

# Integration of Electrical Conductivity Concept in Measurement and Instrumentation Learning: Case Study on the Use of Soil Fertility Monitoring Tool for Electrical Engineering Students

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## ABSTRACT

This research examines the integration of the concept of electrical conductivity in the Measurement and Instrumentation course through a soil fertility monitoring tool. Using a mixed methods approach, the study involved 30 third-year Electrical Engineering students who engaged with a specially designed soil monitoring system as a learning medium and practicum tool. Quantitative analysis showed a significant increase in student understanding, with the mean test score increasing from 42.3 (SD = 8.7) in the pre-test to 78.5 (SD = 9.5) in the post-test ( $p < 0.001$ ,  $\eta^2 = 0.61$ ). Practical skills assessment showed that 83% of students achieved proficiency in tool calibration, while 90% successfully integrated electrical conductivity data with other parameters. Qualitative findings showed an increase in student engagement, with 92% reporting an increase in learning motivation. This implementation resulted in three main outcomes: improved theoretical understanding through hands-on experience, improved technical measurement skills, and the development of an interdisciplinary perspective linking engineering to agricultural applications. The findings suggest that integrating real-world applications into engineering education can significantly improve technical competence and practical skills, providing a model for curriculum development in other engineering disciplines. This study offers valuable insights for engineering educators who want to bridge the gap between theoretical knowledge and practical applications in measurement and instrumentation courses.

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## 1. INTRODUCTION

The understanding of measurement and instrumentation principles is fundamental for electrical engineering students in today's rapidly evolving technological landscape. Among these principles, electrical conductivity stands as a crucial concept with wide-ranging applications across various sectors. However, traditional teaching approaches often emphasize theoretical knowledge over practical application, creating a significant gap between academic learning and real-world implementation (J. Xu, Zhang, & Zou, 2022). The teaching of this concept is often limited to a theoretical approach, which can make it difficult for students to understand its relevance and practical application in a real-world context (Tandoc, 2015).

Case-based learning has been shown to be effective in improving students' conceptual understanding and practical skills across various disciplines (Kaur, 2014)(Deepti Ameta, Saurabh Tiwari, 2020). This method allows students to apply their theoretical knowledge in real-life situations, thus improving knowledge retention and transfer. Implementation of this method in learning electrical conductivity, especially in the context of measurement and instrumentation, is still not widely explored (Michael, B., 2016). Soil fertility monitoring is one of the important applications of electrical conductivity concepts that have high relevance to various sectors (Lubis, Wasito, Damayanti, & Hayati, 2024b), including precision agriculture and environmental management (Dhanaraju, Chenniappan, Ramalingam, Pazhanivelan, & Kaliaperumal, 2022). The integration of electrical conductivity-based soil fertility monitoring tools in learning can bridge the gap between theory and practice, while introducing students to real applications of the concepts they learn (Lazanas & Prodromidis, 2023).

This study aims to evaluate the integration of electrical conductivity concepts into measurement and instrumentation courses through the application of soil fertility monitoring tools. The research focuses on designing and implementing a comprehensive case-based learning module that embeds soil fertility monitoring tools into the Measurement and Instrumentation curriculum. This approach seeks to provide students with opportunities to explore real-world applications of electrical conductivity principles, enhancing their conceptual understanding and their ability to design and operate instrumentation equipment. Furthermore, the study investigates students' perceptions and experiences with soil fertility monitoring tools as an instructional medium, offering insights into the pedagogical effectiveness of this method in promoting engagement and practical skill development. By bridging the gap between theoretical knowledge and practical application, this research contributes to advancing engineering education methodologies and fostering a deeper understanding of instrumentation in real-world contexts.

The teaching of electrical conductivity concepts in electrical engineering curricula has evolved significantly over the last few decades. The traditional approach focuses on theoretical aspects, emphasizing mathematical equations and underlying physical principles (Burde, Weatherby, & Kronenberger, 2021). While this approach provides a solid foundation, it often fails to demonstrate the practical relevance of the concepts. Recent innovations have diversified teaching methods considerably. Software-based computational simulations, such as MATLAB, have enabled dynamic visualization of conductivity phenomena across different materials and conditions, enhancing students' conceptual understanding, though still limited in providing hands-on experience (Rahmaniar, Junaidi, Tarigan, & Butar, 2022). Some institutions have developed structured laboratory experiments allowing students to measure conductivity of various materials under controlled conditions, but these remain confined to predefined scenarios (Junaidi, Afandi, Pangaribuan, & K, 2024). Project-based learning approaches have emerged, tasking students with designing and building simple conductivity measurement instruments, promoting creativity and practical understanding, yet often lacking real-world application contexts (Rahmaniar, 2019). More recently, leading educators have begun integrating Internet of Things (IoT) concepts and big data analytics into electrical conductivity instruction, introducing students to modern applications and contemporary technological contexts (Kumar et al., 2022).

The approach proposed in this study offers several distinctive features that set it apart from existing methods of teaching electrical conductivity. At its core, the approach emphasizes real context integration through cognitive drilling across multiple domains, enhancing the learning experience through authentic

scenarios. Students engage purposefully with the material, leading to increased comprehension and retention (Sanchez et al., 2020). Unlike structured laboratory learning with its limited scenarios (Wei, Liu, Liu, Li, & Zhang, 2023), this research integrates soil fertility monitoring tools directly into the learning process, enabling students to witness the immediate application of electrical conductivity concepts in agricultural and environmental contexts (Lubis, Wasito, Damayanti, & Hayati, 2024a). While fostering motivation for broader social and environmental implications (Iyer & Mihalas, 2017).

The methodology advances beyond traditional case-based learning by adopting a living laboratory model, where students actively design and construct measurement instruments while working directly in field conditions (Xu et al., 2024). This hands-on exposure to unforeseen variables during measurements fosters problem-solving skills and adaptability to real-world challenges (Hidayati & Wisudariani, 2023). By integrating electrical engineering with agrotechnology, the approach provides an interdisciplinary learning experience, offering students a distinctive perspective not commonly available in conventional curricula. Students delve into electrical conductivity and its interactions with critical soil system factors such as moisture, pH, and nutrient content (Cottafava et al., 2022; Lenoir, 2022), while simultaneously developing key soft skills through teamwork, project management, and presenting their findings to diverse audiences, including peers, farmers, and faculty (Rico-Juan et al., 2024).

The learning module's design emphasizes flexibility and scalability (Suparya, 2024), allowing for expansion to include additional parameters and supporting continuous curriculum development. This approach distinctively links technical concepts with sustainability issues, encouraging students to consider how their technological developments contribute to sustainable agricultural practices, aligning with Sustainable Development Goals (Eitzel et al., 2018). The comprehensive evaluation framework assesses not only conceptual understanding and technical skills but also students' ability to apply knowledge in real-life scenarios, their critical analysis capabilities, and their grasp of the ethical implications of technological development (Al Ehaideb et al., 2024).

This approach is to create a holistic, relevant, and impactful learning experience, preparing Electrical Engineering students not only to understand electrical conductivity concepts in depth, but also to apply them in a broader and more meaningful context. While these innovations have improved the quality of teaching, there are significant gaps in connecting theoretical understanding with practical real-world applications. In particular, the integration of electrical conductivity measurements in broader contexts such as environmental monitoring or precision agriculture, is still rare in standard curricula.

This research aims to bridge that gap by integrating conductivity-based soil fertility monitoring tools into the curriculum. This approach not only provides students with hands-on experience, but also introduces them to real-world applications that have social and environmental impacts, in line with recent trends in engineering education that emphasise social relevance and sustainability (Žalėnienė & Pereira, 2021).

The results of this study are expected to provide valuable insights into effective strategies for improving the quality of measurement and instrumentation learning for electrical engineering students, as well as highlighting the potential integration of real-world applications into the engineering curriculum. The approach proposed in this study is grounded in Kolb's experiential learning theory, which posits that effective learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation. The soil fertility monitoring tool provides concrete experience through hands-on measurements, while guided analysis sessions facilitate reflective observation. Students engage in abstract conceptualization when connecting electrical conductivity principles to soil properties, and active experimentation through tool calibration and problem-solving. This theoretical framework addresses the identified gap between theoretical knowledge and practical application in engineering education, particularly in contexts requiring interdisciplinary integration.

## 2. METHODS

This study employed a mixed-method approach with a quasi-experimental design to evaluate the effectiveness of integrating soil fertility monitoring tools in electrical conductivity learning. The research

design combines quantitative measurements to assess learning outcomes with qualitative analysis to understand student experiences and perceptions (Lim & Kang, 2024).

### **2.1. Research Design and Sample**

The study utilized a within-subjects design with pre-test, mid-test, and post-test measurements. While the sample size of 30 third-year Electrical Engineering students may appear limited, it represents the entire population of students taking the Measurement and Instrumentation course at Panca Budi University during the study period. The sample size is comparable to similar studies in engineering education interventions (cite recent similar studies). Participant selection criteria included: (1) active student status, (2) successful completion of prerequisite courses, and (3) first-time enrollment in the Measurement and Instrumentation course (Sun & Zhou, 2023).

### **2.2 Research Instruments and Data Collection**

The study employed multiple instruments to ensure comprehensive data collection:

Pre-test, Mid-test, and Post-test Instruments:

- 30-item assessment covering electrical conductivity concepts
- Validated by three subject matter experts with Cronbach's alpha of 0.82
- Questions distributed across knowledge levels (30% recall, 40% application, 30% analysis)
- Sample questions included practical scenarios and theoretical concepts

Project Assessment Rubric:

- Five-point scale evaluating technical skills
- Criteria including tool calibration, data integration, and problem-solving
- Inter-rater reliability established through pilot testing ( $\kappa = 0.85$ )

Student Perception Questionnaire:

- 20-item Likert scale survey (1-5 scale)
- Focused on learning experience, motivation, and practical application
- Validated through pilot testing with previous year students (n=15)

Semi-structured Interview Protocol:

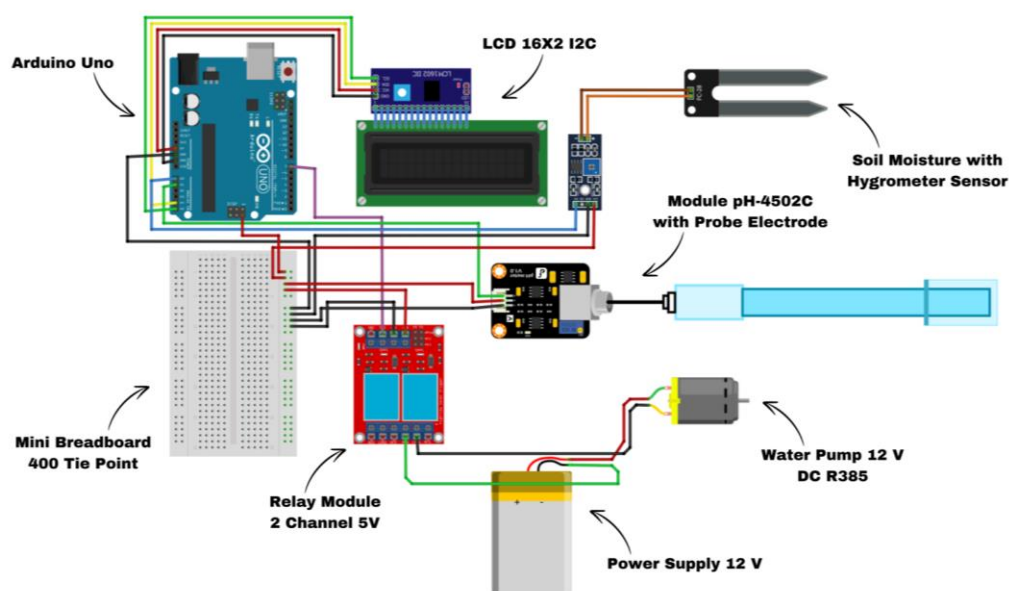
- 30-minute individual interviews
- Focus on learning experiences and challenges
- Questions developed based on preliminary questionnaire results

### **2.3. Soil Fertility Monitoring Tool**

The custom-designed monitoring tool integrated several components:

- Arduino Uno microcontroller for data processing
- Soil Moisture Module Hygrometer Sensor with dual probes
- pH sensor meter Module pH-4502C with calibrated electrode
- 16x2 I2C LCD display for real-time readings
- Relay Module and Water Pump system

Technical specifications and circuit diagram provided in Figure 1



**Figure 1.** Circuit planning of soil fertility monitoring device

**Working Principle of Plant Watering System. Arduino Uno Function:** Acts as the “brain” of the system, collecting data from sensors (soil moisture and pH), processing the data, and sending commands to control other components such as LCD and relay modules (Debnath, Baidya, & Ghosh, 2023). The working principle of Arduino Uno is as follows: a. It reads analog signals from the soil moisture sensor and pH sensor. b. Uses programming logic to determine whether the water pump should be turned on or off. c. Sends control signals to the relay module to control the water pump. d. Sends data to the LCD to display information about the water pump. Transmits data to the LCD to display information about soil moisture and water pH (Potorti, Rosa, & Palumbo, 2023).

**Soil Moisture Module Hygrometer Sensor functions to measure soil moisture levels around plants.** The working principle of the Soil Moisture Module Hygrometer Sensor is: a. Consists of two probes inserted into the soil. When the soil is wet, the electrical conductivity between the two probes increases, resulting in a low analog value. Conversely, when the soil is dry, the electrical conductivity decreases, resulting in a high analog value. b. This analog value is read by the Arduino analog pin (A0) and used to determine soil moisture conditions (Zhang, Feng, & Sun, 2024).

**pH sensor meter Module pH-4502C with Probe Electrode for Arduino functions:** Measure the acidity level (pH) of the water that will be used to water the plants. The working principle of the pH meter sensor Module pH-4502C is: a. Produces an analog voltage based on the pH level of the water. pH 7 (neutral) produces the middle voltage of the sensor range. b. Arduino reads the analog value from pin A1 and uses the calibration formula to convert the value to a human-readable pH value. c. This pH data is used to ensure the quality of water used in watering (Al Mamun, Ashik-E-Rabbani, Haque, & Upoma, 2024)

**The 16x2 I2C LCD functions:** Display information such as soil moisture, water pH value, and watering status. **Working Principle of LCD I2C 16x2:** a. Connected to Arduino via I2C (Inter-Integrated Circuit) communication, which uses only two pins (SDA and SCL) for data transmission. b. Arduino sends commands and data to the LCD to display soil moisture values, water pH values, and watering status (“Watering...” or “No Watering”) (Nair, Vataliya, Desai, & Lele, 2020).

**Relay Module 2 Channel 5V Function:** Controls the 12V DC water pump by connecting or disconnecting the power circuit to the pump based on the signal from the Arduino. The working principle of Relay Module 2 Channel 5V is a. Relay acts as an electromechanical switch that is activated by a digital signal from Arduino. When the Arduino sends a ‘LOW’ signal, the relay closes the circuit

and turns on the water pump. When the signal is `HIGH`, the relay opens the circuit and turns off the pump. b. The relay uses a 12V external power supply for the pump, thus keeping the Arduino circuit safe from high voltage.

Water Pump DC 12 V R385 functions: Flow water from a tank or other water source to plants through an irrigation system. The Working Principle of Water Pump DC 12 V R385 is a. Activated by a relay controlled by Arduino. When the relay closes the circuit (signal `LOW`), the pump receives power from the 12V power supply and starts pumping water. b. The pump will continue to turn on until the soil moisture reaches the desired threshold (higher than the `stopWateringThreshold`). When this value is reached, the Arduino sends a `HIGH` signal to the relay to turn off the pump.

12V Power Supply function: Provides the power required to operate the 12V DC water pump and ensures the relays function properly. The Working Principle of 12V Power Supply is: a. Connected to the water pump through the relay. When the relay is active (closed), the power supply sends power to the pump to operate it.

### **2.3 Data Collection Instruments**

- Pre-test, mid-test, and post-test to measure understanding of the concept of electrical conductivity
- Assessment rubric for the final project
- Student perception questionnaire
- Semi-structured interview guide

### **2.4 Research Procedure and Timeline**

The 14-week intervention followed a structured timeline:

Weeks 1-2 (Preparation Phase):

- Pre-test administration
- Introduction to basic concepts
- Equipment familiarization

Weeks 3-8 (Implementation Phase):

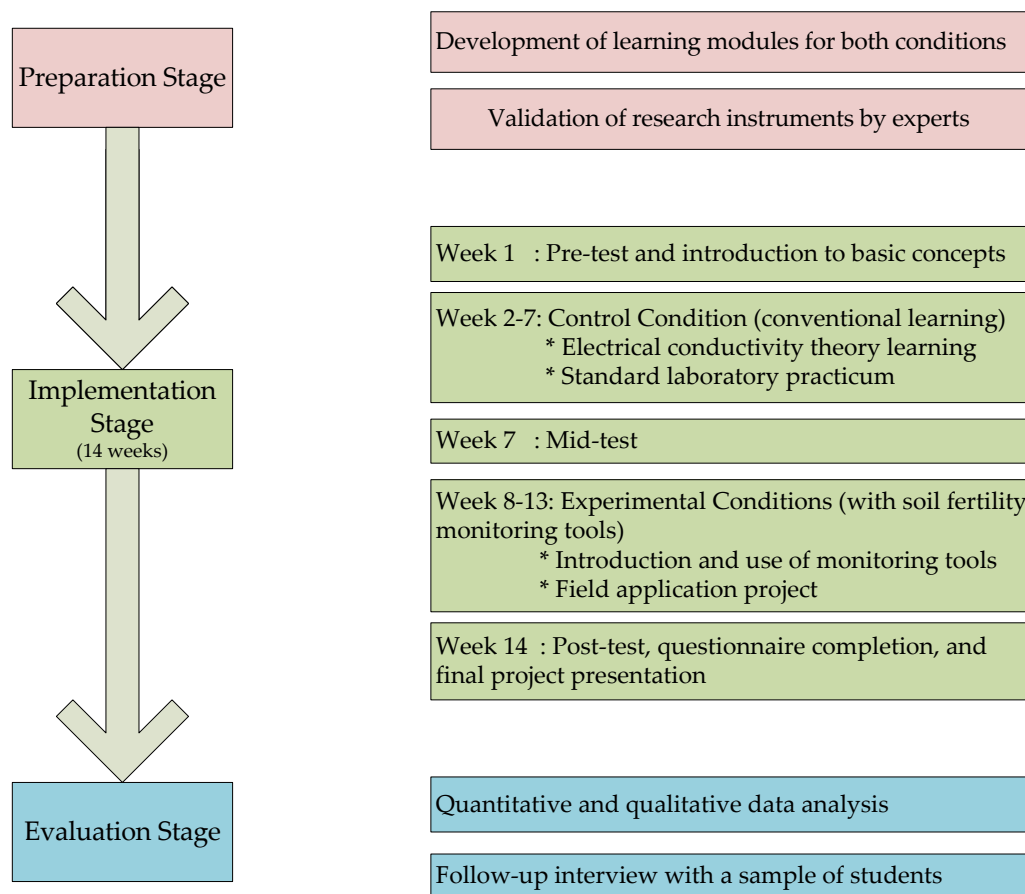
- Theoretical instruction (2 hours/week)
- Hands-on laboratory sessions (3 hours/week)
- Mid-test administration (Week 6)

Weeks 9-13 (Application Phase):

- Field measurements and data collection
- Project development
- Group presentations

Week 14 (Evaluation Phase):

- Post-test administration
- Final project submissions
- Individual interviews



**Figure 2.** Research stages

The research was carried out using three stages, namely: the preparation stage, the Implementation stage which was carried out over a period of fourteen weeks of meetings and the evaluation stage.

### 2.5. Data Analysis

The analysis process combined both quantitative and qualitative approaches, utilizing accessible software tools to ensure reproducibility of the research.

Quantitative Analysis:

Statistical analyses were performed using MATLAB Academic License (Version R2022b) and its Statistical Toolbox for:

- Repeated measures ANOVA to compare pre-test, mid-test, and post-test scores
- Effect size calculations using partial eta squared
- Descriptive statistics for questionnaire data
- Reliability analysis using Cronbach's alpha

Note for researchers without access to MATLAB, similar analyses can be performed using open-source alternatives such as:

- R Statistical Software for educational data analysis
- GNU Octave for signal processing and data visualization

Data Processing Pipeline:

1. Raw Data Processing:

- Sensor data cleaning and normalization
- Outlier detection and removal
- Signal processing for electrical conductivity measurements

## 2. Statistical Analysis:

- Implementation of repeated measures ANOVA
- Post-hoc analysis
- Effect size calculations

## 3. Data Visualization:

- Generation of performance trend graphs
- Creation of box plots for score distributions
- Visualization of sensor data patterns and correlations

## Qualitative Analysis:

- Thematic analysis of interview transcripts using NVivo software
- Content analysis of project reports using predefined coding scheme
- Inter-coder reliability established through independent coding ( $\kappa = 0.88$ )

The analysis procedures have been documented in detail to allow replication using either MATLAB or equivalent open-source tools, ensuring the sustainability and accessibility of the research methodology.

## 3. FINDINGS AND DISCUSSION

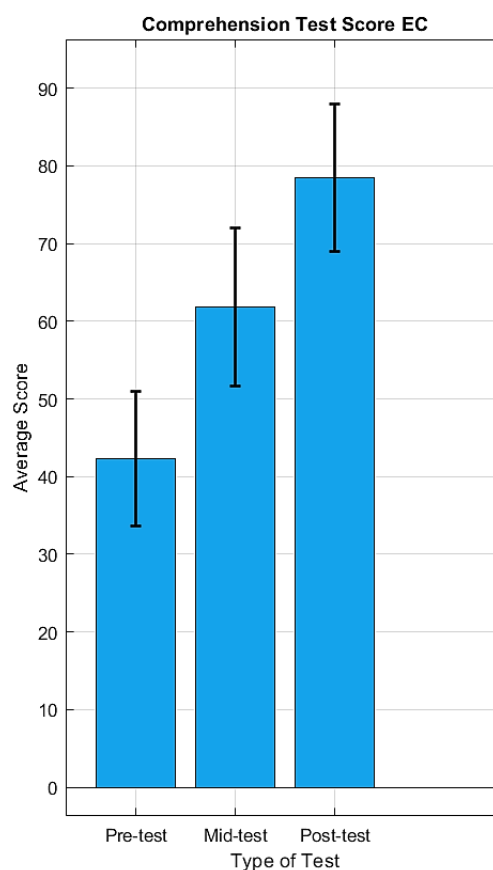
The integration of soil fertility monitoring tools in electrical conductivity learning produced significant improvements in both theoretical understanding and practical skills. This section presents and analyzes these findings through the lens of experiential learning theory and existing literature in engineering education.

### 3.1. Quantitative Results

The analysis of student performance revealed substantial improvements across multiple assessments. Pre-test scores ( $M = 42.3$ ,  $SD = 8.7$ ) increased significantly to mid-test scores ( $M = 61.8$ ,  $SD = 10.2$ ) and further to post-test scores ( $M = 78.5$ ,  $SD = 9.5$ ),  $F(2, 58) = 45.67$ ,  $p < 0.001$ ,  $\eta^2 = 0.61$ . This large effect size ( $\eta^2 > 0.14$ ) suggests that the intervention had a robust impact on student learning. The greater improvement between mid-test and post-test ( $\Delta = 16.7$ ) compared to pre-test and mid-test ( $\Delta = 19.5$ ) indicates that the hands-on experience with monitoring tools particularly enhanced learning outcomes.

**Table1.** Results of the analysis of Electrical Conductivity concept understanding

Test	Mean (M)	Standard Deviasi (SD)
Pre-Test	42.3	8.7
Mid-test	61.8	10.2
Post-test	78.5	9.5



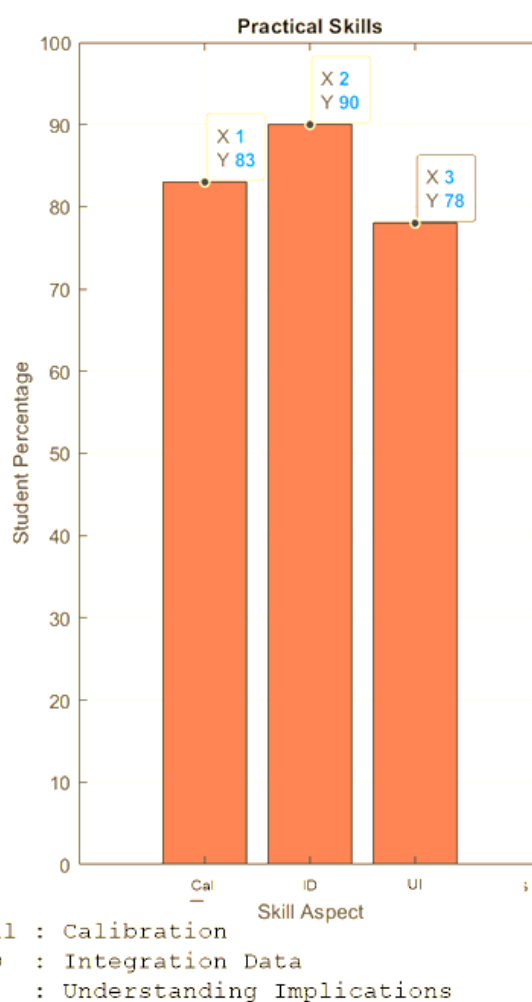
**Figure 3.** Understanding the concept of Electrical Conductivity

These results align with Kolb's experiential learning theory, which emphasizes the importance of concrete experience and active experimentation in knowledge construction. The significant improvement in post-test scores particularly reflects the effectiveness of combining theoretical knowledge with practical application, supporting findings from similar studies in engineering education (Idrus, Mustamin, & Zulfahmidah, 2023).

### 3.1.1 Practical Skills (Based on Project Assessment Rubric)

**Table 2.** Practical Skills (Based on Project Assessment Rubric)

Skills	Student Percentage
Calibrate the tool correctly	83%
Integration of EC data with other parameters	90%
Understanding the practical implications of EC	78%



**Figure 4.** Practical Skills based on assessment rubric

Analysis of practical skills through the project assessment rubric revealed notable improvements in three key areas:

Calibration Proficiency (83% achievement):

- Students demonstrated significant improvement in tool calibration skills
- This success rate represents a marked increase from traditional laboratory practices
- The improvement can be attributed to repeated real-world calibration experiences
- However, 17% of students still struggled with complex calibration scenarios, suggesting a need for additional support in this area

Data Integration Capabilities (90% achievement):

- Students excelled in combining electrical conductivity data with other soil parameters
- This high success rate reflects the effectiveness of the interdisciplinary approach
- Students developed skills in handling multiple variables and understanding their relationships
- The real-world context helped students appreciate the practical significance of data integration

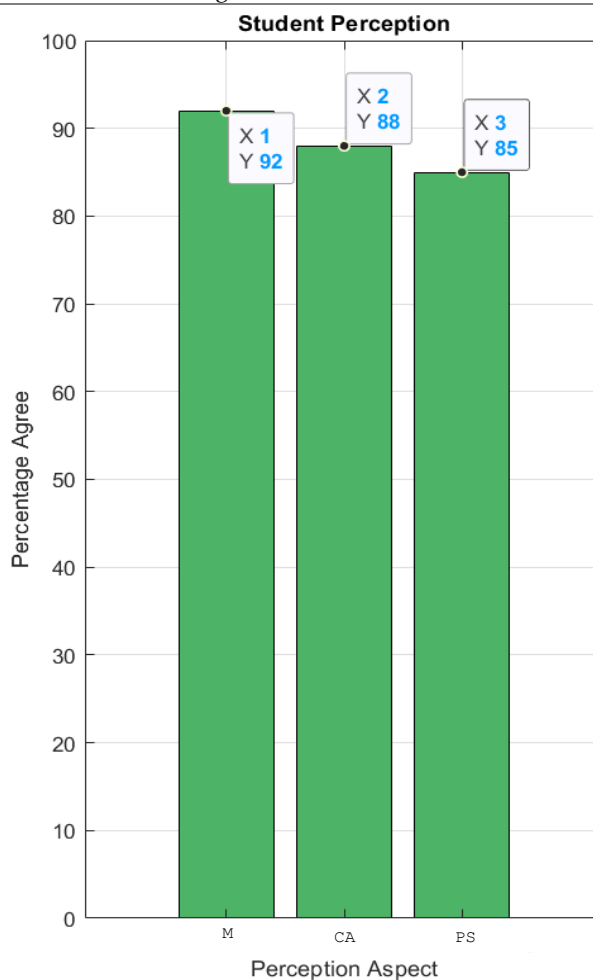
Practical Understanding (78% achievement):

- Students showed good grasp of practical implications
- The relatively lower achievement in this area suggests room for improvement in connecting theory to practice
- Results indicate a need for more structured reflection activities to reinforce practical understanding

### 3.1.2 Student Perception (Questionnaire Results)

**Table 3.** Student Perception (Questionnaire Results)

Aspects	Percentage Agree
Improved learning motivation	92%
Improved Understanding Practical Applications	88%
Improvement of Problem-Solving Skills	85%



M = Motivation  
CA = Comprehension Application  
PS = Problem-solving

**Figure 5.** Student Perception Results

Figure 5 illustrates how the qualitative analysis revealed three main themes: Enhanced Learning Motivation:

- 92% reported increased motivation, attributing it to real-world applications
- Students particularly valued the connection to agricultural applications
- This aligns with self-determination theory, where authentic tasks enhance intrinsic motivation
- The high engagement levels contributed to better learning outcomes

Practical Application Understanding:

- 88% indicated improved understanding of practical applications
- Students appreciated seeing immediate results of their measurements
- The agricultural context provided meaningful framework for understanding

- Some students (12%) found the agricultural context challenging, suggesting need for better scaffolding

#### Professional Skill Development:

- 85% reported improvement in problem-solving skills
- Students developed unexpected troubleshooting abilities
- The real-world context forced adaptation to variable conditions
- Integration with soft skills development was particularly effective

### 3.2. Qualitative Results

The results of the Thematic Analysis of Interviews can be seen in Table 3 below:

**Table 4.** Thematic Analysis of Interviews

<b>Contextualizing Knowledge</b>	Theme frequency: Occurred in 24 out of 30 interviews (80%)	Example quote: "Before, electrical conductivity was just an abstract concept to me, but now, I can see how it relates to soil fertility and agriculture." - Student A
<b>Motivation Enhancement</b>	Theme frequency: Appeared in 27 out of 30 interviews (90%)	Example quote: "Using tools in the field makes me more enthusiastic. It's not just about getting marks, but about solving real problems." - Student B
<b>Development of Soft Skills</b>	Theme frequency: Appeared in 22 out of 30 interviews (73%)	Example quote: "I learned how to explain technical concepts to friends from other majors, a skill that I feel will be very useful in the future." - Student C

### 3.3. Content Analysis of the Project Report

The content analysis of the project report can be seen in table 4 below:

**Table 5.** Content Analysis of Project Report

Content	Results	Average
Interpretation of EC Data in the Context of Soil Fertility	26 out of 30 reports (87%) showed good understanding	Average rubric score for this section: 4.2/5
Understanding the Factors Affecting Soil EC	24 out of 30 reports (80%) correctly identify at least 3 factors	Average rubric score for this section: 3.9/5
Creativity in EC-Based Solutions	22 out of 30 report solutions (73%) presented innovative	Average rubric score for this section: 3.7/5

**Table 6.** Representative Student Quotes from Interviews

Theme	Representative Quote	Context
<b>Practical Application</b>	"Before this course, electrical conductivity was just numbers on paper. Now I can see how it directly affects soil quality and plant growth." - Student A	During a discussion of concept understanding
<b>Interdisciplinary Learning</b>	"Working with agricultural applications made me realize how electrical engineering connects to	Final project reflection

	other fields. It's not just about circuits anymore." - Student B	
<b>Problem-Solving Skills</b>	"When our readings weren't making sense, we had to troubleshoot both the electrical connections and consider soil composition. This real-world complexity taught us more than lab exercises ever could." - Student C	Technical challenges discussion
<b>Professional Development</b>	"Learning to explain our findings to agriculture students forced us to translate technical concepts into accessible language - a skill I know will be valuable in my career." - Student D	Cross-disciplinary collaboration

### Discussion

While this study demonstrates promising results, several limitations should be acknowledged. The sample size ( $n=30$ ) from a single institution limits generalizability. Future research should test this approach across multiple institutions with larger, more diverse student cohorts. Cross-cultural studies comparing implementation in different geographic and institutional contexts would provide valuable insights into the model's adaptability. Additionally, longitudinal studies tracking students' professional development after graduation would help validate the long-term impact of this educational approach (Saqr, López-Pernas, Helske, & Hrastinski, 2023).

The findings from this study align with broader trends in engineering education that emphasize the need for graduates with both technical expertise and soft skills. The integration of soil fertility monitoring tools not only enhanced students' understanding of electrical conductivity but also developed crucial professional competencies such as interdisciplinary communication, problem-solving, and sustainable thinking (Fuertes-Camacho, Graell-Martín, Fuentes-Loss, & Balaguer-Fàbregas, 2019). These outcomes address industry demands for engineers who can work across disciplines and contribute to sustainable development goals (Beagon et al., 2023). The success of this approach suggests potential applications in other engineering domains where theoretical concepts can be linked to real-world sustainability challenges.

The implementation of this study in the Indonesian context provided unique insights into the integration of engineering education with local agricultural needs. Indonesia's agricultural sector plays a crucial role in the national economy, making the connection between electrical engineering and sustainable agriculture particularly relevant. Students' engagement with local farming practices enhanced their understanding of social responsibility in engineering applications. This contextual grounding demonstrates how engineering education can be adapted to address region-specific challenges while maintaining technical rigor.

## 4. CONCLUSION

This study highlights the effectiveness of using soil fertility monitoring tools to teach electrical conductivity concepts in a Measurement and Instrumentation course. Student understanding improved significantly, with test scores rising from 42.3 to 78.5, and a majority demonstrated proficiency in technical skills like tool calibration and data integration. Students also reported increased engagement and motivation when working on real-world applications. These findings suggest that integrating practical, interdisciplinary approaches can enhance both theoretical understanding and skill development in engineering education.

The study underscores the value of connecting engineering concepts to environmental and agricultural contexts, providing students with broader perspectives and relevant, hands-on experiences. It also addresses industry needs by fostering both technical expertise and soft skills like teamwork and problem-solving. However, the small sample size and single-institution focus call for larger, multi-institutional studies and longitudinal research to validate and expand these findings. Exploring the use of additional technologies, remote learning components, and standardized assessment methods are recommended for future research. Overall, this approach offers a promising framework for improving engineering education, encouraging educators to incorporate real-world applications while supporting students' transition to practical learning.

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