BRIDGING DIGITAL LITERACY GAPS THROUGH LEARNING-BY-DOING: AN IOT PROJECT-BASED CURRICULUM FOR AI LITERACY IN VOCATIONAL EDUCATION

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Abstract

This article examines curriculum innovation through the implementation of the institutional compulsory course, "Introduction to Data Literacy and Artificial Intelligence," at the Institut Teknologi Sains Bandung (ITSB) during the even semester of the 2025/2026 academic year. The palm oil processing industry is rapidly transitioning toward automation and Industry 4.0 practices, demanding graduates equipped with data-driven practical skills (future skills) rather than mere mechanical competence. However, the implementation of this course faces significant demographic and pedagogical challenges: most students, primarily originating from outside Java, enter the program with limited prior experience in computer operations, yet rely heavily on generative AI platforms to complete assignments through uncritical copy-pasting—a pattern that erodes genuine conceptual understanding. To address this dual gap, this study introduces and evaluates a learning-by-doing methodology grounded in constructionism and experiential learning theories. Instead of theoretical assignments easily solved by AI, students are directly confronted with authentic technical problems (directly attach the problem): assembling simple electronic circuits based on the ESP32 microcontroller and sensors, and subsequently building fully functional mobile sensor-reading applications using the block-based drag-and-drop platform, MIT App Inventor. This approach is designed to position AI as a proportional assistant (co-pilot) that explains logic rather than acting as a substitute for cognitive processes, transforming students from passive consumers of AI text into active technology designers. Utilizing a descriptive qualitative case study design across three learning stages, this research reveals that visual block-based programming successfully bridges the coding capability gap for non-informatics students, enabling them to comprehensively understand the data flow—from sensor acquisition to data logging and cloud visualization—which is essential for adapting to an increasingly automated palm oil industrial environment. The article concludes with pedagogical implications, research limitations, and recommendations for expanding this approach to other vocational courses.

Keywords: Curriculum Innovation; Future Skills; Data Literacy; Palm Oil Industry; Vocational Education; Project-Based Learning; Block-Based Programming

1. Introduction

The palm oil processing industry in Indonesia is undergoing a structural transformation toward automation and the digitalization of production processes. The implementation of Supervisory Control and Data Acquisition (SCADA) systems, Internet of Things (IoT) sensors, and analytical dashboards in modern Palm Oil Mills (PKS) demands a workforce whose competence is no longer limited to mechanical-operational skills, but who are also capable of critically reading, interpreting, and managing data. This transition compels vocational education institutions to reformulate learning outcomes to align with the future skills demanded by the industry. As a strategic response to these challenges, the Institut Teknologi Sains Bandung (ITSB) introduced the course "Introduction to Data Literacy and Artificial Intelligence" as a compulsory institutional subject in the even semester of the 2025/2026 academic year, taken by students of the Palm Oil Processing Technology Study Program. In its implementation, the course instructor identified two intertwined challenges. First, a demographic challenge: the majority of ITSB Palm Oil Processing Technology students originate from outside Java with wide variations in technological access, meaning not all students possess adequate computer operation experience prior to entering college. Second, paradoxically occurring simultaneously with the first challenge is a heavy reliance on generative AI platforms (such as ChatGPT) to complete assignments. This digital irony manifests in uncritical copy-pasting of AI-generated answers without sufficient cognitive processing, allowing students to "complete" assignments without truly understanding their essence.

This phenomenon highlights an urgent pedagogical need for intervention: how to design a curriculum that accommodates the use of AI while encouraging students to use it proportionally and reflectively, rather than as a cognitive shortcut. While previous studies have extensively discussed AI literacy in general or the challenges of palm oil industry automation separately, research specifically connecting the two within the context of Indonesian palm oil vocational education remains limited particularly regarding the consideration of students foundational digital literacy gaps. Based on this background, this study aims to:Describe the curriculum design and learning-by-doing methodology applied in the course "Introduction to Data Literacy and Artificial Intelligence" at ITSB; Evaluate students' cognitive transition process from passive consumers of AI text to active technology designers through a sensor-reading mobile application project using MIT App Inventor; Identify pedagogical implications and provide recommendations for developing data-AI literacy curriculatiin other industry-based vocational programs.The main contribution of this article is offering a directly attach the problem learning model as a contextual strategy to counter AI text manipulation while bridging coding competency gaps through visual programming, tailored to a population of non-informatics vocational students with heterogeneous technological backgrounds

2. Literature Review

2.1. Industry 4.0 and Agroindustry Automation

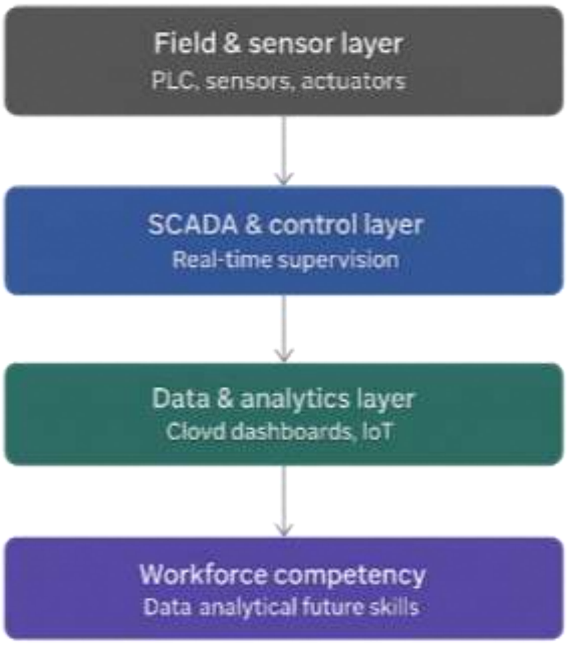


Figure 2.1 Layered architecture of an industrial automation and data analytics system

The transition towards automation, Supervisory Control and Data Acquisition (SCADA) systems, and real-time monitoring in modern manufacturing and agroindustry demands a workforce equipped with data-analytical "future skills." As highlighted by the World Economic Forum (2023) and Spöttl & Windelband (2021), vocational education must evolve to match the digital demands of modern palm oil processing plants, where operational efficiency relies heavily on continuous data acquisition and systems monitoring. In this context, competency is no longer limited to operating physical machinery, but increasingly requires the ability to interpret, validate, and act upon streams of sensor-generated data in real time — a skill set directly relevant to IoT-based monitoring systems such as the one developed in this study.

2.2. The AI Cognitive Threat and Cognitive Offloading

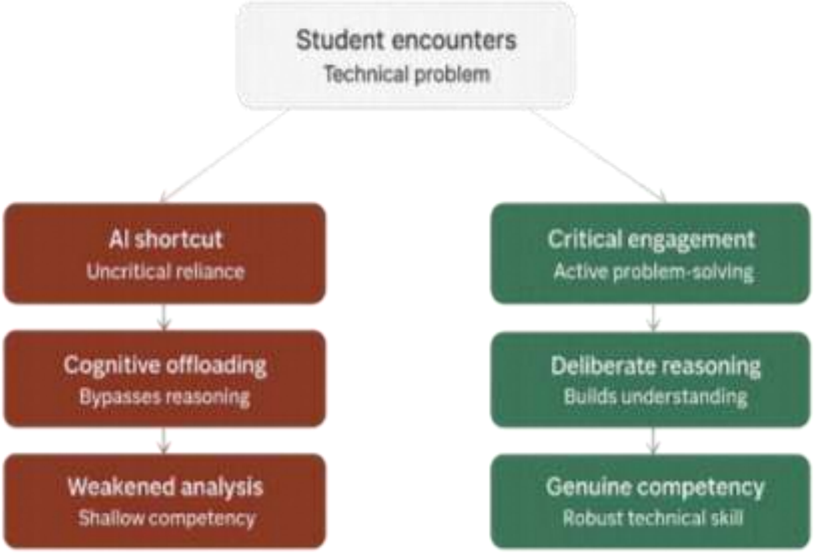
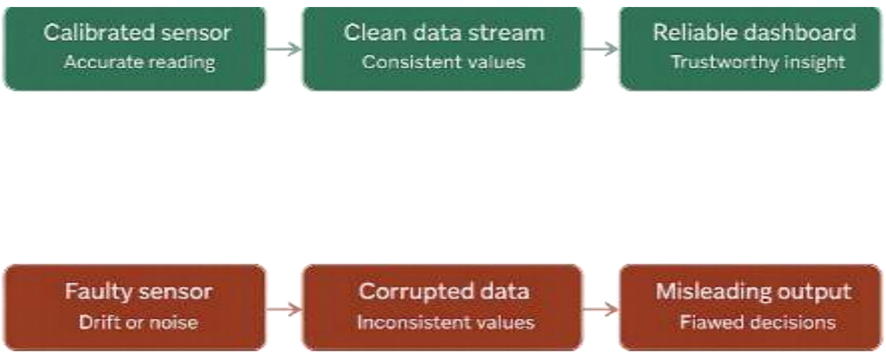


Figure 2.2 Two contrasting learning pathways when students encounter technical problems

While Generative AI tools (such as ChatGPT and Gemini) offer unprecedented accessibility, unrestricted or uncritical use as a shortcut triggers "cognitive offloading." According to Baidoo-Anu & Ansah (2023) and Risko & Gilbert (2016), this phenomenon bypasses critical thinking and weakens students' analytical capabilities, posing a significant threat to foundational learning in technical education. Students frequently rely on AI to generate answers or code without understanding the underlying logic, necessitating pedagogical strategies that prevent passive consumption. This risk is particularly acute in embedded systems and IoT development, where superficial code generation without comprehension of sensor behavior, signal noise, or hardware limitations can produce systems that function unpredictably in real field conditions.

2.3. Data Literacy and the "Garbage In, Garbage Out" (GIGO) Principle

True data literacy extends beyond software utilization; it requires a fundamental comprehension of the physical origin of data. Incorporating hands-on Internet of Things (IoT) project-based learning is essential to teach students the classic "Garbage In, Garbage Out" (GIGO) principle, ensuring they understand how physical hardware errors directly corrupt cloud-based data analytics (Maksimović, 2017; Thomas, 2000). By combining virtual simulation tools (such as Wokwi), hardware tinkering, and no-code mobile app development (such as MIT App Inventor), students can bridge the gap between physical sensor data and cloud data logging (Google Sheets) effectively. This hands-on approach counteracts the cognitive offloading risk described in Section 2.2, since direct engagement with physical hardware — calibrating a sensor, observing measurement drift, or troubleshooting a faulty reading — forces critical, first-principles reasoning that cannot be shortcut by AI-generated output alone.



Figgure 2.3 Influence of sensor accuracy on data quality and decision reliability

3. Research Methods

3.1. Object, Time, and Place

This section describes the object, timeline, and specific location of the research to provide clear context regarding its scope. The objects of this study are the students and the learning phenomenon observed during the implementation of curriculum innovation. The research was conducted during the even semester of the 2025/2026 academic year at the Institut Teknologi Sains Bandung (ITSB). Specifically, the study took place within the classrooms and laboratories utilized by the Palm Oil Processing Technology Program.

3.2. Data Collection Techniques

To gather relevant data aligned with the research objectives, this study employed multiple data collection methods. The techniques utilized include:

1) Participatory Observation: Direct observation of students during the 16-week learning intervention stages.
2) Documentation: Systematic collection of student work artifacts, including virtual simulation designs (Wokwi), hardware tinkering photos, MIT App Inventor block-based projects, and Google Sheets real-time data logs.
3) Theoretical Examinations: Academic tests administered to measure students' cognitive mastery and theoretical understanding.

3.3. Data Analysis Techniques

The collected data were analyzed using a qualitative analytical approach suitable for a descriptive case study. Content analysis and coding methods were applied to evaluate student work artifacts, observation notes, and assessment results. This analytical technique ensures that the evaluation of students' cognitive transition—from passive AI consumers to active technology designers remains valid, accountable, and strictly aligned with the research objectives.

3.4. Learning Intervention Procedures

The educational intervention spanned a 16-week period, structured into three main learning stages structured around a 4-phase "Learning by Doing" framework:

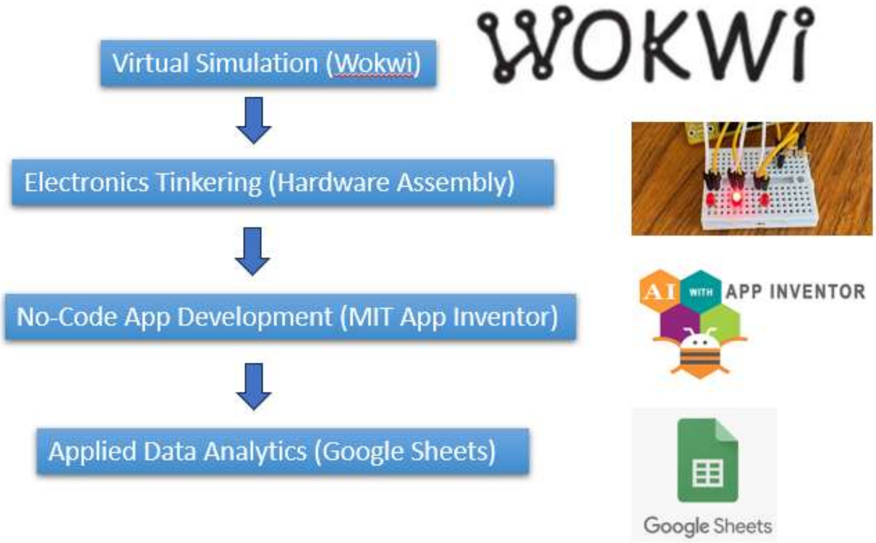


Figure 3.1 Progressive learning workflow for IoT-based industrial automation

1) Virtual Simulation: Students were first introduced to microcontrollers and sensors via virtual simulation platforms (such as Wokwi) before attempting physical assembly.
2) Electronics Tinkering: Students transitioned from virtual platforms to hands-on hardware assembly, physically wiring components such as ESP32 microcontrollers, I2C LCDs, and sensors on breadboards.
3) No-Code App Development: Utilizing MIT App Inventor's drag-and-drop interface, students built functional mobile applications without requiring advanced text-based coding backgrounds.
4) Applied Data Analytics: Students implemented real-time data logging connecting hardware directly to Google Sheets, enabling comprehensive data flow comprehension from the physical sensor to the cloud.

The proposed instructional workflow integrates virtual simulation, hardware prototyping, no-code application development, and cloud-based data analytics to strengthen practical digital engineering skills.

4. Results and Discussion

4.1. Research Results

The 16-week learning intervention implemented across three classes in the Palm Oil Processing Technology Program at ITSB successfully demonstrated a structured transition from fundamental digital concepts to applied IoT development. The implementation of the four-phase "Learning by Doing" framework yielded tangible student works and performance metrics across the instructional stages:

1) **Virtual Simulation Phase:** Students learned virtual simulation using the Wokwi platform, starting from basic programming with a single LED and an ESP32 microcontroller, progressing to reading DHT sensor data, displaying it, and interfacing it with a servo motor actuator

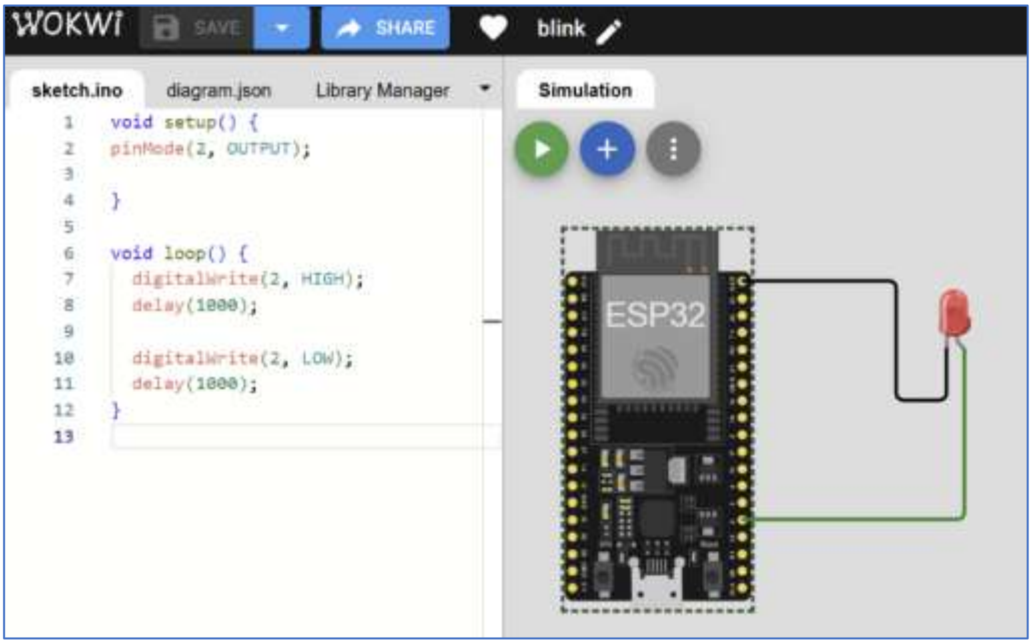


Figure 4.1. Started simulation with very simple programming via Wokwi platform

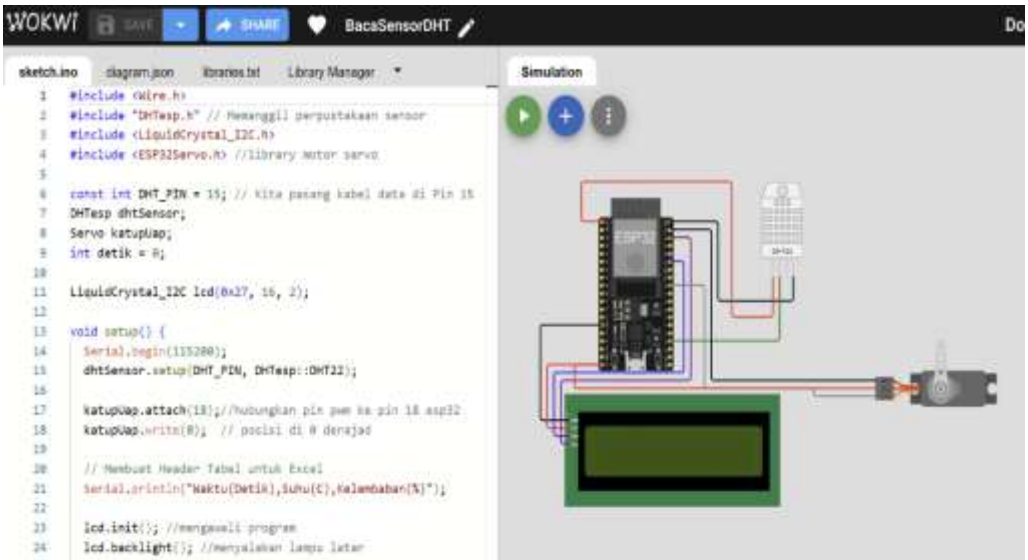


Figure 4.2. Example simulation and programming with sensor and actuators via Wokwi.

2) **Electronics Tinkering Phase:** Students successfully transitioned from virtual simulations to physical hardware assembly, wiring ESP32 boards, I2C LCD screens, and sensors on breadboards within the classroom.

Figure 4.3 Students physically wiring the ESP32 and I2C LCD on a breadboard.

3) **No-Code Software Development Phase:** Despite lacking formal IT backgrounds, students successfully built functional mobile interfaces using MIT App Inventor's drag-and-drop block-based programming environment.

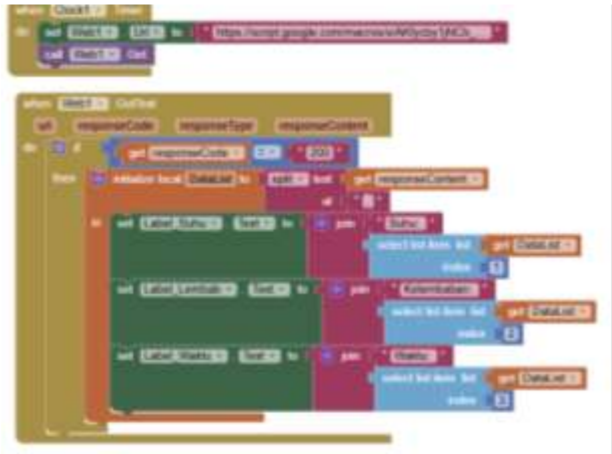


Figure 4.4.(a) MIT App Inventor visual block structure for cloud data integration

Figure 4.4.(b) students developing functional mobile application interfaces without requiring prior coding experience

4) **Applied Data Analytics Phase:** Students established reliable communication pathways by logging real-time sensor data (such as temperature and humidity) directly to Google Sheets, achieving successful data writing and reading operations.

4.2. Discussion

The findings of this study indicate that integrating hands-on IoT project-based learning effectively addresses the challenges posed by students' heterogeneous technological backgrounds. Although many students entered the program with low familiarity in basic computer operations and a tendency to rely uncritically on generative AI tools, the structured pedagogical intervention successfully leveraged visual tools like Wokwi and MIT App Inventor to bridge the digital literacy gap.

By progressing from virtual simulations to physical hardware tinkering, students grasped the physical origin of data, reinforcing the "Garbage In, Garbage Out" (GIGO) principle. Furthermore, logging real-time data to Google Sheets provided a concrete understanding of data architecture, illustrating how information flows seamlessly from physical sensors in the field to cloud storage.

4.3. Relevance to Research Objectives

The results directly address the core objectives of this study by validating the effectiveness of the curriculum innovation introduced at ITSB. The combination of visual programming and hardware implementation successfully transformed students from passive consumers of generative AI into active technology designers. Ultimately, equipping vocational students with these data-analytical competencies ensures they possess the essential *future skills* required for modern, automated environments within the palm oil processing industry

5. Conclusion

In conclusion, this study successfully demonstrates the effectiveness of the curriculum innovation implemented through the compulsory institutional course "Introduction to Data Literacy and Artificial Intelligence" at ITSB. By addressing the research objectives, the findings confirm that utilizing a structured 4-phase "Learning by Doing" approach moving from Wokwi virtual simulations and physical hardware tinkering to no-code MIT App Inventor development and Google Sheets data analytics, successfully bridges the digital literacy gap for non-informatics vocational students. Furthermore, this pedagogical model effectively counters the risks of AI cognitive offloading by transforming students from passive consumers of generative AI into active technology designers. Ultimately, equipping graduates with a practical comprehension of data architecture and flow ensures they are well-prepared with the essential *future skills* required to thrive in the automated and digitalized palm oil processing industry.

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