and inadequate data analysis skills. Previous research (Hussain et al., 2023) confirmed that Inquiry-Based Blended Learning (IIBL) modules positively impacted students' academic achievement in electronics, indicating the effectiveness of integrating inquiry and blended learning (Santosa et al., 2025). As (Kintu et al., 2017; Leif et al., 2021) emphasized, grounded instructional design in STEM education requires iterative alignment between inquiry activities and digital tools, ensuring that online and laboratory experiences are mutually reinforcing.

The IIBL model was designed to support active student engagement through exploration, experimentation, data analysis, reflection, and collaborative learning activities. By integrating inquiry-based learning with blended learning environments, the model is expected to enhance higher-order thinking skills and support the development of 21st-century competencies in vocational electronics education. Therefore, this study aims to develop and validate the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning in vocational engineering education using a Design-Based Research (DBR) approach. The findings are expected to contribute both theoretically and practically to the development of technology-enhanced learning models in vocational and engineering education.

RESEARCH METHODOLOGY

This study employed a Design-Based Research (DBR) approach with the aim of developing and testing the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning in a systematic, iterative, and contextually grounded manner (Van Zyl & Karsten, 2022; Wang & Hannafin, 2004). DBR was considered appropriate because it enables the integration of educational theory with real classroom practice while generating innovative solutions to challenges in technical education. Furthermore, DBR supports model development through iterative cycles that involve continuous design, implementation, evaluation, and revision. DBR is a systematic yet flexible methodology conducted through problem analysis, the design and development of theory-driven solutions, real-world implementation, and subsequent evaluation and reflection. The concept of DBR was first introduced by Brown and Collins at 1992 under the term design experiments, emphasizing the importance of testing educational innovations directly in authentic learning environments as part of developing practical learning theories. This framework was further elaborated as a research methodology for technology-enhanced educational innovation (Cheng, 2024). The present study followed a DBR framework consisting of problem analysis and literature review, design and development of the initial model, expert validation and revision, and model implementation stages (Reeves, 2021).

Problem Analysis and Literature Review

The initial stage involved identifying instructional problems in the Electricity and Electronics course, particularly students' low literacy levels, limited laboratory practice time, and lack of structured guidance in independent learning. This analysis was reinforced by a review of relevant learning models, including Inquiry-Based Learning and Blended Learning, as well as the integration of digital learning technologies.

Design and Development of the Initial Model

Based on the analysis and theoretical review, the researcher developed an initial design of the IIBL model. The design consisted of five structured learning syntaxes, instructional materials (modules, e-books, animated videos), and the development of the Smart Learning platform as a digital support tool. The initial draft of the model and its supporting resources were subsequently validated by subject matter experts.

Expert Validation and Model Revision

The developed IIBL model was validated by eight (8) experts from diverse academic and professional backgrounds. An instructional design expert provided feedback on the coherence and flow of the syntaxes to ensure alignment with constructivist pedagogical principles. A technical/electronics content expert verified that the learning materials and resources met disciplinary standards and reflected the characteristics of engineering courses. A methodology expert evaluated the research design and procedures for academic rigor and logical soundness. A language expert reviewed the clarity and readability of instructional texts. A media expert assessed the visual quality, interactivity, and effectiveness of the digital learning media used. In addition, an industry representative was involved to ensure the model's relevance to 21st-century workplace skills, thereby aligning academic validity with practical applicability.

Table 1. Profiles and Roles of Expert Validators

No	Expert Category	Number of Experts	Qualification/Expertise	Role in Validation
1	Instructional Design Experts	2	Experts in instructional design and learning model development	Evaluated the coherence of learning syntax and constructivist pedagogical alignment
2	Electronics Content Experts	2	Lecturers in Electrical and Electronics Engineering	Assessed the suitability and accuracy of technical learning materials
3	Research Methodology Expert	1	Specialist in educational research methodology	Evaluated the rigor and consistency of the research design
4	Language Expert	1	Expert in academic and instructional language	Reviewed clarity, readability, and language accuracy
5	Learning Media Experts	2	Specialists in digital learning media and educational technology	Evaluated media quality, interactivity, and effectiveness of Smart Learning integration

The validation process addressed three main aspects: the syntax structure of the model, the feasibility of instructional resources, and the appropriateness of Smart Learning platform integration. The validation results served as the basis for revising and refining the model to make it more robust, contextual, and applicable in technical education. Construct validity of the IIBL model was further examined using SEM-PLS through the following indicators, Convergent validity based on factor loadings and Average Variance Extracted (AVE), Construct reliability assessed through Composite Reliability (CR), and Discriminant validity determined using the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) Ratio.

Limited Implementation and Practicality Testing

This preliminary stage was conducted to assess the technical readiness and functionality of the model prior to full practicality testing. The activity involved five (5) lecturers and 15 students from engineering programs selected using purposive convenience sampling based on participant availability and field relevance to vocational engineering education. This sampling approach was considered appropriate for the preliminary implementation stage because the study focused on evaluating the feasibility and practicality of the model in a real instructional context rather than generating broadly generalizable findings.

The evaluation focused on the clarity of the model syntax, ease of use of instructional resources (such as videos and e-books), effectiveness of technological features, and integration with day-to-day learning activities. The analysis indicated that the IIBL model demonstrated strong potential for practical application, though certain improvements were suggested regarding digital interaction and efficiency of group reflection time. This stage was not intended to generate generalizable findings but rather to identify technical aspects requiring refinement and to provide a foundation for model improvement prior to formal practicality testing. Subsequently, the practicality test was conducted with five lecturers of the Electricity and Electronics course and 15 students from the Department of Automotive Engineering. The results of the practicality testing are presented in Table 2 (lecturer evaluation) and Table 3 (student evaluation).

Table 2. Practicality test results of the IIBL model for lecturers

Assessment Aspect	Indicator/Item	N	Mean	TCR Percentage	Remark
Attractiveness	ADT1	5	4.40	88%	Highly Practical
	ADT2	5	4.20	84%	Highly Practical
	ADT3	5	4.00	80%	Highly Practical
	ADT4	5	4.00	80%	Highly Practical
	ADT5	5	4.40	88%	Highly Practical
Ease of Implementation	AKI1	5	4.20	84%	Highly Practical
	AKI2	5	4.40	88%	Highly Practical
	AKI3	5	4.20	84%	Highly Practical
	AKI4	5	4.00	80%	Highly Practical
	AKI5	5	4.40	88%	Highly Practical
Functionality and Usefulness	AKK1	5	4.00	80%	Highly Practical
	AKK2	5	4.20	84%	Highly Practical
	AKK3	5	4.40	88%	Highly Practical
	AKK4	5	4.80	96%	Highly Practical
	AKK5	5	4.60	92%	Highly Practical
	AKK6	5	4.40	88%	Highly Practical
	AKK7	5	4.60	92%	Highly Practical
Time Effectiveness	EPW1	5	4.40	88%	Highly Practical
	EPW2	5	4.00	80%	Highly Practical
	EPW3	5	4.00	80%	Highly Practical
	EPW4	5	4.20	84%	Highly Practical
	EPW5	5	4.40	88%	Highly Practical

As presented in Table 2, the practicality test of the IIBL model involving five lecturers of the Electricity and Electronics course yielded highly positive results. The evaluation was conducted across four major aspects comprising 21 indicators. For the attractiveness aspect, all five indicators (ADT1–ADT5) achieved mean scores ranging from 4.00 to 4.40 with TCR percentages between 80% and 88%, all categorized as highly practical. The ease of implementation aspect showed consistent results, with mean scores of 4.00–4.40 and TCR values of 80–88% across all five indicators (AKI1–AKI5). The functionality and usefulness aspect received the highest ratings among all aspects. The seven indicators (AKK1–AKK7) recorded mean scores of 4.00–4.80 with TCR percentages between 80% and 96%. Indicator AKK4 obtained the highest score of 4.80 (96%), followed by AKK5 and AKK7 with scores of 4.60 (92%). Finally, the time effectiveness aspect, represented by five indicators (EPW1–EPW5), demonstrated mean scores of 4.00–4.40 with TCR percentages of 80–88%, all within the highly practical category. The evidence strongly indicates that the IIBL model is highly practical to implement in vocational and engineering education, as reflected in consistent ratings from lecturers and students, where almost all indicators were categorized as highly practical and only one remained at the practical level.

Table 3. Practicality test results of the IIBL model for students

Assessment Aspect	Indicator/Item	N	Mean	TCR Percentage	Category
Attractiveness Aspect	ADT1	15	4.87	97.4%	Very Practical
	ADT2	15	4.27	85.4%	Very Practical
	ADT3	15	4.13	82.6%	Very Practical
	ADT4	15	3.87	77.4%	Practical
	ADT5	15	4.60	92%	Very Practical
Ease of Implementation Aspect	AKI1	15	4.00	80%	Very Practical
	AKI2	15	4.47	89.4%	Very Practical
	AKI3	15	4.13	82.6%	Very Practical
	AKI4	15	4.20	84%	Very Practical
	AKI5	15	4.47	89.4%	Very Practical
Learning Atmosphere Aspect	ASP1	15	4.33	86.6%	Very Practical
	ASP2	15	4.00	80%	Very Practical
	ASP3	15	4.40	88%	Very Practical
	ASP4	15	4.07	81.4%	Very Practical
	ASP5	15	4.33	86.6%	Very Practical
Interaction in Learning Aspect	AIP1	15	4.33	86.6%	Very Practical
	AIP2	15	4.40	88%	Very Practical
	AIP3	15	4.47	89.4%	Very Practical
	AIP4	15	4.13	82.6%	Very Practical
	AIP5	15	4.00	80%	Very Practical

Based on the data presented in Table 3, the practicality testing results of the IIBL model involving 15 students from the Automotive Engineering Department demonstrated highly satisfactory outcomes with varied scores across indicators. The attractiveness aspect was evaluated through five indicators (ADT1–ADT5), obtaining mean scores ranging from 3.87 to 4.87 with TCR percentages ranging from 77.4% to 97.4%. Indicator ADT1 achieved the highest evaluation score with a mean of 4.87 and a TCR percentage of 97.4%, while ADT4 obtained the lowest score with a mean of 3.87 and a TCR percentage of 77.4%, although it was still categorized as practical. The remaining indicators were categorized as very practical.

The ease of implementation aspect demonstrated good consistency, with five indicators (AKI1–AKI5) obtaining mean scores ranging from 4.00 to 4.47 and TCR percentages between 80% and 89.4%, all categorized as very practical. The learning atmosphere aspect, consisting of five indicators (ASP1–ASP5), obtained mean scores ranging from 4.00 to 4.40 with TCR percentages between 80% and 88%, all within the very practical category. Similarly, the interaction in learning aspect showed positive results, with five indicators (AIP1–AIP5) obtaining mean scores ranging from 4.00 to 4.47 and TCR percentages between 80% and 89.4%, all categorized as very practical.

Overall, the practicality testing results indicate that the IIBL model is highly practical to implement based on students' evaluations, with the majority of indicators categorized as very practical and only one indicator categorized as practical.

Nevertheless, the study was conducted within a limited vocational engineering context and involved relatively small participant groups. Therefore, broader implementation involving larger and more diverse samples is recommended for future studies to strengthen the generalizability of the findings.

Effectiveness Testing and Reflection

The final stage of the study involved measuring the effectiveness of the model through analysis of students' learning outcomes (post-test), the development of 21st-century skills, and student engagement during the learning process. These data were analyzed to evaluate the effectiveness of the model and to provide reflections for further improvement. The effectiveness of the model was evaluated by comparing students' learning outcomes before and after the implementation of the model, as well as by examining improvements in 21st-century skills and active participation during the learning activities. Descriptive statistics were employed as the primary analysis technique, with a minimum mastery criterion of ≥70 set as the standard benchmark for achievement. Prior to comparing the control and experimental groups, normality and homogeneity tests were conducted to ensure that the data met the assumptions required for statistical analysis.

All research instruments were developed based on relevant learning theories and were reviewed by experts prior to implementation. The pre-test and post-test instruments underwent content validity and reliability testing before being administered in the study. Content validity was assessed by experts in vocational engineering education and instructional design to ensure alignment with learning objectives and Higher-Order Thinking Skills (HOTS) indicators. Reliability testing was conducted through a pilot study using Cronbach's Alpha analysis, yielding coefficients above 0.70, which indicated acceptable reliability standards. Furthermore, item analysis was performed to examine the difficulty level and discrimination index of each item, and all items met the established criteria for implementation. Descriptive statistics were employed as the primary analysis technique, with a minimum mastery criterion of ≥70 established as the benchmark for achievement. The criterion was determined based on the university academic assessment standard, in which a minimum score of 70 corresponds to the "Good" (B) category in the Electricity and Electronics course. The instruments were adapted to the stages of the study, including validation, practicality testing, and effectiveness testing, as presented in Table 4.

Table 4. Research Instruments

Instrument Type	Function	Format
Model Validation Sheet	To assess the feasibility of the IIBL syntax and supporting materials	4-point Likert scale, validated by experts
Practicality Questionnaire	To evaluate the ease of use, applicability, and functionality of the model and Smart Learning	Student and lecturer questionnaires, Likert scale
Pre-test and Post-test	To measure students' cognitive achievement	Multiple-choice items based on HOTS
Skills Observation Sheet	To assess practical skills and the application of concepts	Observation scale, 0–100
Attitude and 21st-Century Skills Evaluation Sheet	To assess students' attitudes, collaboration, communication, and creativity	Lecturer observation sheet, 1–4 scale

The effectiveness of the model was evaluated by comparing students' learning outcomes before and after the implementation of the model, as well as by examining improvements in 21st-century skills and active participation during the learning activities. The control class was taught using conventional instructional methods commonly applied in vocational electronics courses, consisting of teacher-centered explanations, textbook-based learning, routine laboratory activities, and limited use of digital learning media. Meanwhile, the experimental class implemented the IIBL model supported by the Smart Learning platform, which emphasized inquiry activities, blended learning, collaborative discussions, and interactive digital learning support. Descriptive statistics were employed as the primary analysis technique, with a minimum mastery criterion of ≥70 set as the standard benchmark for achievement.

Respondents

Since this study employed a Design-Based Research (DBR) approach, different participant groups were involved at each stage according to the research objectives. The construct validation stage involved 8 expert validators. Practicality testing involved 5 lecturers and 15 students to evaluate the usability and implementation practicality of the IIBL model. Effectiveness testing was conducted using two groups consisting of 20 students in the experimental class and 21 students in the control class, like table 5.

Table 5. Distribution of Respondent

Research Stage	Participants	Number	Purpose
Construct Validation	Expert validators	8 experts	Evaluate the construct validity of the IIBL model and research instruments
Practicality Testing	Lecturers	5 lecturers	Assess the practicality and usability of the IIBL model
Practicality Testing	Students	15 students	Evaluate implementation practicality from the student perspective
Effectiveness Testing	Experimental class	20 students	Examine the effectiveness of the IIBL model implementation
Effectiveness Testing	Control class	21 students	Compare learning outcomes with conventional learning approaches

Research Location

This research was conducted in the Electrical Engineering Education Study Program, Universitas Negeri Padang, Indonesia. The implementation of the IIBL model was carried out in electronics learning courses supported by the Smart Learning platform.

RESULT AND DISCUSSION

Result

This section presents the results and discussion of the development and evaluation of the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning. The discussion covers the product development process, construct validity, practicality testing, effectiveness testing, and the implementation outcomes of the model in vocational electronics education.

Product

The product developed in this study was the Integrated Inquiry Blended Learning (IIBL) model supported by the Smart Learning platform. The model was designed through a Design-Based Research (DBR) approach by integrating inquiry-based learning, blended learning, and adaptive digital learning technologies to support vocational electronics education. The developed product includes five structured learning syntaxes, digital learning resources, and Smart Learning features that facilitate both online and face-to-face learning activities.

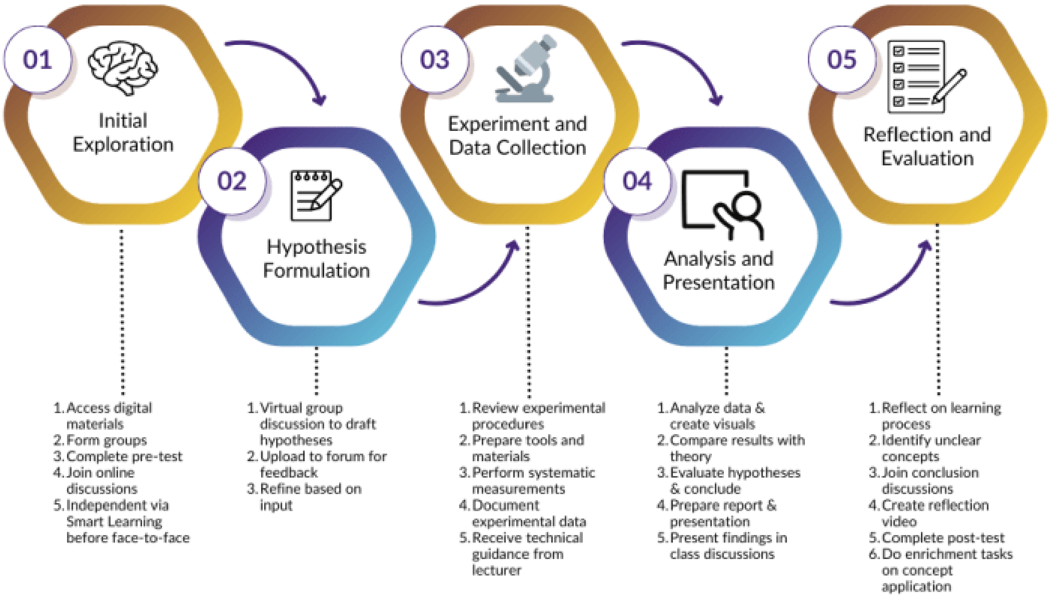

Figure 2. Syntax IIBL model

Complementing the visualization of IIBL syntaxes in Figure 2, Table 6 offers a more comprehensive account. Beyond the activities presented, the table incorporates the estimated duration, theoretical foundations, and instructional supports associated with the implementation of the IIBL model.

Table 6. Syntaxes of the IIBL Model, Learning Activities, Theories, and Supporting Tools

No	Developed Model (IIBL)	Learning Activities within the Developed Model (IIBL)	Learning Mode and Estimated Time Required	Underlying Learning Theories	Supporting Tools/Resources
1	Initial Exploration	Students respond to the pre-test questions and complete the preparatory tasks provided in the labsheet.	Online asynchronous, approx. 2–5 hours	Cognitivism by Bruner (Bruner, 1960)	Smart Learning LMS platform
		Students study the learning materials through the Smart Learning platform and review the stated learning objectives in the labsheet.		Evaluation and Measurement Theory by Bloom, Thorndike (Guskey, 2005)	Animated videos E-book
		Students engage in brief discussions through online forums (e.g., Telegram group) to foster motivation and learning interest.		Constructivism by Piaget, Bruner (Blake & Pope, 2008)	Online discussion forum via Telegram Chat
		Students observe the phenomena or problems presented by the instructor as a trigger for the learning process.		Social Constructivism by Vygotsky (Bada & Olusegun, 2015)	IIBL-based labsheet Google Quiz
2	Hypothesis Formulation	Students formulate questions or hypotheses related to the problem under investigation, either individually or in	Online discussion, approx. 25–30	*Inquiry-Based Learning Theory* (Bruner, 1960;	Smart Learning LMS platform, animated videos, e-book,

No	Developed Model (IIBL)	Learning Activities within the Developed Model (IIBL)	Learning Mode and Estimated Time Required	Underlying Learning Theories	Supporting Tools/Resources
		groups.	minutes	Dewey, 1938); *Self-Regulated Learning* (Hamzah et al., 2023).	Telegram discussion forum, IIBL-based labsheet, Google Quiz.
3	Experimentation and Data Collection	Students conduct experiments and collect experimental data in accordance with the procedures specified in the labsheet.	face-to-face (laboratory-based), approx. 6.5–7 hours	Experiential Learning – learning through direct experience (Kolb, 2011). Learning by Doing (Dewey, 1938)	IIBL-based labsheet. Laboratory equipment and materials.
4	Analysis and Presentation	Students process experimental data, present it in the form of graphs or tables, and interpret the results to test the validity of their formulated hypotheses. Students prepare written reports or digital presentation media. Students present their findings to the class through either face-to-face or online sessions.	Face-to-face and online. Data analysis: approx. 3–3.5 hours. Presentation: approx. 1.5–2 hours.	Social Constructivism by Vygotsky – collaborative meaning-making. Cognitive Apprenticeship.	*Smart Learning platform.* *Animated videos.* *E-book.* *Spreadsheet.* *Canva.* *PowerPoint.* *Presentation videos.*
5	Reflection and Evaluation.	Students summarize the results of their investigation and discuss them with peers in groups or class-wide forums. Students present their responses to the hypotheses and articulate their understanding or learning experiences, either through video presentations or written reports. Students complete the post-test questions via the Smart Learning platform.	Face-to-face and online. Reflection: approx. 1.5–2 hours. Evaluation: approx. 1 hour.	Constructivism (Blake & Pope, 2008), Metacognitive Reflection (Dewey, 1938) Evaluation and Measurement Theory (Bloom, 1956)	*Smart Learning LMS platform.* *Google Quiz.*

The five syntaxes of the IIBL model are systematically organized through the development of instructional modules that guide students' activities from pre-experiment, experimental implementation, to post-experiment stages. Students are not only engaged in laboratory practices but are also supported online through the Smart Learning platform and Telegram chatbot, ensuring that the entire learning process, both on campus and at home, remains under the lecturer's supervision and follows the sequential IIBL framework. The Initial Exploration stage is designed to build students' learning readiness through the activation of prior knowledge, understanding of learning objectives, and introduction to problem contexts. This stage is reinforced by Cognitivism (Bruner, Ausubel), which emphasizes the role of cognitive structures in constructing new understanding, and by Evaluation and Measurement theory (Bloom, Thorndike), which helps identify students' initial levels of comprehension through pre-tests. Learning occurs online via Smart Learning and Telegram discussion forums, offering flexibility and early interaction that foster active learning motivation.

The Hypothesis Formulation stage reflects the essence of Inquiry Learning (Dewey, Bruner), where students are encouraged to independently construct questions and hypotheses. This activity focuses on developing critical thinking and scientific reasoning skills. Conducted online in a short but meaningful session, this stage leverages forums and the LMS to enable both individual and collaborative planning. It is further supported by Self-Regulated Learning theory, which trains students to manage their strategies and learning goals independently. The Experimentation and Data Collection stage in the IIBL model engages students in laboratory-based activities where they conduct experiments and gather data according to structured procedures. This process aligns with Experiential Learning Theory, which emphasizes that knowledge emerges through the transformation of experience via a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 2011). In line with this, Dewey's principle of Learning by Doing underscores that authentic practice and direct engagement with materials enable learners to bridge abstract theories with real-world applications (Dewey, 1938). Recent studies have confirmed that experiential and inquiry-based approaches in laboratory settings significantly enhance students' problem-solving and scientific reasoning (Mubarok et al., 2019). Thus, combining classical theories with modern applications ensures that laboratory learning not only validates conceptual understanding but also equips students with the competencies required in 21st-century engineering practice (Kerimbayev et al., 2023)

The fourth syntax, The Analysis and Presentation stage requires students to process experimental data, represent it through graphs or tables, and interpret the results to evaluate the validity of their hypotheses. This process is reinforced by Social Constructivism, which emphasizes that knowledge is co-constructed through social interaction and collaborative meaning-making (Liu et al., 2024). Collaborative discussions and peer presentations create opportunities for students to negotiate meaning, refine their arguments, and build deeper conceptual understanding. Furthermore, the principles of Cognitive Apprenticeship highlight that learning complex problem-solving skills is most effective when students are guided through modeling, scaffolding, and reflection within authentic contexts. By combining these perspectives, classroom presentations whether face-to-face or online become platforms for students to articulate findings, engage in constructive critique, and internalize scientific reasoning (Hoffa & Freeman, 2007).

The final syntax, Reflection and Evaluation, is designed to strengthen metacognitive skills and foster lifelong learning. Students reflect on their learning processes and outcomes, respond to their hypotheses, and document their understanding and learning experiences in the form of videos or written reports. They also complete post-tests via Smart Learning. This stage is supported by Constructivism (Blake & Pope, 2008), Metacognitive Reflection (Dewey, 1938) and Evaluation and Measurement theory (Bloom, 1956). Reflection enables students to deepen understanding, identify gaps, and improve learning strategies continuously.

Collectively, these five syntaxes provide a holistic framework that integrates modern pedagogy with intelligent technology support. Each syntax interconnects to form a flexible yet structured cycle of learning, enabling engineering and vocational students to actively engage in meaningful learning both in class and online. The IIBL model is designed to address the complexities of technical education through inquiry-based approaches that promote exploration and problem-solving, as well as blended learning that extends learning space and time. Its strength lies in aligning learning theories with practical needs, supported by an adaptive Smart Learning platform. The model is not only grounded in strong educational theory but is also oriented toward fostering digital literacy, independent learning, and scientific thinking skills essential for facing the challenges of the Fourth Industrial Revolution.

Validity Testing

The validation instrument was administered to experts to evaluate the feasibility of the model syntax, the coherence of the instructional components, and the appropriateness of their integration with the Smart Learning platform. The results served as the basis for establishing content validity and for refining the model to ensure greater rigor and applicability.

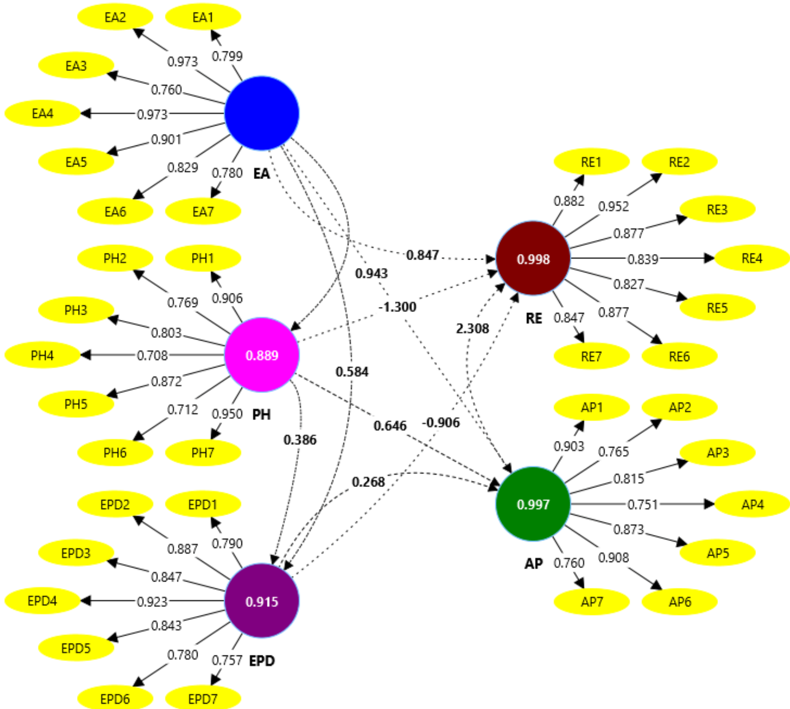

Figure 3. Graphical output of the SEM-PLS for the IIBL syntax model

Figure 3 presents the SEM-PLS graphical model of the IIBL syntax structure. Each construct is represented using indicator codes, namely Initial Exploration (EA), Hypothesis Formulation (PH), Experimentation and Data Collection (EPD), Analysis and Presentation (AP), and Reflection and Evaluation (RE). The validity and reliability values for each construct are presented in Table 7.

Table 7. Construct Reliability and Validity Syntax Model IIBL

Syntax	Cronbach's Alpha	Composite Reliability		Average Variance Extracted (AVE)
		(rho_a)	(rho_c)	
Initial Exploration (EA)	0.941	0.950	0.953	0.746
Hypothesis Formulation (PH)	0.917	0.925	0.935	0.675
Experimentation and Data Collection (EDP)	0.927	0.939	0.941	0.696
Analysis and Presentation (AP)	0.922	0.925	0.938	0.685
Reflection and Evaluation (RE)	0.947	0.949	0.957	0.761

According to the data presented in Table 7, all aspects of the IIBL syntax model demonstrated excellent reliability, with Composite Reliability (ρc) values exceeding 0.90. The Reflection and Evaluation (RE) aspect obtained the highest score (0.957), followed by Initial Exploration (EA) at

0.953 and Experimentation and Data Collection (EDP) at 0.941. The remaining aspects, Analysis and Presentation (AP) and Hypothesis Formulation (PH), also performed strongly with values of 0.938 and 0.935, respectively. Cronbach's Alpha values confirmed strong internal consistency across all aspects, ranging from 0.917 to 0.947. RE achieved the highest reliability (0.947), while PH recorded the lowest yet still excellent value (0.917). Indicator reliability (ρa) also yielded satisfactory results, ranging from 0.925 (AP and PH) to 0.950 (EA).

Furthermore, the Average Variance Extracted (AVE) for all aspects exceeded the recommended threshold of 0.50, indicating strong convergent validity. RE reported the highest AVE (0.761), followed by EA (0.746) and EDP (0.696). The lowest AVE was recorded by PH (0.675), though still above the minimum acceptable level. Overall, the SEM-PLS analysis using SEM-PLS confirmed that the IIBL syntax model possesses robust validity and reliability across the five evaluated aspects. The results of the Confirmatory Factor Analysis (CFA) further validated the theoretical structure of the Integrated Inquiry Blended Learning model, showing that the observed indicators consistently measured the latent constructs underlying each syntax.

The analysis was conducted based on evaluations involving 5 lecturers and 21 students from the Department of Automotive Engineering, Faculty of Engineering, Universitas Negeri Padang. Data analysis was performed using the SEM-PLS approach. The comprehensive evaluation included validity and reliability testing, discriminant validity assessment using the Heterotrait-Monotrait (HTMT) Ratio and Fornell-Larcker Criterion, as well as evaluation of the model's Goodness of Fit. The CFA results of the IIBL syntax model are presented in the SEM-PLS graphical output, as shown in Figure 4.

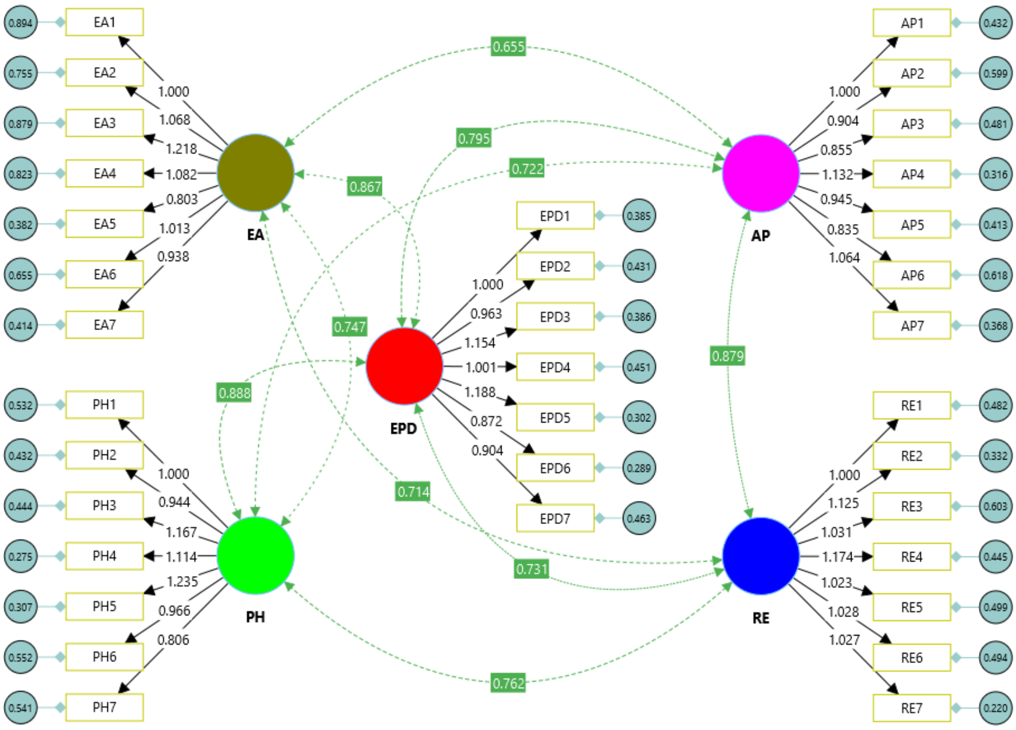

Figure 4. Graphical output of SEM-PLS CFA for the IIBL syntax model

Table 8. Validity and Reliability Results of CFA for the IIBL Syntax Model

Aspect	Cronbach's Alpha	Composite Reliability (ρc) Standardized	Composite Reliability (ρc) Unstandardized	AVE
Initial Exploration (EA)	0.880	0.876	0.878	0.516
Hypothesis Formulation (PH)	0.882	0.882	0.887	0.529
Experimentation and Data Collection (EDP)	0.891	0.891	0.895	0.548
Analysis and Presentation	0.887	0.887	0.886	0.528

(AP)				
Reflection and Evaluation (RE)	0.879	0.875	0.880	0.522

As shown in Table 8, the validity and reliability testing results demonstrate that all aspects of the IIBL syntax model achieved excellent reliability. *Cronbach's Alpha* values for all aspects exceeded 0.875, indicating strong internal consistency. The *Composite Reliability (ρc)* values were consistent with the *Cronbach's Alpha* scores, confirming good construct reliability. Moreover, the *Average Variance Extracted (AVE)* for all aspects was greater than 0.50, demonstrating that each construct explained more than half of the variance in its observed indicators. The Experimentation and Data Collection aspect recorded the highest AVE (0.548), followed by Hypothesis Formulation with 0.529. These results affirm that the IIBL syntax model is both valid and reliable based on empirical evidence.

Although the sample size was relatively limited, the CFA/SEM analysis in this study was primarily intended for preliminary construct validation within the Design-Based Research framework. SEM analysis may still be applied in models with limited complexity and strong indicator loadings. Therefore, the present analysis focused on examining the consistency and adequacy of the proposed IIBL syntax model (Hair & Alamer, 2022).

Table 9. Discriminant Validity Results of the IIBL Syntax Model Using the HTMT Criterion

Syntax	AP	EA	EDP	PH	RE
Initial Exploration (EA)					
Hypothesis Formulation (PH)	0.665				
Experimentation and Data Collection (EDP)	0.823	0.877			
Analysis and Presentation (AP)	0.756	0.765	0.888		
Reflection and Evaluation (RE)	0.672	0.735	0.752	0.785	

The results of the discriminant validity test using the *Heterotrait-Monotrait Ratio (HTMT)* criterion, as presented in Table 9, show that all values were below the threshold of 0.90. This confirms that each construct is unique and can be clearly distinguished from the others. The highest HTMT value of 0.888 was observed between *Hypothesis Formulation* (PH) and *Experimentation and Data Collection* (EDP). Although close to the threshold, this value remains within the acceptable range. Therefore, all constructs of the IIBL model supported by *Smart Learning* demonstrate adequate discriminant validity, meeting the necessary requirements.

Table 10. Fornell–Larcker Criterion Results of the IIBL Syntax Model

Syntax	AP	EA	EDP	PH	RE
Initial Exploration (EA)	0.727				
Hypothesis Formulation (PH)	0.655	0.718			
Experimentation and Data Collection (EDP)	0.795	0.867	0.740		
Analysis and Presentation (AP)	0.722	0.747	0.888	0.727	
Reflection and Evaluation (RE)	0.879	0.714	0.731	0.762	0.722

The results of the discriminant validity test using the Fornell–Larcker Criterion, as presented in Table 10, indicate that most constructs achieved acceptable discriminant validity, as the square roots of the AVE values were generally higher than the inter-construct correlations. However, several correlations among closely related inquiry stages, particularly Experimentation and Data Collection (EPD), Analysis and Presentation (AP), and Reflection and Evaluation (RE), exceeded the corresponding square root of AVE values, indicating relatively close conceptual relationships between these constructs. Nevertheless, the HTMT analysis showed values below the recommended threshold of 0.90, suggesting that the overall discriminant validity of the proposed IIBL syntax model remains acceptable for preliminary construct validation within the Design-Based Research framework. This finding indicates that the constructs are sufficiently distinguishable while still reflecting the integrated nature of the inquiry-based learning process.

In general, the results suggest that students may still experience conceptual difficulties in distinguishing between the stages of experimentation, hypothesis formulation, data analysis, and reflection. This finding is consistent with the implementation results, where students encountered challenges in developing clear hypotheses and conducting reflective analysis of experimental outcomes. Strengthening instructional guidance for hypothesis formulation and data analysis, as well as providing exemplar reflection products through the Smart Learning platform, are therefore recommended for future refinements of the model. Strengthening instructional guidance for hypothesis formulation and data analysis, as well as providing exemplar reflection products through the Smart Learning platform, are therefore recommended for future refinements of the model. Such pedagogical support was evident in this study, where lecturers' active roles in monitoring Smart Learning interactions contributed significantly to students' conceptual clarity and reflective practice, consistent with findings emphasizing the importance of teacher support and digital facilitation in blended inquiry learning models(Zhao & Song, 2021).

Theoretical Justification

The IIBL model was designed as an integrated and sequential learning system, which naturally leads to high correlations among its syntaxes. Rather than being a limitation, this feature reflects the coherence and complementarity of the instructional design. Traditional inquiry-based learning emphasizes a sequential series of tasks to guide learners through the stages of inquiry, with assessments integrated seamlessly into the learning process. This theoretical basis aligns with Vygotsky's social constructivism, which posits that "every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first between people (interpsychological), and then inside the child (intrapsychological)." In the context of IIBL, each syntax facilitates the gradual internalization of knowledge through both social interaction and individual construction.

Methodological Justification

HTMT has been widely recommended in recent SEM-PLS literature as a robust criterion for assessing discriminant validity, particularly for models with conceptually related constructs. Its use has been widely adopted in recent SEM-PLS studies. Therefore, employing HTMT as the primary criterion in this study is both appropriate and methodologically sound.

Empirical Justification

The HTMT results confirmed that each syntax remains unique, despite their strong interconnections. This outcome is consistent with classroom implementation, where the syntaxes were shown to complement one another in practice. For instance, students cannot formulate accurate hypotheses without first acquiring foundational knowledge through initial exploration activities such as reading e-books, completing assignments, or engaging with instructional videos. Similarly, experimentation and data analysis are only effective when built upon prior knowledge and hypotheses. Finally, reflection and evaluation become meaningful only when the preceding four syntaxes are executed effectively. This sequential interdependence aligns with constructivist theory, which emphasizes problem-solving, critical thinking, and the integration of new knowledge with prior experience. Taken together, the statistical evidence and empirical observations reinforce the overall validity of the model. The findings suggest that the IIBL model demonstrates adequate validity and practical applicability in vocational and engineering education contexts.

Practicality Test

The practicality test of the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning was conducted in the Automotive Engineering Study Program, involving one lecturer and 21 second-semester students enrolled in the Electricity and Electronics course. The participants were selected based on technological readiness, the relevance of course content, and the lecturer's commitment to implementing innovative learning approaches. The practicality evaluation focused on four key aspects: (1) clarity and coherence of the IIBL syntax, (2) ease of use of digital tools, (3) accessibility and effectiveness of Smart Learning, and (4) integration of online and face-to-face learning activities.

The results of questionnaires and observations indicated that the IIBL model was rated as highly practical by both lecturers and students. Most indicators were categorized as "highly practical," suggesting that the learning syntax was easy to understand, the digital tools effectively supported learning activities, and the Smart Learning platform was accessible and functional in vocational learning contexts. These findings reflect the principles of usability, attractiveness, and effective integration in authentic learning environments, which are essential aspects of instructional practicality and technology acceptance in digital learning systems (Akyol et al., 2009). Therefore, the findings indicate that the IIBL model demonstrates strong practical feasibility for implementation in technology-based vocational education.

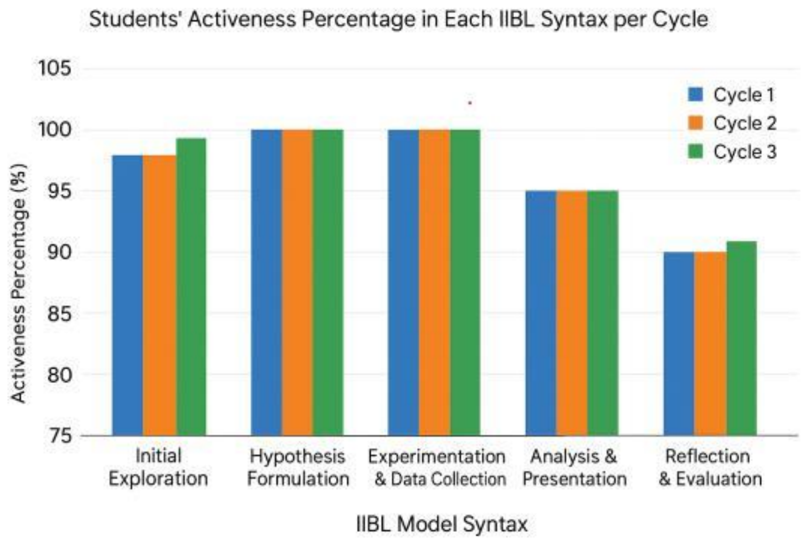

Figure 5. Percentage Of Student Engagement Across Syntaxes And Learning Cycles

Comparison of Learning Cycles

To ensure the validity of comparisons across learning cycles, the assessment instruments were developed based on the same learning objectives, competency indicators, and cognitive difficulty levels. Each cycle employed comparable concepts and consistent scoring criteria to maintain the equivalence of assessment measurements across cycles. As presented in Figure 6, in the first cycle, only 3 out of 21 students (14.3%) achieved a post-test score of ≥70. This low performance was primarily due to limited prior understanding, minimal participation in group reflection, and insufficient utilization of the Smart Learning platform. In the second cycle, improvements were made by providing more structured instructions and adjusting the online learning materials. As a result, student outcomes increased, with 12 students (57.1%) reaching scores of ≥70, alongside notable gains in 21st-century skills, particularly collaboration and digital literacy.

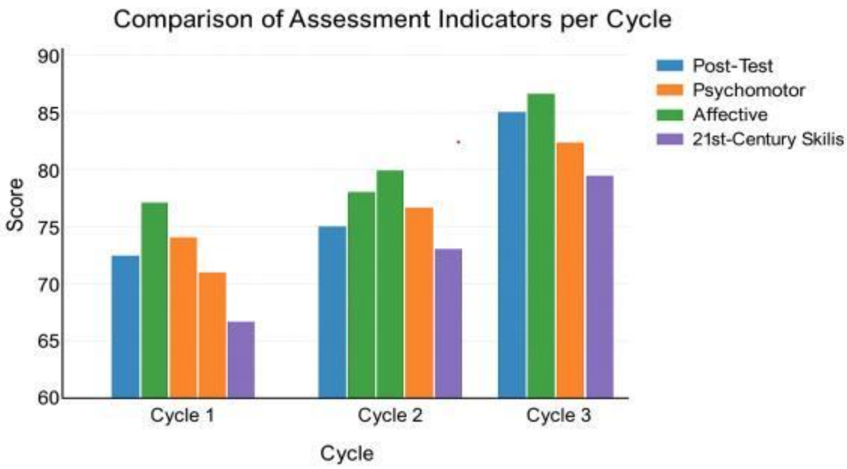

Figure 6. Comparison Of Assessment Indicators Across Learning Cycles

Although student engagement was relatively high from the first cycle, post-test achievement remained moderate during the early implementation stage. This condition indicates that active participation in inquiry activities does not immediately translate into high cognitive achievement, as students still required time to adapt to hypothesis formulation, experimental analysis, and reflective learning processes within the IIBL model. By the third cycle, all students (100%) successfully achieved the minimum score of ≥70, with average results of 84.19 (cognitive), 85.81 (psychomotor), 81.76 (affective), and 85.48 (21st-century skills). These findings suggest that the iterative implementation of the IIBL model supported by Smart Learning contributed to consistent and meaningful improvements in students' learning outcomes across learning cycles.

Effectiveness Testing and Reflection

The effectiveness of the model was further supported by comparisons between the control and experimental classes, showing that students in the experimental group achieved higher competencies across all domains. These findings indicate that the IIBL model demonstrates adequate construct validity, practical feasibility, and potential effectiveness in supporting technology-based engineering education.

Table 11. Frequency Distribution Of Research Data

		Statistic					
Data Group	Indicator		Pre-Test	Post-Test	Affective	Psychomotor	21st-Century Skills
Control Class	N	Valid	20	20	20	20	20
		Missing	0	0	0	0	0
	Mean		53.85	74.55	74.30	76.05	74.35
	Median		53.50	74.50	74.50	75.50	74.00
	Std. Deviation		2.796	3.605	2.638	2.800	2.907
	Minimum		50	68	70	72	70
	Maximum		59	82	79	82	80
Experimental Class	N	Valid	21	21	21	21	21
		Missing	0	0	0	0	0
	Mean		56.05	84.19	81.76	85.81	85.48
	Median		56.00	84.00	82.00	85.00	85.00
	Std. Deviation		3.324	2.909	3.986	2.620	2.400
	Minimum		50	80	75	82	82
	Maximum		62	90	89	92	90

Based on the descriptive statistical analysis in Table 11, which involved 20 students in the control group and 21 students in the experimental group with no missing data, several key findings emerged regarding the performance differences between the two groups. In the pre-test, the control group obtained a mean score of 53.85 (SD = 2.796), while the experimental group achieved a slightly higher mean of 56.05 (SD = 3.324). The score ranges were similar, with the control group scoring between 50 and 59 and the experimental group scoring between 50 and 62. The median values (53.50 for the control group and 56.00 for the experimental group) were close to the respective means, indicating relatively symmetric data distributions at the initial stage.

Striking differences appeared in the post-test and across the three additional domains. In the post-test, the experimental group demonstrated substantial improvement with a mean score of 84.19 (Mdn = 84.00, SD = 2.909), compared to the control group with a mean of 74.55 (Mdn = 74.50, SD = 3.605). Consistent superiority was also observed in the affective domain, where the experimental group reached a mean of 81.76 (Mdn = 82.00, SD = 3.986) versus the control group mean of 74.30 (Mdn = 74.50, SD = 2.638). In the psychomotor domain, the experimental group again outperformed the control group, achieving a mean of 85.81 (Mdn = 85.00, SD = 2.620) compared to 76.05 (Mdn = 75.50, SD = 2.800). Similarly, in 21st-century skills, the experimental group scored a mean of 85.48 (Mdn = 85.00, SD = 2.400), while the control group obtained 74.35 (Mdn = 74.00, SD = 2.907).

The effectiveness testing was conducted by comparing students' learning outcomes before and after the implementation of the IIBL model supported by Smart Learning. The analysis focused on cognitive achievement through pre-test and post-test scores in both the control and experimental groups. Statistical analysis indicated significant differences between pre-test and post-test scores in both groups. However, the experimental group demonstrated greater improvement after the implementation of the IIBL model supported by Smart Learning. Table 10, The findings indicate that the implementation of the IIBL model supported by Smart Learning contributed positively to improving students' learning outcomes and active participation in vocational engineering education. In addition, the integration of inquiry-based learning activities with digital learning support created a more interactive and student-centered learning environment.

Table 12. Statistical Test Results

Group	t-value	Sig. (2-tailed)
Control Class	2.64	<0.05
Experimental Class	3.12	<0.001

Overall, the comparison between groups revealed that the experimental group experienced greater improvement, with a mean gain of 28.143 points, compared to 20.700 points in the control group. This represents a 7.443-point advantage associated with the implementation of the IIBL model supported by Smart Learning over conventional instruction. The observed improvements indicate that students in the experimental group demonstrated better learning progress during the implementation process.

Discussion

This section discusses the implications of the findings obtained from the development, validation, practicality testing, and effectiveness evaluation of the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning. The discussion emphasizes the contribution of the model to vocational engineering education, its alignment with previous studies and learning theories, as well as its potential to enhance students' engagement, learning outcomes, and 21st-century skills.

Discussion of Product Development

The development of the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning reflects an effort to integrate inquiry-based learning, blended learning strategies, and adaptive digital learning support into a unified instructional framework for vocational electronics education. The integration of these components was designed to address the growing need for more interactive, student-centered, and technology-supported learning environments in vocational higher education. The IIBL model emphasizes structured inquiry activities through stages of exploration, hypothesis formulation, experimentation, analysis, and reflection, allowing students to actively construct knowledge and connect theoretical understanding with practical applications.

The integration of Smart Learning also enabled learning continuity beyond classroom activities by facilitating access to digital learning materials, online discussions, assignments, and reflective learning activities. These findings are consistent with previous studies emphasizing that blended learning integrated with digital technology can increase learning flexibility, accessibility, and student engagement in vocational and engineering education contexts (Ahmed et al., 2022; Hussain et al., 2023). Similarly, Santosa et al. (2025) highlighted that technology-supported learning environments contribute positively to students' independent learning and collaborative learning experiences. The development of the IIBL model is also aligned with constructivist learning theory, which emphasizes active knowledge construction through interaction, experience, and reflection. In vocational education, inquiry-oriented learning environments are considered particularly relevant because students are expected not only to understand conceptual knowledge but also to develop practical competencies, communication skills, collaboration abilities, and digital literacy required in modern industrial contexts.

Discussion of Construct Validity

The construct validity findings indicate that the IIBL model possesses a coherent and theoretically grounded instructional structure. The validation process confirmed that the syntax stages, supporting components, and Smart Learning integration were aligned with the principles of inquiry learning, blended learning, and vocational instructional design. The positive validation results suggest that each stage of the IIBL syntax was systematically interconnected and capable of supporting meaningful learning activities in vocational electronics education. The integration of Smart Learning strengthened the flexibility and accessibility of the instructional process by enabling students to continue learning activities beyond face-to-face classroom interaction.

These findings support previous studies emphasizing that effective instructional models should demonstrate coherence between pedagogical design, learning objectives, digital support systems, and learning activities to ensure successful implementation (Pedaste et al., 2015). Furthermore, previous studies in vocational and engineering education have reported that inquiry-oriented instructional frameworks supported by digital learning environments can improve learning engagement, conceptual understanding, and collaborative learning experiences (Corral-Barraza et al., 2024).

Therefore, the construct validity findings reinforce the theoretical feasibility of the IIBL model for implementation in vocational engineering education. The model not only demonstrates alignment between instructional syntax and learning objectives but also reflects the integration of digital learning support appropriate for contemporary vocational education environments.

Discussion of Practicality

The practicality findings indicate that the IIBL model supported by Smart Learning was feasible and easy to implement in vocational electronics learning activities. The positive responses from lecturers and students suggest that the syntax structure, digital learning support, and integration between online and face-to-face learning activities were understandable and manageable within the instructional process. The inquiry-based learning activities encouraged students to participate actively in exploration, experimentation, and collaborative discussion, while the Smart Learning platform facilitated access to learning resources and communication outside classroom sessions.

This condition contributed to greater learning flexibility and improved student engagement during the learning process. These findings are consistent with previous studies reporting that blended inquiry-based learning environments can improve usability, accessibility, and student participation in vocational education contexts (Hussain et al., 2023). Similar findings were also reported by Ahmed et al. (2022), who found that technology-supported blended learning environments improved interaction and learning accessibility among students in technical education. In vocational education settings, technology-supported inquiry learning is particularly important because it allows students to connect practical laboratory activities with independent and collaborative digital learning experiences. Therefore, the practicality findings indicate that the IIBL model supported by Smart Learning demonstrates strong feasibility for implementation in technology-based vocational engineering education.

Discussion of Effectiveness

The effectiveness findings demonstrate that the implementation of the IIBL model supported by Smart Learning contributed positively to students' learning outcomes, learning participation, and 21st-century skills development. The improvement observed during the implementation process indicates that inquiry-based and technology-supported learning activities encouraged students to become more actively involved in constructing knowledge, conducting investigations, and solving problems collaboratively. The inquiry process enabled students to investigate concepts through experimentation, data analysis, and reflection, thereby strengthening conceptual understanding and practical competence simultaneously. In addition, the blended learning environment facilitated continuous interaction and learning access through Smart Learning, which supported independent learning and collaborative engagement beyond classroom meetings. The progressive improvement across learning cycles also indicates that students gradually adapted to the inquiry-based learning environment and became more confident in participating actively during learning activities.

These findings support constructivist learning perspectives, which emphasize active learning experiences and student-centered instructional processes. The findings are also consistent with previous studies reporting that inquiry-based and blended learning approaches are effective in improving critical thinking, learning engagement, collaboration, and problem-solving skills in vocational and engineering education contexts (Pedaste et al., 2015). Similarly, Corral-Barraza et al. (2024) found that inquiry-oriented engineering instruction enhanced students' motivation and conceptual understanding in technological problem-solving activities.

Implications for Practice or Policy

The validated IIBL model supported by Smart Learning provides important implications for vocational and engineering education at multiple levels.

For educators**,** the model offers structured guidance to integrate inquiry-based and blended learning approaches in laboratory-oriented courses. By combining exploration, experimentation, analysis, and reflection with adaptive digital platforms, lecturers can strengthen students' conceptual literacy, higher-order thinking, and 21st-century competencies. Importantly, Smart Learning enables self-directed learning beyond the classroom, allowing students to build independence while still receiving structured guidance and feedback.

For institutions, particularly those delivering vocational and engineering programs**,** the study emphasizes the importance of investing in adaptive learning infrastructures tailored to practice-based education. Smart Learning features such as real-time monitoring, automated feedback, chatbots, and multimedia resources can serve as benchmarks for strengthening digital ecosystems in vocational higher education. By adopting such platforms, institutions can integrate laboratory-based learning with online environments more effectively, enhance curriculum flexibility, and ensure that graduates are equipped with both discipline-specific competencies and transferable 21st-century skills. This not only supports institutional innovation but also aligns vocational education with global quality assurance standards and the evolving demands of industry.

For policymakers, the IIBL framework highlights the relevance of blended and inquiry-based learning models for national strategies in higher education. The model can inform curriculum reform, accreditation, and quality assurance mechanisms by ensuring that technology-enhanced learning improves academic achievement while also preparing students for workplace readiness. In this way, the IIBL model contributes to bridging the gap between academic outcomes and labor market expectations, reinforcing broader policy objectives in strengthening vocational and technical education in the digital era.

CONCLUSION

The findings of this study indicate that the Integrated Inquiry Blended Learning (IIBL) model supported by Smart Learning demonstrates adequate construct validity, practical applicability, and positive trends in effectiveness in vocational engineering education. The construct validity analysis generally met the recommended validity criteria, with Average Variance Extracted (AVE) values above 0.50, Composite Reliability values above 0.70, and Heterotrait–Monotrait Ratio (HTMT) values below the recommended threshold of 0.90. These findings indicate that each instructional stage represents a distinct yet interconnected component within the overall inquiry-based learning framework.

The practicality evaluation involving lecturers and students showed that the IIBL model was categorized as highly practical, particularly in terms of syntax clarity, learning flexibility, digital accessibility, and the integration of online and face-to-face learning activities. Furthermore, the implementation results demonstrated improvements in students' cognitive achievement, psychomotor skills, affective aspects, and 21st-century skills through inquiry-based and technology-supported learning activities. Progressive improvements across learning cycles also suggest that the IIBL model contributed positively to students' engagement, collaboration, communication, and reflective learning processes in vocational electronics education.

These findings suggest that the integration of inquiry-based learning activities with Smart Learning support has the potential to create more interactive, student-centered, and technology-oriented learning environments in vocational education. However, this study involved a limited number of participants and was conducted within a single vocational study program, which may limit the generalizability of the findings. Therefore, future studies are recommended to implement and evaluate the IIBL model in broader vocational and engineering education contexts involving larger samples, different disciplines, and longitudinal research designs.

Recommendations

The IIBL model supported by Smart Learning may serve as an alternative instructional framework for vocational and engineering education, particularly in courses requiring inquiry activities, practical experimentation, and digital learning integration. Future research is encouraged to further investigate the long-term impact of the model on students' independent learning, digital literacy, and professional competencies in diverse educational settings.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used AI-assisted tools (e.g., ChatGPT) to improve the clarity, grammar, and readability of the manuscript. The use of AI was limited to language refinement to ensure that the content is easily understood by readers. All research concepts, data collection, procedures, and analysis were carried out independently by the authors through actual fieldwork. The authors have reviewed and edited the content as needed and take full responsibility for the content of this publication.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Investigation; Validation; Writing - - original draft; review and editing.

Author 2: Conceptualization; Data curation; Methodology.

Author 3: Data curation; Investigation.

Author 4: Formal analysis; Methodology; review

Author 5: Resources.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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