JPPIPA 12(4) (2026)

Jurnal Penelitian Pendidikan IPA

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Development of an IoT-Based Soil Sensor Practical Tool Integrated with Performance Assessment to Improve Critical Thinking in Grade X High School Students

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Received: October 25, 2025
Revised: March 20, 2026
Accepted: April 25, 2026
Published: April 30, 2026

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DOI: 10.29303/jppipa.v12i4.13256

Abstact: The world of education requires practical tools that are not just demonstrations, but also provide relevant active learning experiences that trigger curiosity and fulfill 21st-century skills, namely critical thinking. This study aims to evaluate the effectiveness of an IoT-based soil sensor practical tool integrated with performance assessment in improving students' critical thinking skills. This study used an embedded mixed-methods experimental design, with a purposive sampling technique to select two classes with similar levels of critical thinking at the beginning of the study. The study involved pre-tests and post-tests in the experimental and control classes. The results showed that the experimental class experienced a significant increase in critical thinking skills, with a post-test score increasing sharply from 48.54 to 90.42, while the control class only increased from 56.60 to 72.99. A significant difference between the two classes was revealed through the ANCOVA test ($p = 0.000$), which showed that the use of IoT-based tools had a significant impact on students' critical thinking skills, with a Partial Eta Squared of 0.550. Thus, the IoT-based soil sensor practical tool integrated with performance assessment has proven effective in encouraging the improvement of students' critical thinking skills, making it an innovative solution in more interactive and applicable science learning.

Keywords: Development, Practical Tools, Soil Sensor, IoT, Performance Assessment, Critical Thinking, Students, Class X, High School.

Introduction

Today's education system desperately needs practical activities that go beyond mere demonstrations of concepts, but also active, relevant learning experiences that spark students' curiosity (Ngango, 2025). Engaging practicals should involve hands-on exploration of connected devices and real-time data analysis to spark deep understanding and critical problem-solving (Gilly Marlya Tiwow, 2025). Furthermore, adequate equipment and materials, along with clear yet flexible guidance, are essential (Suslistya & Mahadewi, 2023). Opportunities to experiment and analyze results independently and in real time are essential for fostering the deep understanding and application skills needed in this ever-evolving era (Srivastava, 2023).

Practical tools in education continue to evolve with increasingly sophisticated technological innovations. Research by Yu et al. (2021) reviews advances in IoT-based soil moisture sensor technology that enables real-time monitoring, addressing the accuracy and calibration issues inherent in traditional sensors (Yu et al., 2021). Potdar et al. (2021) developed a portable sensor to detect soil nutrients using optical methods, although its accuracy was affected by environmental factors (Potdar et al., 2021). In addition, Mikhailova et al. (2025) showed that mobile geospatial applications can enrich earth science learning with soil remote sensing,

How to Cite:
Rista, G., Diawati, C., Rosidin, U., Fadiawati, N., & Herlina, K. (2026). Development of an IoT-Based Soil Sensor Practical Tool Integrated with Performance Assessment to Improve Critical Thinking in Grade X High School Students. *Jurnal Penelitian Pendidikan IPA*, *12*(4), 188–199. https://doi.org/10.29303/jppipa.v12i4.13256

despite the limited accuracy of mobile phone built-in sensors (Mikhailova et al., 2025).

Indonesia also continues to develop laboratory tools and produce various interesting innovations. Researchers such as Yunita Rahmani have developed an Arduino-based demonstration tool for fluid viscosity, which not only measures the travel time of a falling ball but also its velocity with very high accuracy (Rahmani et al., 2022). Furthermore, an IoT-based laboratory tool developed by Barsalinus Milenius Dupat for fire prevention monitoring in laboratory spaces has shown significant progress. The use of sensors to control temperature, humidity, and air quality with an IoT system makes this tool more sophisticated than previous laboratory tools (Dupat, 2023).

However, there remains a significant gap in the availability of devices that allow students to observe experimental results in real-time and measurably. Many existing lab tools focus primarily on demonstrations of concepts or manual measurements, which require further interpretation. This reduces students' opportunities for hands-on experience in validating learned theories, even though the ability to directly observe changes and data during lab work is crucial for deeper understanding and practical application of concepts (Annisya Fauzia Aini, 2025).

The existence of practical tools that can present real-time results has great potential in honing 21st-century skills, one of which is students' critical thinking skills. Critical thinking is the ability to analyze information objectively and reflectively to make reasoned judgments (Miranda et al., 2023). When students can observe changes that occur due to the manipulation of variables in an experiment, they are encouraged to analyze cause-and-effect relationships directly (Ramadhanti, 2022). This process trains their ability to identify patterns, evaluate data objectively, and draw conclusions based on empirical evidence, not just theory (Limiansih, 2024). Direct experience in seeing measurable results will strengthen students' critical thinking skills and build deep understanding (Shahnaz Surayya et al., 2024).

Causal relationships in student learning materials are frequently encountered in everyday life (Supartik & Pasaribu, 2021). For example, in chemistry learning in everyday life, few researchers have developed tools for real-time observation within the surrounding environment. In accordance with the recommendations of previous research by Anisa Syinta Bella, who developed a soil fertility sensor using only lamps and did not describe the soil's content, the need for further development is warranted (Bella, 2025). This is supported by observations in the Purbolinggo area, where cassava factories are located adjacent to farmers' fields, which indicate differences in soil fertility. This environmental issue can be a focus for students in learning to analyze the chemical content of farmers' soil and its impact on soil fertility.

Using IoT technology in lab tools can provide a real solution to this challenge, as it allows the tools to continuously collect sensor data and transmit the data to an application or platform that can be accessed in real time by students and teachers. By integrating pH, moisture, and NPK sensors, students can directly observe the interaction between soil conditions and factors that influence soil fertility (Munfarid et al., 2025).

Challenges arise because the practicum process is only assessed based on the results. Several studies have offered solutions, such as the study by Nsabayezu et al. (2022) who developed a rubric-based formative assessment to support organic chemistry learning, but the lack of real-time interaction is a challenge (Nsabayezu et al., 2022). Haka et al. (2025) created the E-LAAS application to assess Generation Z's scientific literacy, but it has not been fully integrated into chemistry learning with real-time practicum tools (Haka et al., 2025). Desty Endrawari Subroto's analysis of 500 high school respondents across Indonesia shows that 76% of schools have computer labs with limited access, and 24% use technology-enabled labs. At SMAN 1 Purbolinggo, practicum assessment is not optimal because the performance assessment instrument used is still general and without a rubric or structured grid. An analysis of 30 teachers there revealed that 87.34% stated that their school had not yet used sensor-based lab tools, and 90.40% desired IoT-based soil sensor lab tools. Furthermore, 76.40% of teachers had not integrated performance assessment into their teaching, while 85.17% desired more effective and easier-to-implement instruments. The results are as follows (Figure 1).

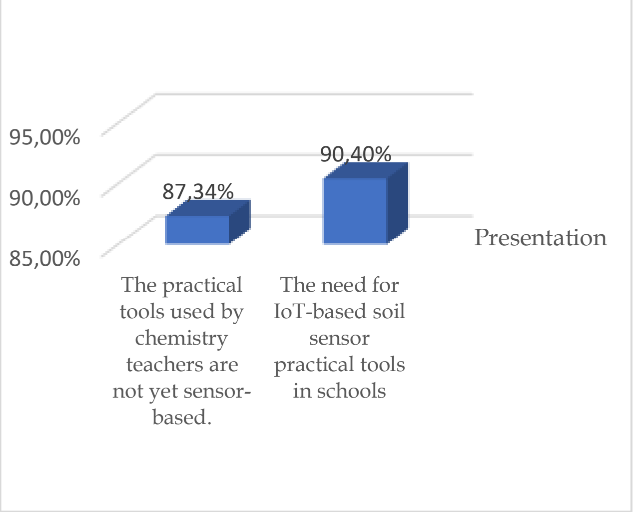

Figure 1. Percentage of Use and Need for IoT-based Soil Sensor Practical Tools

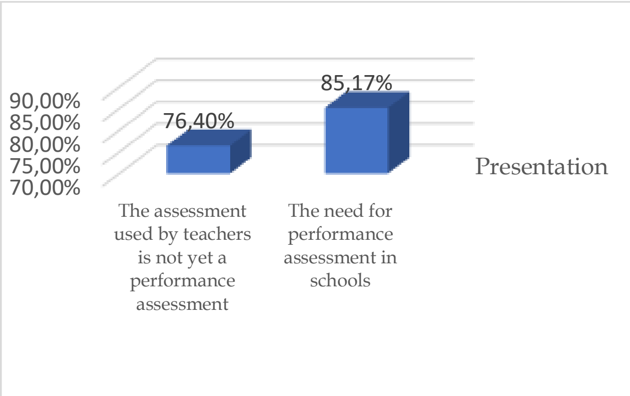

Figure 2. Percentage of Use and Needs *for Performance Assessment*

Researchers offer a solution by developing an IoT-based soil sensor lab tool that integrates performance assessment to improve students' critical thinking skills. By using three main sensors: pH, humidity, and NPK, this lab tool provides real-time data that allows students to quickly observe soil changes. This tool is integrated with *performance assessment* , so students are not only assessed on the final results, but also in the experimental process. Thus, learning becomes more structured and can improve students' critical thinking skills as a whole. This research aims to contribute to the development of more efficient and effective lab tools in improving student understanding through measurable and relevant direct experiences in learning (Budianto et al., 2025).

Method

This study used an embedded mixed-methods experimental design, which began with a qualitative approach through interviews, questionnaires, and assessment of the Independent Curriculum Learning Outcomes before the intervention (Jack R. Fraenkel, Norman E. Wallen, 2011). The culmination of this phase was the development and validation of the Teaching Module and IoT-based sensor practicum tools integrated with performance assessment. The intervention phase involved administering pretests and posttests to the control and experimental classes, with the implementation of the IoT sensor practicum tools only in the experimental class. After the intervention, teacher and student response data were collected through questionnaires and in-depth interviews. The final stage was the analysis of quantitative data supported by qualitative data to draw conclusions regarding the effectiveness of the practicum tools in improving students' critical thinking skills. The following is the design of the research carried out:

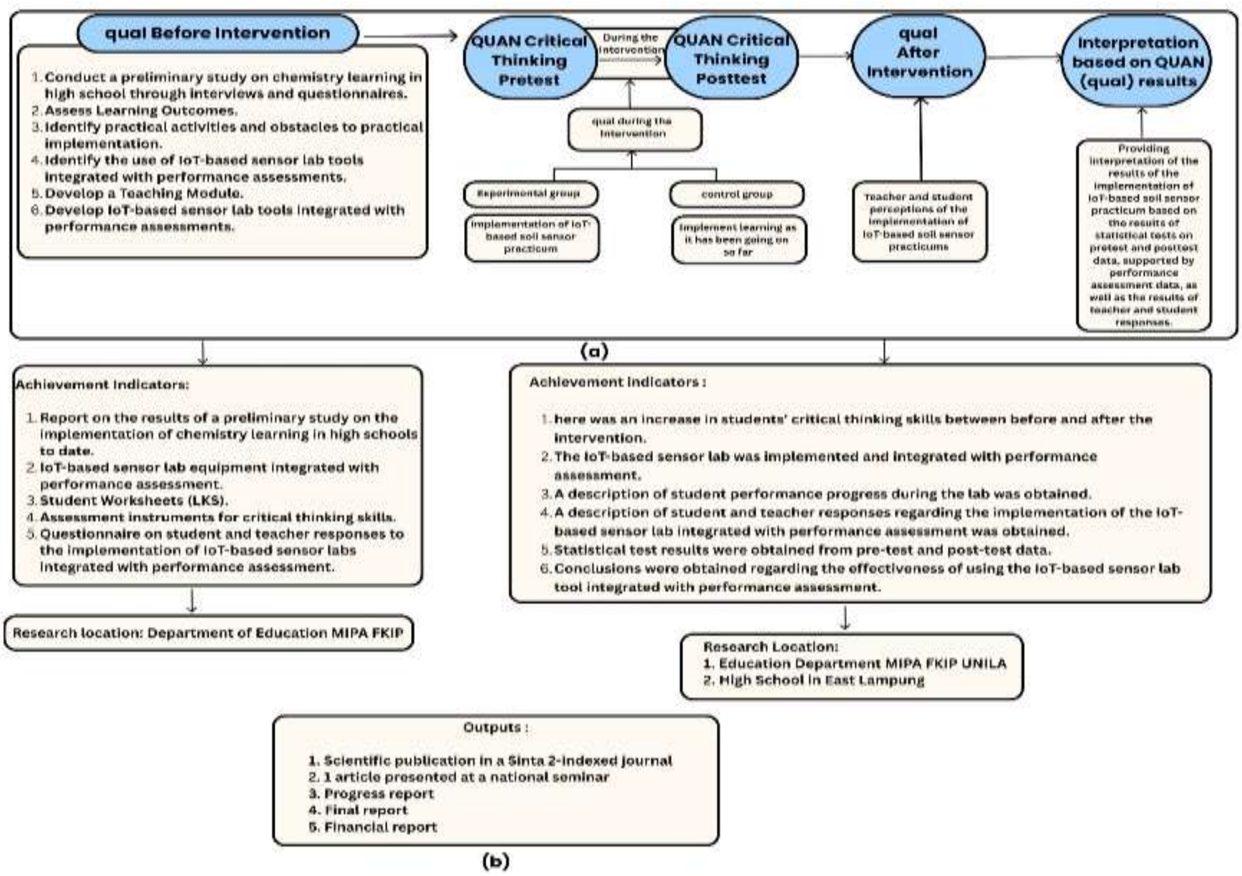

Figure 3. Embedded Mixed-Methods Experimental Design

This study used a purposive sampling technique, where two classes were selected based on similar or not significantly different levels of critical thinking at the beginning of the study. This study used 36 students in the control class and 36 students in the experimental class. Data collection instruments consisted of questionnaires, essay test questions, interviews, and documentation, all of which were validated theoretically by relevant experts. The results of this validation produced an instrument ready for use in data collection. The instrument was divided into several sections according to the objectives , including critical thinking questions to evaluate students' critical thinking skills, student worksheets (LKPD) and analytical rubrics to measure critical thinking skills, content and construct validation questionnaires to assess the feasibility of the media and practicum materials developed.

After the data was collected, analysis was conducted using qualitative and quantitative approaches, which included test and non-test instruments. The test instrument consisted of essay questions on critical thinking related to the material of chemical content in everyday life, which were tested for validity and reliability using the biseral correlation coefficient formula and KR-21. In addition, difficulty and discrimination analysis were conducted to ensure the quality of the questions.

The non-test instruments included an expert validation questionnaire and a teacher and student response questionnaire, which were analyzed using Likert and Guttman scales to measure the feasibility and attractiveness of the IoT-based practicum tool integrated with performance assessment. The analysis was carried out by calculating the percentage of answers which were then categorized according to the product's feasibility and attractiveness criteria. The effectiveness test of the IoT-based soil sensor practicum tool used the N-Gain formula to measure the improvement of students' critical thinking skills. In addition, normality, homogeneity, and ANCOVA tests were conducted to examine data distribution, uniformity of variance between groups, and differences in learning outcomes between the control and experimental classes.

Results and Discussion

This study uses a *mixed method research type* , namely an *embedded mixed-methods experimental design* to evaluate the effectiveness of an Internet of Things (IoT)-based soil sensor practicum tool in improving students' critical thinking skills (Jack R. Fraenkel, Norman E. Wallen, 2011). The results of the study were obtained through data analysis consisting of quantitative data in the form of pre-test and post-test results of critical thinking skills as well as qualitative data obtained from interviews, questionnaires, and observations of teacher and student responses.

In the first stage, qualitative data was obtained through interviews, observations, and questionnaires that resulted in data that science teachers in PBL had implemented performance assessments, but the instruments were still general, without clear specifications, rubrics, and structured grids, so that teachers had difficulty assessing student performance effectively while guiding.

Furthermore, an analysis of 30 PBL high school teachers showed a percentage of 87.34% of teachers stated that schools had not used technology-based chemistry practicum tools such as sensor-based ones, and 90.40% of teachers stated that schools needed IoT-based soil sensor practicum tools. Then the results of the performance assessment needs questionnaire calculation showed that an average percentage of 76.40% of teachers stated that they had not integrated performance assessments in learning, and 85.17% of teachers stated that teachers needed performance assessment instruments that were more effective and easy to implement in learning. This can be explained in figures 4 and 5 which show the following graphs:

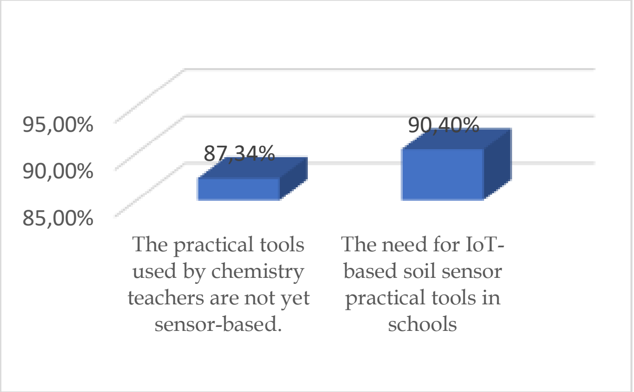

Figure 4. Percentage of Use and Need for IoT-based Soil Sensor Practical Tools

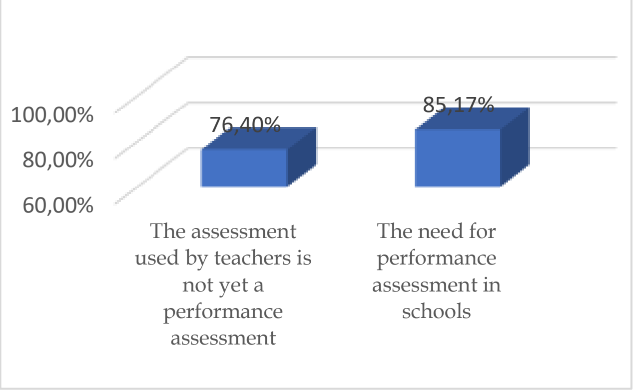

Figure 5. Percentage of Use and Needs *for Performance Assessment*

The material needs analysis focuses on the learning outcomes (CP) that must be achieved by students in phase E of grade X of high school, which include abilities such as observing, questioning, predicting, planning research, analyzing data, and communicating results in the form of experiments. These outcomes are related to various topics, including alternative energy, global warming, environmental pollution, and basic chemistry and its role in everyday life. This research focuses on basic chemistry material and its role in everyday life. The learning objective (TP) after studying the chemical content practicum is for students to be able to plan investigations and provide solutions to everyday life problems by analyzing their relationship to the chemical content.

The challenges in science learning, particularly in improving students' critical thinking skills, have prompted researchers to offer a solution through the development of an IoT-based soil sensor lab tool integrated with performance assessment. This tool utilizes three primary sensors pH, moisture, and NPK that provide real-time data, enabling students to quickly observe changes in soil conditions. Furthermore, this lab tool not only assesses the final results of the experiment but also takes into account the processes students go through during the experiment. This approach makes learning more structured and effective in honing students' critical thinking skills. This research aims to contribute to the development of more efficient, relevant, and measurable lab tools, thereby enhancing student understanding through deeper, hands-on experiences.

In the next stage, namely the planning or design steps in the research, including material planning, assessment planning, media design, and language planning. In planning the critical thinking question grid according to (Ennis, 1996) with 10 essay questions used based on the grid in Table 1.

Table 1. Critical Thinking Indicators in Research

Question Indicator	Critical Thinking Skills are trained	Question Number
Presented with a discourse on the problem of cassava factory waste on soil content, students can ask 3 questions.	Clarifying issues by asking critical questions	1, 3
Presented with a discourse on soil pollution due to cassava factory waste, students are asked to write down the information needed to determine the condition of the chemical content in the soil.	Gathering important information about the issue	2, 4
Presented with a discourse, students can use the information available in the discourse to choose alternative solutions that will be offered to minimize the occurrence of soil pollution.	Think logically from various points of view	5, 7
Students can write down the assumptions underlying the assessment of soil quality by paying attention to the chemical content in the soil.	Gathering more information	6, 8
Presented with a discourse on the condition of the soil content around cassava factory waste, students can provide solutions to solve the problems contained in the discourse and write down the reasons.	Making and communicating decisions	9, 10

The critical thinking instrument used in the study, as outlined in Table 1, underwent expert validation testing and empirical testing, including validity, reliability, and discrimination, resulting in 10 questions deemed suitable for use in the study. This is shown in Tables 2, 3, and 4.

Table 2. Results of the Validity Test of the Critical Thinking Essay Question Instrument

Magnitude (rxy)	Interpretation	Question Items	Number of Questions
Rxy<0.329	Invalid	0	0
Rxy≥0.329	Valid	1,2,3,4,5,6, 7,8,9,10, 11,12,13,14,15	10

Based on the test results in Table 2, it shows that there are 0 questions in the unfeasible category and 15 questions in the feasible category, which is then strengthened by the results of the reliability test in Table 3.

Table 3. Results of the Reliability Test of the Critical Thinking Essay Question Instrument

Cronbach's Alpha	N of Items
0.824	15

Table 3 shows a Cornbach's alpha value of 0.824, indicating that the reliability value is in the "very high" category. However, the results of the discriminatory power indicate that not all questions can be used, as explained in Table 4.

The results of the discriminatory power (DP) show that there are 5 questions with poor discriminatory power (DP < 0.20), namely questions number 11, 12, 13, 14, and 15. There are 6 questions with good discriminatory power (0.41 ≤ DP ≤ 0.70), namely questions number 2, 3, 4, 5, 8, and 10. Meanwhile, 4 questions have very good discriminatory power (0.71 ≤ DP ≤ 1.00), namely questions number 1, 6, 7, and 9. Based on these results, it can be concluded that questions with poor discriminatory power should be deleted, while questions with good and very good discriminatory power can be used because they are more effective in differentiating students' abilities (Blegur et al. 2023) . So from the validity, reliability, and discriminatory power tests it can be concluded that there are 10 questions that can be used in research.

Table 4. Results of the Test of the Differential Power of the Critical Thinking Essay Question Instrument

Down Payment Amount	Interpretation	Question Items	Number of Questions
DP < 0.20	Bad	11,12,13,14,15	5
0.21 ≤ DP ≤ 0.40	Enough	0	0
0.41 ≤ DP ≤ 0.70	Good	2,3,4,5,8,10	6
0.71 ≤ DP ≤ 1.00	Very good	1,6,7,9	4

The next step was to design an IoT-based soil sensor lab tool integrated with performance assessments, consisting of a sensor and application. The soil sensor tool uses a complete sensor suite consisting of NPK, pH, soil moisture, air humidity, temperature, and conductivity sensors. It is then connected to an application using an ESP8266, accessible to teachers and students.

The application in the teacher server provides a space for teachers to access the profile menu consisting of personal identity, photo, user, password, and mobile number so that students can easily contact the teacher. Then there is a menu for adding materials, assignments such as LKPD in which teachers can provide performance assessments and written feedback virtually, essay questions, multiple choice questions, access student data, add groups, and extract student results, and teachers can access the results of soil chemical content sensors in the application. Then the student server is more or less the same, there is a profile, then materials and rubrics that can be read by students, students can work on LKPD directly in the application and upload videos of practicums carried out, work on essay and multiple choice questions, students can view assessment results and written feedback from teachers, and can access the results of soil chemical content sensors in the application. Meanwhile, language planning includes language that is easy for students to understand according to their level of language understanding and in accordance with PUEBI and EYD.

After the design is completed, it then enters the development stage. The following shows the APP-based soil sensor tool TerraAssessment (electronic alternative assessment) that was developed:

Figure 6. IoT-Based Soil Sensor Display

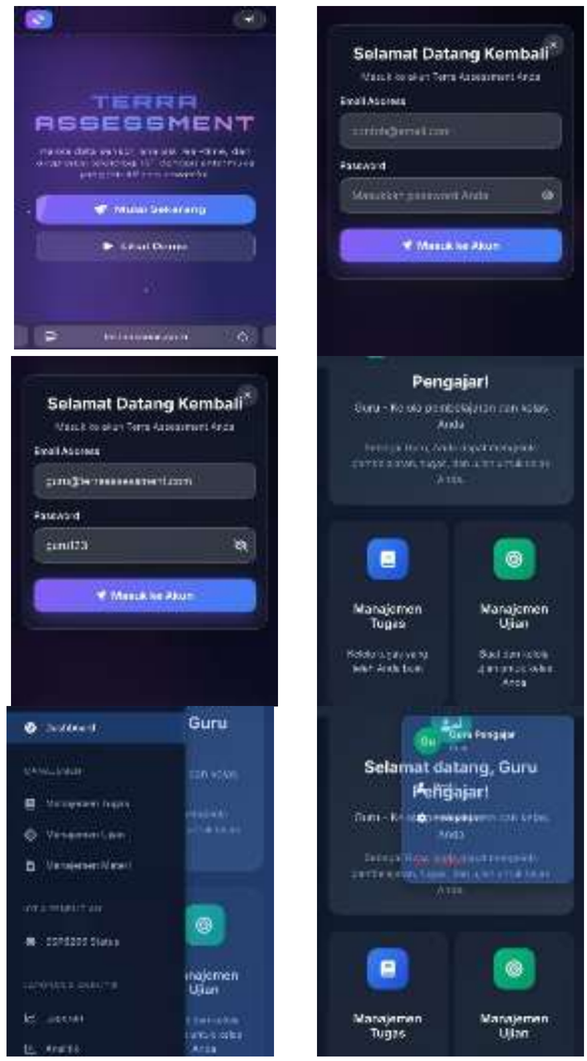

Figure 7. TerraAssessment Educator Display

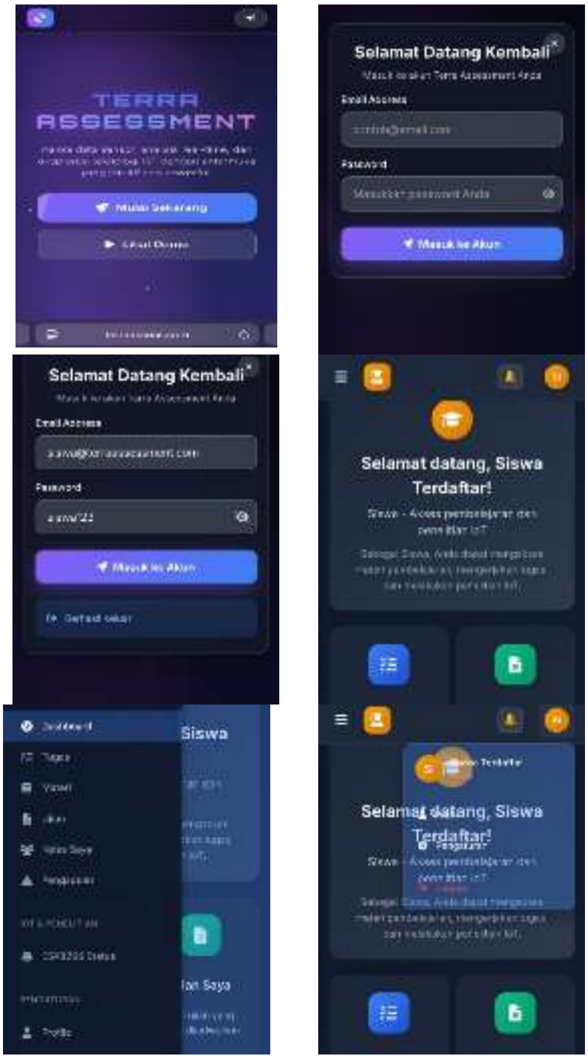

Figure 8. Student TerraAssessment Display

Based on figures 6, 7, and 8, it can be seen that the IoT-based soil sensor device supported by ESP8266 can be connected to an application that can be accessed by two servers, namely teachers and students. This app-based practical tool has been validated by 2 validation experts who assessed the content and construction which showed a very high category, this is depicted in Figure 7.

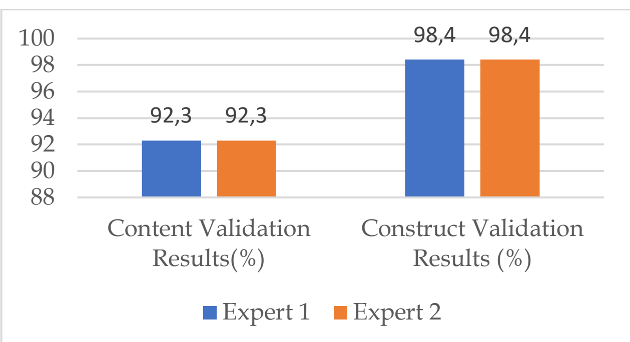

Figure 7. Comparison Results Of Expert Validation 1 And 2

Figure 7 shows the validation results for the IoT-based soil sensor instrument and lab tool integrated with performance assessment. Based on the assessment by two experts (Expert 1 and Expert 2), the value obtained for content validation was 92.3%, indicating that the instrument was considered relevant and appropriate to the material or topic being taught. Meanwhile, for construct validation, the two experts gave a slightly higher value, namely 98.4%, indicating that this lab tool is very appropriate for measuring what should be measured, in accordance with existing theories or models. Thus, these results indicate that the validated lab instrument and lab tool received very high recognition from the experts, both in terms of content and construction, and are ready to be used in learning.

After the development of the IoT-based soil sensor practicum tool was completed, a limited-scale test with 15 students and a large-scale test with 36 students were conducted by administering a response questionnaire to the students. The responses to the questionnaire were given to 15 students, 36 students, and one chemistry teacher in the limited and large-scale tests. The following are the results (Figure 8).

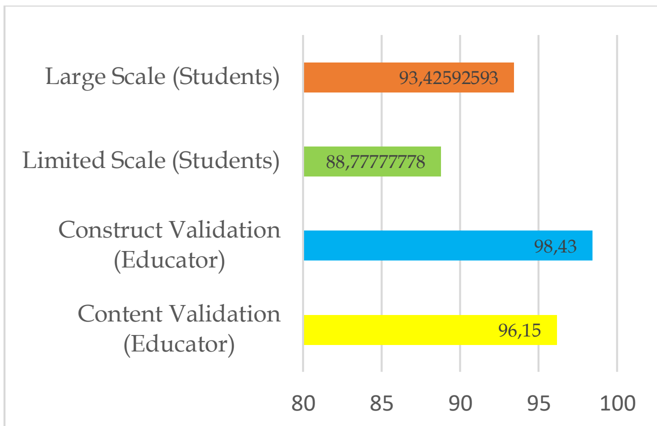

Figure 9. Results of Comparison of Teacher and Student Responses

The results of the response test for the IoT-based soil sensor practicum tool integrated with performance assessment in Figure 9 show a very high level of validity and acceptance. Content validation by educators reached 96.15%, while construct validation by educators reached 98.43%, indicating that this tool is theoretically in line with learning objectives and is able to measure students' critical thinking skills. Testing on a limited scale with students resulted in a response of 88.78%, while on a broad scale it reached 93.43%, indicating that the majority of students considered this practicum tool interesting, easy to use, and relevant to their learning. These findings are in line with previous research by Sofiyan et al. (2025), which showed that the integration of technology-based sensors, including IoT, in science practicums increases student engagement and learning effectiveness, and supports more comprehensive process- and outcome-based assessments (Sofiyan et al., 2025). These results confirm that the developed practicum tool is not only valid in content and construct, but also well-accepted by students on a broader scale.

The results of the use of an IoT-based soil sensor practicum tool integrated with performance assessment showed an increase in students' critical thinking indicators, particularly in the experimental class compared to the control class. The following are the results of the pre-test and post-test for critical thinking in the experimental and control classes (Figure 10).

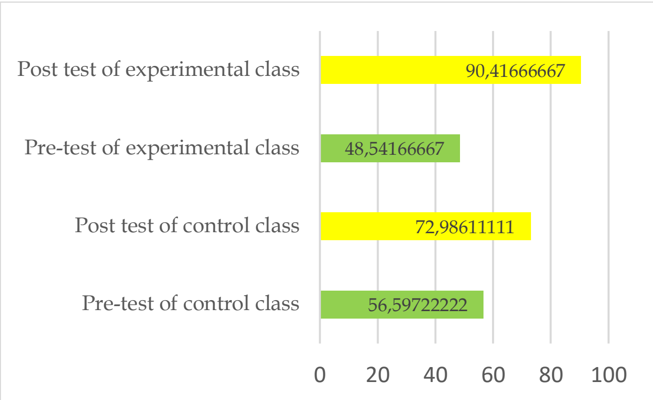

Figure 10. Comparison Results of Pre-Test and Post-Test of Experimental Class and Control Class

The pre-test of the control class (56.60) was higher than that of the experimental class (48.54), indicating that the initial abilities of the control class students were better. However, after the treatment, the post-test results of the experimental class increased sharply to 90.42, far exceeding the control class which only rose to 72.99. The difference in increase in the control class was 16.39 points, while the experimental class increased by 41.88 points. This shows that the treatment in the experimental class was much more effective in improving learning outcomes than the method in the control class. The results of students' critical thinking according to the instrument used showed higher results in the experimental class which supports the results of Figure 9, which can be seen in Figure 11.

The results of the study in Figure 11 show a significant difference between the experimental and control classes in critical thinking indicators after treatment. Before treatment (pre-test), the control class had shown higher results in several indicators such as "Gathering Basic Information" and "Conducting Basic Clarification of the Problem". However, after treatment (post-test), the experimental class showed a significantly greater increase in all indicators, with the highest score in the "Conducting Basic Clarification of the Problem" indicator (92.71). This increase indicates that the use of integrated IoT-based soil sensors in teaching in the experimental class is more effective in improving students' critical thinking skills. This also reflects the effectiveness of learning methods that use IoT technology that facilitate student engagement in a more interactive and applicable learning process.

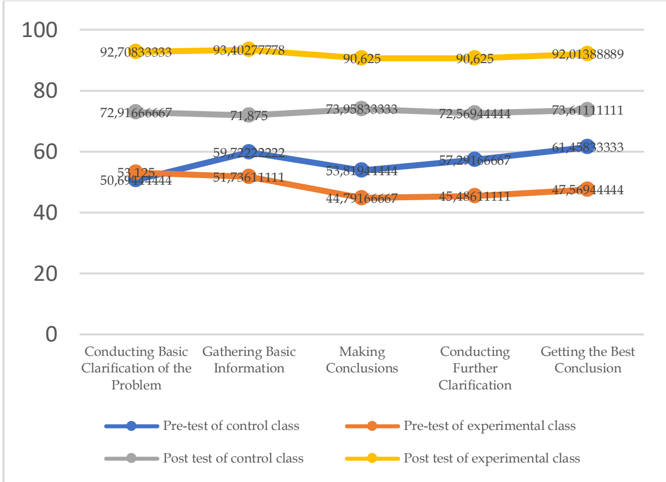

Figure 11. Comparison of Students' Critical Thinking Indicator Values

In the control class, students tended to use traditional methods that focused more on passively absorbing information, such as listening to teacher explanations and recording basic facts without much direct engagement with data or learning tools. They focused on "Gathering Basic Information" and "Conducting Basic Clarification of the Problem," but tended to be limited to processing existing information without much in-depth exploration. In contrast, in the experimental class, the use of integrated IoT-based soil sensors facilitated students' more active involvement in the learning process, such as collecting data directly from the environment and analyzing it. With a more applied and technology-based approach, students in the experimental class not only gathered information but also clarified problems in greater depth, asked critical questions, and drew conclusions based on the data they obtained.

In the experimental class, in addition to actively collecting data and clarifying problems, students were also given the opportunity to propose hypotheses related to the soil conditions they observed using IoT-based soil sensors. With this technology, they could formulate conjectures or hypotheses about changes in pH, moisture, or nutrient content in the soil, which were then tested through further observations. This not only encouraged them to think more critically and analytically but also enabled them to connect basic chemistry theory with real-world practice (Xayrullo o'g

& Rajabboyovna, 2024). This ability to propose and test hypotheses was one of the factors supporting the significant improvement in critical thinking indicators in the experimental class, compared to the more passive approach in the control class (Rivas et al., 2023). This explains why the experimental class showed significantly greater improvement in all critical thinking indicators, particularly in "Conducting Basic Clarification of the Problem," reflecting improved students' analytical and critical skills.

Previous research has also shown that the use of technology-based tools in education can improve critical thinking skills. For example, a study by Rathna et al. (2024) that examined the use of technology in learning showed that technology can improve students' understanding in solving complex problems more effectively (Rathna Sekhar & Goud, 2024). Another study by Munandar et al. (2025) also revealed that IoT-based tools can improve students' problem-solving and critical thinking skills, as these tools allow students to collect data in real time and analyze it, which improves their analytical skills (Munandar & Haling, 2025). Therefore, the higher results in this experimental class can be attributed to the positive influence of the use of these technologies in learning.

The average student achievement can be seen from the increase in the N-Gain value in Figure 12.

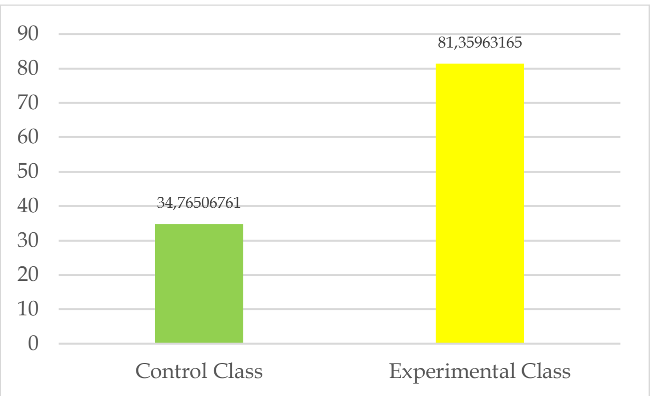

Figure 12. Results of Comparison of N-Gain Values

The N-Gain results show that the experimental class experienced a significantly greater improvement compared to the control class. The control class had an N-Gain value of 34.77, indicating a relatively small improvement after treatment. Meanwhile, the experimental class showed an N-Gain value of 81.36, reflecting a significant increase in learning achievement. This indicates that the use of IoT soil sensor-based learning methods in the experimental class was much more effective in improving student abilities compared to the methods applied to the control class.

Student performance assessment also shows that the experimental class has superior performance compared to the control class as described in Figure 13.

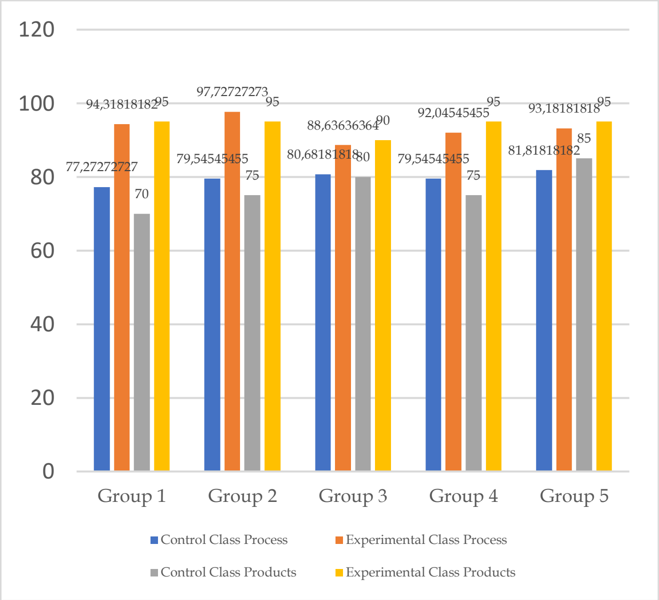

Figure 13. Results of Student Performance Assessment Process and Product

The results in Figure 13 show a comparison between the process and product scores in the control and experimental classes for each group. In general, the process scores in the experimental classes were higher than those in the control classes in each group, indicating that the use of IoT-based lab tools or other methods in the experimental classes was more effective in improving students' skills or knowledge during the learning process. For example, in Group 1, the process score in the experimental class (94.32) was higher than that in the control class (77.27), and the resulting product was also higher in the experimental class (95) compared to the control class (70). This was consistent across groups, with the experimental class producing higher products (all 95) despite variations in their process scores. This improvement can be explained by the fact that the more interactive and technology-based process in the experimental classes allowed students to better understand and master the material, resulting in better products compared to traditional methods in the control class.

The students' learning outcomes were then statistically tested to prove the hypothesis that there was an influence of the use of IoT-based soil sensor practical tools integrated with performance assessment on students' critical thinking with the ANCOVA test, starting with the normality test and homogeneity test as pre-requisites for the NACOVA test, which are shown in Tables 5 and 6.

Table 5. Normality Test Results

		Pre-Test Score	Post-Test Score
N		72	72
Normal	Mean	52.57	81.70
Parameters [a,B]	Standard Deviation	11,559	11,837
Most Extreme	Absolute	0.100	0.103
Differences	Positive	0.100	0.103
	Negative	-0.097	-0.092
Test Statistics		0.100	0.103
Asymp. Sig. (2-Tailed)		.073 [c]	.055 [c]

A. Test Distribution Is Normal.
B. Calculated From Data.
C. Lilliefors Significance Correction.

The Kolmogorov-Smirnov test results in Table 5 show a small difference between the distributions of pre-test and post-test scores. The pre-test score has a test statistic of 0.100 with a significance value of 0.073, while the post-test score has a test statistic of 0.103 with a significance value of 0.055. Both significance values are greater than 0.05, indicating that the distributions of these two samples do not significantly differ from a normal distribution. In other words, both the pre-test and post-test score distributions can be considered normal, indicating that the data do not deviate significantly from normality.

Table 6. Results of Homogeneity Test

Dependent Variable:	Post-Test Score		
F	Df1	Df2	Sig.
0.196	1	70	0.660

Tests The Null Hypothesis That The Error Variance Of The Dependent Variable Is Equal Across Groups.

The results of the homogeneity test in Table 6 using Levene's Test show an F value of 0.196 with a significance value (Sig.) of 0.660. Because the significance value is greater than 0.05, there is insufficient evidence to reject the null hypothesis. This means that the error variance in the post-test scores is homogeneous or the same in both groups tested, indicating that the assumption of homogeneity of variance is met. After the prerequisite test is met, the hypothesis test using the ANCOV test can be continued, as shown in Table 7.

Table 7. Ancova Test Results

Dependent Variable: Post-Test Score

Source	Type III Sum Of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5468.837 [a]	1	5468.837	85,470	0.000	0.550
Intercept	480608.420	1	480608.420	7511.195	0.000	0.991
Class	5468.837	1	5468.837	85,470	0.000	0.550
Error	4478.993	70	63,986			
Total	490556.250	72				
Corrected Total	9947.830	71				

A. R Squared = .550 (Adjusted R Squared = .543)

The significant ANCOVA test results indicate that the use of an IoT-based soil sensor practicum tool integrated with performance assessment has a positive impact on improving students' critical thinking. With a significance value of 0.000 and a high F value, these results indicate that the intervention provided (in this case the use of an IoT-based tool) has an important role in improving critical thinking skills compared to the traditional method applied in the control class. The use of this tool allows students to interact directly with data and produce technology-based analysis, which improves their ability to understand and solve problems more critically and applicably. In addition, the Partial Eta Squared value of 0.550 indicates a fairly large effect, with 55% of the variability in post-test results can be explained by the treatment given.

Previous research also supports these findings, such as that conducted by Munandar et al. (2025), which showed that the use of technology in education, such as IoT-based tools, can improve students' critical thinking skills (Munandar & Haling, 2025). In their study, students who used technology in their learning showed significant improvements in problem-solving and analytical thinking skills compared to those who did not use technology. Another study by Nurzaman et al. (2024) also found that the use of sensor technology in science learning increased student engagement, facilitated real-time data exploration, and encouraged students to think more critically in analyzing information (Nurzaman Ahmed, Flavio Esposito, 2024). These results strengthen the argument that the use of IoT-based tools can provide significant benefits in improving students' critical thinking skills.

Conclusion

The conclusion of this study shows that the use of an IoT-based soil sensor lab tool integrated with performance assessment has a significant impact on improving students' critical thinking skills, especially in the experimental class. The results showed a significantly greater improvement in the experimental class compared to the control class, both in pre-test and post-test results, as well as in the critical thinking indicators tested. The experimental class experienced a significant improvement in critical thinking skills, such as "Conducting Basic Clarification of the Problem", which can be explained by the use of an IoT-based lab tool that allows students to collect data directly, propose hypotheses, and analyze soil conditions in more depth. This indicates that an IoT-based learning approach is more effective in encouraging student engagement and improving their understanding of basic chemistry concepts.

The ANCOVA test results also strengthen this finding with a very low significance value (0.000), indicating that the use of IoT-based soil sensor practicum tools has a significant effect on improving students' critical thinking skills. The Partial Eta Squared value of 0.550 indicates that 55% of the variation in post-test results can be explained by the treatment received by the experimental class. In addition, the validity, reliability, and discriminatory power of the critical thinking test instrument used in this study also showed very good results, thus reinforcing that the tools and methods used are effective in improving the quality of learning. This study is in line with previous research findings showing that the use of technology in education can significantly improve students' critical thinking skills, by facilitating more interactive and data-driven learning.

Acknowledgments
I would like to express my gratitude to the University of Lampung (UNILA) for its full support in this research. My deepest gratitude goes to my supervisor, Prof. Dr. Chansaynah Diawati, M.Si, for her invaluable guidance, direction, and support in completing this research. I would also like to thank myself, Rista, as the author, for her tireless efforts in carrying out this research with full dedication. This research was also supported by a grant, which made it possible to carry out this research successfully.

Author Contribution
Conceptualization, Rista and Chansyanah Diawati; methodology, Rista; software, Rista; validation, Rista, Chansyanah Diawati, and Rista; formal analysis, Rista; investigation, Rista; resources, Rista; data curation, Rista; writing, preparation, original draft, Rista; writing, review, and editing, Chansyanah Diawati; visualization, Rista; supervision, Chansyanah Diawati; project administration, Rista; funding acquisition, Chansyanah Diawati. All authors have read and approved the published version of the manuscript.

Funding
This research was funded by a research grant from the University of Lampung (UNILA).

Conflict of Interest
The authors declare no conflict of interest.

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