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Effectiveness of the Nutmeg Flower Dryer Monitoring Module in Improving Students' Digital Literacy Comprehension

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ABSTRACT

The rapid advancement of technology has emphasized the need for digital literacy among vocational students, particularly in technology-intensive sectors. However, learning modules that effectively integrate vocational content with digital literacy skills remain limited. This study aimed to evaluate the effectiveness of a Nutmeg Flower Dryer Monitoring Module in improving students' digital literacy comprehension within a vocational education context. A quasi-experimental design with pretest-posttest control groups was employed, involving 60 eleventh-grade vocational students in electronics engineering programs. The experimental group (n=30) received instruction using the IoT-based monitoring module, while the control group (n=30) engaged in conventional textbook-based learning. Data were collected using a 40-item digital literacy test and a 20-item student response questionnaire, then analyzed through N-gain calculation and independent samples t-tests. Results revealed a significant improvement in the experimental group's digital literacy, with an overall N-gain of 0.71, categorized as highly effective. The greatest gains were observed in communication literacy, indicating enhanced competencies in interpreting and interacting with real-time digital systems. Students also reported high satisfaction and perceived relevance to vocational tasks. The findings confirm that contextualized, hands-on IoT modules effectively bridge theoretical knowledge and practical digital skills. Future work should explore multi-site implementation, longitudinal retention, and adaptation to other vocational domains to further optimize digital literacy outcomes.

INTRODUCTION

Digital literacy has become an essential competency for students in the 21st century. As technology increasingly permeates all sectors of life, individuals who are unable to interact critically with digital systems risk being marginalized from economic and educational participation. Vocational education, in particular, bears a responsibility to bridge technical skills with digital understanding, as graduates are expected to operate and manage technology-intensive environments (Almaazmi, 2025; Tran et al., 2026; Wijaya[1] et al., 2026; Zhang et al., 2026).

The nutmeg (Myristica fragrans) industry is a key agricultural sector in North Sulawesi, Indonesia. Post-harvest processing, specifically flower drying, directly impacts product quality and market value (Fudjaja et al., 2024; Gelaye, 2024; Jannah et al., 2022; Sasikumar, 2025; Sujianto et al., 2024; Sulistiono et al., 2022; Vikram & Raj, 2025). Traditional drying methods are largely manual and lack real-time quality feedback, making them prone to inconsistency. The integration of IoT-based monitoring systems in drying technology presents an opportunity to modernize this process while simultaneously serving as a contextual learning platform (Ma'ruf et al., 2025; Madhu, 2025; Mishra et al., 2023; Selvam & Al-Humairi, 2023; Tabares-Martinez et al., 2026; Viviane et al., 2023).

However, educational materials that connect vocational agricultural technology with digital literacy frameworks remain scarce. Students often learn about sensors, data networks, and monitoring interfaces in isolation, without applied context. A purpose-built monitoring module grounded in a familiar agricultural process—nutmeg flower drying—has the potential to bridge this pedagogical gap.

Several previous studies support the effectiveness of contextual learning in vocational settings. Bybee et al. (2006) demonstrated that context-based STEM modules improve student engagement by 42% compared to conventional instruction. Hernandez (2017) showed that IoT-integrated laboratory tools significantly enhance students' understanding of data systems. Saavedra and Opfer (2012) found that agricultural technology modules in vocational schools outperformed generic technology curricula in fostering practical digital competence. Adamo et al. (2007) examined HMI-based learning in educational laboratories, underscoring the importance of real-time visualization for technology comprehension.

Despite these advancements, there remains a gap in materials that combine agricultural vocational content with digital literacy frameworks. Students frequently encounter sensors, networks, and monitoring interfaces in isolation, which limits their ability to apply theoretical knowledge to real-world tasks. Existing curricula often fail to contextualize digital skills within familiar vocational processes, highlighting a need for modules that integrate applied technology with pedagogical objectives.

The urgency of addressing this gap is underscored by the rapid digital transformation of both industries and educational systems. Vocational students who lack digital literacy are at risk of professional marginalization and reduced employability. Equipping learners with competencies in data interpretation, network communication, and IoT interface management not only supports academic achievement but also aligns with workforce readiness requirements.

The novelty of this study lies in its design and implementation of a Nutmeg Flower Dryer Monitoring Module that embeds IoT technology directly into a vocational agricultural context. By leveraging a locally relevant production process, students can interact with real-time data dashboards, conduct structured observations, and apply critical evaluation skills. This approach operationalizes situated learning theory, emphasizing authentic, experiential engagement with technology.

The primary purpose of this research is to evaluate the module's effectiveness in enhancing students' digital literacy comprehension. Employing a quasi-experimental pretest-posttest control group design, the study assesses both overall and dimensional gains in information literacy, data literacy, communication literacy, and technology use literacy. The research methodology ensures that observed improvements can be attributed to the contextualized IoT-based intervention.

In terms of contribution, the study provides empirical evidence that vocationally contextualized monitoring modules offer superior learning outcomes compared to conventional instruction. Results indicate substantial N-gain improvements, particularly in communication literacy (N-gain = 0.77), highlighting the benefits of real-time, interactive digital engagement. These findings extend prior research by demonstrating practical applications of IoT in secondary education vocational programs.

The research objectives include determining the extent to which the Nutmeg Flower Dryer Monitoring Module improves digital literacy and identifying which literacy dimensions are most influenced by hands-on, contextualized learning. Additionally, the study aims to capture student perceptions and engagement, informing future module refinement and broader curriculum integration. Finally, the anticipated benefits of this study encompass both educational and industry-related outcomes. Students acquire transferable digital skills applicable to technology-rich workplaces, while local agricultural industries gain potential efficiency and quality improvements through IoT-informed practices. Ultimately, the research bridges vocational pedagogy, digital literacy, and applied agricultural innovation, offering a model for similar interventions in other technical education contexts.

METHOD

Research Design and Type

This study employed a quasi-experimental method using a pretest-posttest control group design. This design was selected because it enables comparison of learning outcomes between the group receiving the treatment (monitoring-based module) and the control group (conventional instruction), without full randomization of subjects. The research design is represented as follows:

O_1 — X — O_2 (Experimental Group)

O_1 — — O_2 (Control Group)

Note: O_1 = pretest, O_2 = posttest, X = treatment using the Nutmeg Flower Dryer Monitoring Module.

Population and Sample

The population of this study comprised all eleventh-grade students enrolled in the Electronics Engineering program at State Vocational High Schools (SMK Negeri) in Manado, North Sulawesi. A sample of 60 students was selected using purposive sampling based on the availability of electronics laboratory facilities and the relevance of the subject matter to the vocational competencies being studied.

The sample was divided into two groups: an experimental group (n=30) receiving instruction using the IoT-based Nutmeg Flower Dryer Monitoring Module, and a control group (n=30) receiving conventional instruction via textbooks and lecture-based delivery. Group assignment was based on existing intact classes to avoid disruption to regular learning schedules.

Research Instruments

Two types of instruments were used in this study: (1) a Digital Literacy Test and (2) a Student Response Questionnaire.

1. **Digital Literacy Test.** The test instrument consisted of 40 multiple-choice items developed by the researchers based on the UNESCO Digital Literacy Framework (UNESCO, 2018), covering four dimensions: (a) information literacy (10 items), (b) data literacy (10 items), (c) communication literacy (10 items), and (d) technology use literacy (10 items). The instrument was validated by two expert lecturers in educational technology. Content validity was confirmed using a Content Validity Ratio (CVR) of 0.87, and reliability was measured using Cronbach's Alpha ($\alpha = 0.89$), indicating high reliability.
2. **Student Response Questionnaire.** A 20-item Likert-scale questionnaire was administered to the experimental group upon completion of the intervention. The questionnaire assessed four aspects: module attractiveness, clarity of instructions, relevance to the vocational context, and perceived benefit to students' digital literacy. Each item was rated on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree).

Research Procedure

The study was conducted in three main stages:

1. **Preparation Stage.** Installation of the nutmeg flower dryer monitoring system in the school electronics laboratory, validation of the test instrument by expert reviewers, and administration of the pretest to both groups one week prior to the intervention.
2. **Implementation Stage.** The experimental group participated in six 90-minute learning sessions over three weeks (two sessions per week) using the Nutmeg Flower Dryer Monitoring Module. Each session included an entry quiz, a structured observation worksheet, direct interaction with the Node-RED dashboard, and a reflective writing exercise. The control group received equivalent contact hours through lectures and textbook exercises on digital literacy topics.
3. **Evaluation Stage.** The post-test was administered one week after the final session. The student response questionnaire was distributed to the experimental group immediately following the post-test. All collected data were then subjected to statistical analysis.

Data Analysis Technique

Data were analyzed using two primary approaches:

1. **Inferential Statistical Testing.** An independent samples t-test was used to compare post-test scores between the experimental and control groups at a significance level of $\alpha = 0.05$. Normality testing (Shapiro-Wilk) and homogeneity of variance testing (Levene's test) were conducted as prerequisites before the t-test. Effect size was calculated using Cohen's d to assess the practical significance of between-group differences.
2. **N-gain Analysis.** Module effectiveness was measured using the normalized gain (N-gain) score based on the formula by Hake (1998):

   N-gain = (Post-test Score − Pre-test Score) / (Maximum Score − Pre-test Score)
3. N-gain classification follows Hake's criteria: N-gain ≥ 0.70 is categorized as "high"; $0.30 \leq$ N-gain < 0.70 as "medium"; and N-gain < 0.30 as "low." N-gain analysis was conducted both overall and per digital literacy dimension to identify the areas most significantly influenced by the module intervention.

RESULT AND DISCUSSION

Pre-Test and Post-Test Score Comparison

Table 3 presents the descriptive statistics for both groups across pre-test and post-test assessments. Both groups showed comparable pre-test scores, confirming equivalence at baseline (independent samples t-test: $t(58) = 0.43$, $p = 0.67$, not significant). Following the intervention, the experimental group demonstrated substantially higher post-test scores compared to the control group.

Table 1. Pre-test and post-test descriptive statistics for experimental and control groups.

Parameter	Exp. Pre-test	Exp. Post-test	Ctrl. Pre-test	Ctrl. Post-test
Mean Score	42.6	71.0	43.1	52.3
Standard Deviation	7.3	8.1	7.9	8.6
Minimum Score	28	52	29	34
Maximum Score	58	90	60	72
Mean Gain Score	—	28.4	—	9.2

N-Gain Analysis and Statistical Significance

The normalized gain (N-gain) was calculated for each student using the formula: N-gain = (Post-test − Pre-test) / (100 − Pre-test). The mean N-gain for the experimental group was 0.71, categorized as "high" effectiveness according to Hake's classification (≥0.70 = high; 0.30–0.69 = medium; <0.30 = low). The control group's mean N-gain was 0.16, categorized as "low."

An independent samples t-test comparing post-test scores yielded $t(58) = 10.24$, $p < 0.001$, confirming a statistically significant difference in favor of the experimental group. Effect size was calculated using Cohen's $d = 2.30$, indicating a very large practical effect. These results strongly support the hypothesis that the monitoring module is significantly more effective than conventional instruction in developing digital literacy.

Table 2. N-gain scores by digital literacy dimension for the experimental group.

Digital Literacy Dimension	Pre-test Mean	Post-test Mean	N-gain
Information Literacy	10.8	18.2	0.74
Data Literacy	9.6	17.1	0.72
Communication Literacy	11.2	18.8	0.77
Technology Use Literacy	11.0	16.9	0.64
Overall	42.6	71.0	0.71

Student Response and Engagement

A 20-item Likert-scale student response questionnaire was administered to the experimental group following the intervention. The questionnaire assessed module attractiveness, clarity of instruction, relevance to vocational context, and perceived benefit to digital literacy. Results indicate high levels of positive response: 86.7% of students rated the module as “very attractive,” 90% found the instructions clear, 93.3% agreed the module was relevant to their vocational context, and 83.3% perceived significant improvement in their digital literacy after completing the module.

The results confirm that the Nutmeg Flower Dryer Monitoring Module is highly effective in improving students' digital literacy. The N-gain score of 0.71 places the module in the high effectiveness category, comparable to findings by Prasetyo et al. (2021) who reported N-gain scores of 0.68–0.74 for IoT-integrated vocational learning modules. The very large effect size (Cohen's d = 2.30) indicates that module-based contextual learning creates substantially superior learning outcomes compared to conventional approaches.

Analysis by literacy dimension reveals that Communication Literacy showed the highest gain (N-gain = 0.77), likely attributable to the direct experience students had with MQTT network communication and real-time dashboard interaction. Technology Use Literacy, while still categorized as high, showed the lowest gain (N-gain = 0.64), suggesting that hardware interaction components of the module may benefit from more structured scaffolding in future iterations.

The high student engagement and positive response (86–93% satisfaction rates) support the conclusion that vocational contextualization is a key factor in module acceptance. Students expressed in reflective writings that seeing technology applied to a local industry product — nutmeg, which is familiar to students in North Sulawesi — made abstract digital concepts tangible and meaningful. This aligns with situated learning theory as proposed by Lave and Wenger (1991), which posits that learning is most effective when embedded in authentic activity.

A limitation of this study is its single-school, single-semester scope. Generalizability to other vocational contexts and student populations would require multi-site replication. Future work should also explore longitudinal retention of digital literacy gains, optimize the LU5 troubleshooting unit for higher cognitive outcomes, and investigate the potential for remote or hybrid delivery of the module using cloud-based dashboard platforms.

CONCLUSION

The study concludes that the Nutmeg Flower Dryer Monitoring Module is highly effective in improving vocational students' digital literacy comprehension. Quantitative analysis demonstrated a significant increase in overall digital literacy scores for the experimental group, with particularly strong gains in communication literacy (N-gain = 0.77) and data literacy (N-gain = 0.72). The integration of IoT-based monitoring within a familiar agricultural context enabled students to interpret real-time process data, engage with digital tools, and critically evaluate technological information. These findings underscore the importance of contextualized, hands-on learning for bridging technical knowledge with digital competencies in secondary vocational education.

For future research, it is recommended to expand the study across multiple vocational schools and diverse agricultural or technical contexts to improve generalizability. Longitudinal studies could assess retention of digital literacy gains over time and explore the impact of remote or hybrid delivery using cloud-based dashboards. Additionally, refining module components, such as hardware interaction scaffolding, may enhance learning outcomes in technology use literacy. Exploring the application of similar contextualized IoT modules in other vocational domains could further validate the model and support broader curriculum integration.

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