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Application Of Transformer Diagnostic Application To Improve Students' Analytical Skills In Transformer Courses Of Electrical Engineering D4 Program

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ABSTRACT
Objective: This study aimed to address the prevalent difficulty among electrical engineering students in applying theoretical knowledge to the practical interpretation of transformer diagnostic data. The primary objective was to assess the effectiveness of a purpose-built diagnostic software application in improving the analytical skills required for this task. **Method**: The research employed a quasi-experimental, one-group pretest-posttest design involving a sample of 36 undergraduate students in a D4 Electrical Engineering program. Participants' analytical skills were measured before and after the intervention, which consisted of training with the diagnostic application. Data were collected through quantitative tests, student perception surveys, and instructor observation sheets. The analysis involved paired sample t-tests and N-Gain calculations, with findings triangulated using qualitative feedback to enhance validity. **Result**: The intervention yielded highly positive outcomes, demonstrating a statistically significant improvement in students' analytical abilities. The mean score rose from 56.19 to 82.58, and an average N-Gain score of 0.61 classified the application's effectiveness in the "medium improvement" category. These quantitative findings were strongly supported by qualitative data, wherein students reported the application to be highly intuitive and effective in transforming passive learning into an active, contextualized, and confidence-boosting experience. **Novelty**: The novelty of this research lies in providing empirical evidence for a scalable and effective pedagogical tool that bridges the critical gap between academic theory and industry-required practical skills. This study presents a validated software-based solution to a persistent challenge in vocational engineering education, demonstrating a tangible method for better preparing graduates to meet professional demands in transformer diagnostics.

INTRODUCTION

Transformers are essential components of electrical power systems and play a vital role in energy transmission and distribution (Saleh et al. 2023; T. Wang et al. 2024). The overall reliability of the electrical system largely depends on transformer performance, making mastery of operating principles, as well as analysis and diagnosis techniques for transformer faults, a core competency required of students in the D4 Electrical Engineering Program (Jin et al. 2023; Nanfak et al. 2023). Engineering education has long emphasized the importance of a theoretical understanding of transformer characteristics, potential types of faults, and appropriate handling methods. However, there is a significant gap between students' mastery of theoretical concepts and their practical skills in comprehensively interpreting transformer-diagnostic data (Cao, Zhang, and Huang 2024; Yasong Li et al. 2024; Memari et al. 2024). Students often struggle to connect concepts with real-world practice, particularly in understanding test results, such as winding ratios, insulation resistance, and other electrical parameters (Song, Shin, and Shin 2024; K. Wang et al. 2024). Limitations in

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practical media, lack of exposure to real case studies, and predominantly conceptual learning approaches further widen the gap between academic learning and professional job requirements. In response to these challenges, this study developed and evaluated a transformer diagnostic application specifically designed as a data-driven learning medium. The application presents test data from various transformer fault scenarios that have been technically validated, with the main goal of enhancing students' ability to interpret technical information, analyze fault symptoms, and draw data-based conclusions (Akbar et al. 2023; Mallek et al. 2024; Parvin et al. 2023). Thus, this application serves not only as a learning tool but also as a pedagogical intervention with the potential to bridge the gap between theory and practice. This study aimed to analyze the effectiveness of a transformer diagnostic application in improving students' competency in interpreting diagnostic data. The contributions of this research are intended not only to enhance student competence but also to benefit lecturers as an innovation in teaching approaches and vocational education institutions in their efforts to design learning models that are relevant to industry demands.

RESEARCH METHOD

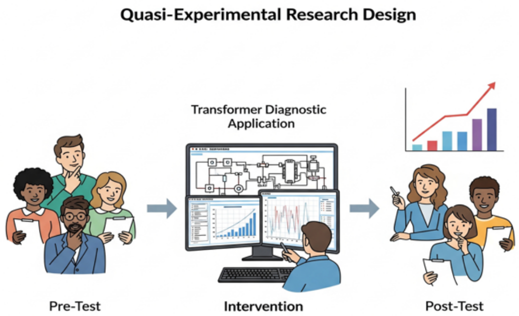

Figure1. Quasi-experimental designs

This study used a quasi-experimental approach with a one-group pretest-posttest design. This design was chosen because random assignment of subjects in the field was not possible. The one-group pretest-posttest design within the quasi-experimental approach was seected because field conditions did not allow for random assignment of subjects; however, it still provides an adequate framework to systematically evaluate the effectiveness of an intervention. In this context, students' analytical abilities were measured before (pre-test) and after (post-test) receiving treatment in the form of learning based on a transformer diagnostic application (Campoamor et al. 2024; Yue Li et al. 2024; Prümmer, van Steen, and van den Berg 2024). The pretest was used to map students' initial abilities, while the posttest was used to assess changes that occurred after the intervention. This design allowed researchers to examine the direct impact of the application on improving students' competencies, particularly in terms of conceptual understanding, analytical skills, and the ability to diagnose transformer conditions based on technical data (Kiegaldie and Shaw 2023; Y.-F. Wang et al. 2024).

The population of this study comprised students enrolled in the Transformer course in the Diploma IV (D4) Electrical Engineering Program at Universitas Negeri Makassar during the current semester. Given the constraints of field-based research particularly the inability to randomly assign participants the sample was selected using

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purposive sampling, based on the following inclusion criteria: (1) active enrollment in the Transformer course, (2) completion of prerequisite courses (e.g., Fundamentals of Electrical Power Engineering), and (3) voluntary willingness to participate fully in all stages of the intervention. All 36 eligible students who met these criteria and consented to participate were included in the study, resulting in a total sample of 36 students. This sample size is considered adequate for a one-group pretest-posttest quasi-experimental design, particularly given the high internal consistency of the instrument (Cronbach's $\alpha \geq 0.85$) and the use of parametric analyses (paired t-test, N-Gain), for which a minimum of $n \geq 30$ is generally sufficient to approximate normality and ensure statistical power (Gay et al., 2012; Field, 2018).

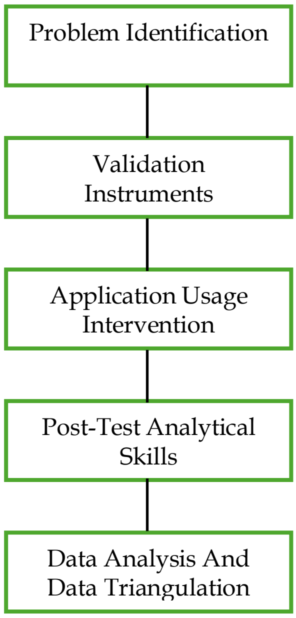

Figure 2. Flow Diagram

The primary instrument was an 18-item analytical skills test, developed through a three-stage process (dimension identification, cognitive alignment with Bloom's L3–L6, and expert validation) to measure students' ability to interpret transformer diagnostic data and make evidence-based decisions grounded in IEC 60076-1 and IEEE 43-2013 standards. Items were distributed across five dimensions: Technical Data Interpretation (5 items, 20%), Pattern and Anomaly Recognition (4, 20%), Fault Cause Diagnosis (4, 25%), Logical Conclusion Drawing (3, 20%), and Maintenance Recommendation (2, 15%), using varied formats (multiple-choice, short-answer, case analysis, essay, and decision tasks). Psychometric evaluation confirmed high validity (item-total $r = 0.76–0.82 > r_{table} = 0.361$, $p < 0.05$) and reliability (Cronbach's $\alpha = 0.89–0.91$ for pre/post-test; 0.85 for N-Gain), supporting its use in vocational engineering education. This application not only bridges the gap between theory and practice, but also strengthens students' critical thinking skills and technical decision-making abilities (Al-Adwan et al. 2025; Arifin, Suryaningsih, and Arifudin 2024).

In addition to the application, three supporting instruments were also used for data collection purposes, namely: Analysis Ability Test, in the form of pre-test and post-test questions designed to measure students' ability to analytically interpret transformer testing data. The Perception Questionnaire, in the form of a Likert scale

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questionnaire, was used to explore students' perceptions of the usefulness of the application in learning, as well as their learning experiences during the intervention (Fahad Mon et al. 2023; Ma and Lei 2024). Observation Sheet, used by the instructor to record student engagement, interaction, and dynamics of learning activities during the intervention process. The following table presents the results of the reliability and validity analyses for the pre-test, post-test, and N-Gain data based on the information provided. These data are assumed to have been calculated using statistical methods, such as Pearson's correlation for validity and Cronbach's alpha for reliability (Mutiafani and Hakim 2025).

Table 1. Validity and Reliability

No	Variable	Reliability (Cronbach's Alpha)	Validity (r-count)	Validity Criteria
1	Pre-test	0.89	0.76	Valid
2	Post-test	0.91	0.82	Valid
3	N-Gain	0.85	0.78	Valid

The analysis results show that all instruments pre-test, post-test, and N-Gain have very high reliability, with Cronbach's Alpha values above 0.80, indicating strong internal consistency. In addition, the validity values for each instrument also exceed the r-table (0.361), thus all instruments are declared valid and suitable for use in this research. The research procedure was carried out systematically in three main stages. First, during the introduction phase, students were given a pretest to measure their initial ability in analyzing transformer data. After that, the instructor demonstrated the main functions and features of the application. Second, in the practice phase (intervention), students actively used the application to work on case-based exercises that had been prepared, which required the application of theory and critical reasoning in real technical contexts. Third, in the evaluation phase, students took a posttest to assess the improvement in their analytical skills. In addition, data from perception questionnaires and observation sheets were also collected to provide a more holistic overview of the effectiveness of application-based learning. Although this quasi-experimental approach allows for the evaluation of intervention effectiveness in real-world contexts, it has a key limitation: the absence of a control group. The lack of a comparison group means that improvements in students' abilities cannot be attributed exclusively to the application intervention. External factors such as the natural growth of students' knowledge, variations in instructors' teaching styles, or additional learning experiences outside the classroom may also influence the results.

RESULTS AND DISCUSSION

Results

This section presents the data collected from the 36 students of the Electrical Engineering Diploma programme who participated in this study. The data included quantitative results from the pre- and post-tests and qualitative data from the perception questionnaire and observation sheet. The findings of this study conclusively show that the use of the transformer diagnostic application significantly improves the analytical skills of D4 Electrical Engineering students. The increase in the mean score from 56.19 in the pre-test to 82.58 in the post-test was statistically significant, indicating

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that the performance improvement is highly unlikely to be due to chance (citation). The effectiveness of the intervention was further reinforced through the N-Gain analysis, which yielded an average score of 0.61. This value places the improvement of student abilities in the "medium" category. The fact that not a single student (0%) fell into the "low" category suggests that the app universally benefited all participants, lifting the competence of the group as a whole and not just those who were already performing well (Cheung et al., 2023; Mwansisya et al. 2022).

The strength of these quantitative findings was validated using consistent, qualitative data. This triangulation of data, where statistical figures, students' subjective perceptions, and an instructor's objective observations confirm each other, provides strong, layered evidence of the app's success as a learning tool (Bazhenova et al. 2022; Yang and Chen 2023). The findings of this study are consistent with and contribute to the existing literature on the use of educational technology in engineering education. One of the main challenges in transformer diagnostics is the risk of data misinterpretation by technicians, even though measurement instruments provide precise results (Goldberg et al. 2022; Hafiz et al. 2023). The results of this research align with and enhance the current body of literature regarding the application of educational technology in engineering education. A significant challenge in transformer diagnostics is the potential for technicians to misinterpret data, despite the fact that the measurement tools yield accurate outcomes (Ngwenyama and Gitau 2024; Pourdana 2022; Shao et al. 2023).

The application developed in this study directly addresses such issues by providing an interface that simplifies technical information. The results of this study have significant implications for vocational education programs, especially D4 Electrical Engineering. The implementation of this application proves to be a vital bridge that connects theoretical understanding with the practical skills needed in the industry. Graduates from programs that integrate this kind of tool will not only master transformer theory but also have semi-practical experience in interpreting diagnostic data, a competency that is highly valued by the industry (Boltsi et al. 2024; Einloft et al. 2024; Hazrat et al. 2023). Institutionally, the adoption of such learning technologies directly contributes to improving the quality of graduates and the reputation of the program (Beheshti Asl, Fofana, and Meghnefi 2024).

For educators, the application enables a more engaging and organized analysis of case studies. By offering a secure and consistent platform for practice, educational institutions can guarantee a uniform level of competency among all students without necessitating a significant investment in physical equipment for every session. While the findings of this study are encouraging, it is crucial to recognize its limitations to ensure a well-rounded interpretation. The primary limitation of this research is the employment of a one-group pretest-posttest quasi-experimental design that lacks a control group (Febriyan, Fatkhurrokhman, and Irwanto 2025; Purba et al. 2025). The lack of a comparison group complicates the ability to discern the specific impact of the intervention. The noted improvement could be affected by various other factors (confounding variables), including the natural development of students over a semester, the teaching style of the lecturers, or the interactions among students in the learning environment. Caution must also be exercised when generalizing the findings of this study, as the sample comprised 36 students from a single cohort in the D4 Electrical Engineering program at one institution. Consequently, these findings may not

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be entirely replicable in other institutions that have different curricula, student demographics, or available resources.

Table 2. Students' Pre-test, Post-test, and N-Gain Scores

		Pre-test	**Post-test**	**N-Gain**
N	Valid	36	36	36
	Missing	0	0	0
Mean		56.19	82.58	0.62
Median		55.50	82.50	0.60
Mode		57 & 58	80	0.57 & 0.60
Standard Deviation		5.54	5.53	0.09
Sample Variance		30.69	30.58	0.01
Range		23	24	0.36
Minimum		45	70	0.45
Maximum		68	94	0.81
Sum		2023	2973	22.16
Count		36	36	36

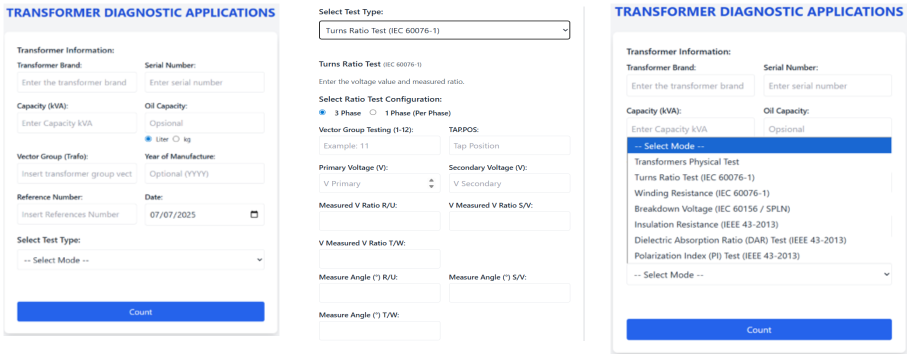

Figure 2. Application Diagnostic Transformer

Quantitative Findings

1. Comparison of Test Scores Before and After the Intervention

The raw score data from the pre-test (before using the app) and post-test (after using the app) are presented below. The maximum score for both the tests was 100. N-Gain scores were also calculated to measure the effectiveness of the improvement in each student's analytical skills.

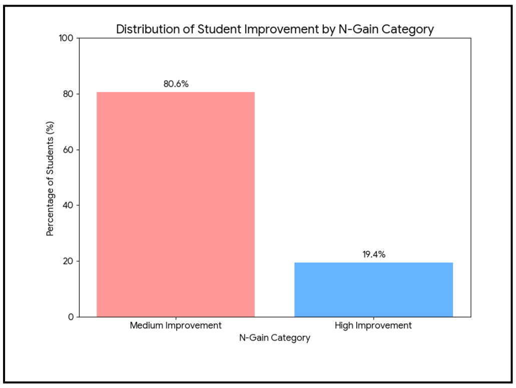

Figure 3. Pre- and Post-Test Analytical Skill Scores

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2. Statistical Analysis of Student Performance Descriptive and inferential analyses were conducted on the score data of student performance.

Table 3. Descriptive Statistics of Pre-test and Post-test Scores (N=36)

Statistics	Pre-test	Post-test
Rate-ratio (Mean)	56.19	82.58
Standard Deviation	5.54	5.53
Minimum Value	45	70
Maximum Value	68	94

Paired Sample T-test Analysis

Table 4. T-Test

Analysis	t-value	df	Sig. (p-value)	Interpretation
Pre-test vs. Post-test	-25.84	35	< 0.001	Highly statistically significant

The Kolmogorov-Smirnov normality test showed that the pre- and post-test data scores were normally distributed ($p > 0.05$). Furthermore, a paired-sample t-test was conducted to compare the mean scores before and after the intervention..

a) The test results showed a highly statistically significant difference between the post- and pre-test scores (35) = -25.84, $p < 0.001$).
b) This indicates that the increase in scores from the pre-to post-test was not due to chance.

3. Trends in Analytical Skill Development (N-Gain Analysis)
N-Gain analysis was used to measure the effectiveness of the intervention in improving participants' analytical skills.
   a) Average N-Gain: The average N-Gain value for the entire group was 0.61. Based on these criteria, the score fell into the moderate improvement category.
   b) N-Gain Category Distribution
      1) High (N-Gain ≥ 0.7): 7 students (19.4%)
      2) Medium (0.3 ≤ N-Gain 0.7): 29 students (80.6%)
      3) Low (N-Gain 0.3): 0 students (0%)

   The findings show that the intervention successfully improved the analytical skills of all students, with the majority improving at a moderate level and a significant proportion improving at a high level.

Qualitative Findings

1. Themes from the Student Perception Survey
The perception questionnaire used a 5-point Likert scale (1=Strongly Disagree, 5=Strongly Agree).

Table 5. Summary of Student Perception Survey Results (N=36)

Assessment Aspects	Average Score	Interpretation
The Application's Usability	4.45	Highly intuitive
Learning Engagement	4.62	Highly intuitive
Students' Understanding of Diagnostic Topics	4.51	Excellent
Perception of Enhanced Analytical Ability	4.58	Significantly Improved

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a) Key Theme 1: Positive User Experience. Students consistently reported that the app was easy to navigate and that its interface was intuitive. One respondent stated, "At first I thought it would be complicated, but the features are clear and easy to understand, especially the data visualization."
b) Key Theme 2: Active and Contextualized Learning. The survey highlighted that the app successfully transformed passive learning into active learning. Students feel more engaged because they can directly tinker with the data and see the consequences of various fault scenarios, bridging the gap between classroom theory and field practice.
c) Key Theme 3: Increased Confidence. Many students felt more confident in their ability to analyze transformer data. "Before I only memorized the TTR formula, now I understand what it means if the ratio is deviated," wrote a student in the comment section.

2. Instructor Observations of Student Engagement and Learning
The observation sheets filled out by the instructors during the intervention sessions revealed important patterns.
a. Initial Phase: In the first session, the students tended to work individually and were still adapting to the interface of the system. There were some technical questions regarding the interpretation of graphs.
b. Mid Phase: Significant changes occurred in the mid-phase. Students start discussing in small groups, comparing the results of their analyses of a given case study. Class noise levels increased productively, with technical discussions being dominant.
c. Problem Solving Dynamics: The instructor observed "moments of enlightenment" when students successfully connected simulation data (e.g., transformer ratio results and DC Winding Resistance) to specific potential causes of damage that they had learned about theoetically.

Discussion

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This study offers several innovations: (1) empirically, as the first evidence at the D4 level that analytical skills in transformer diagnostics can be developed significantly and evenly through simulations based on verified technical data (IEC/IEEE), without relying on physical laboratories or field experience; (2) theoretically, by expanding Contextual Learning Theory with the concept of double contextualization (technical+cognitive), resulting in a new model called Contextualized Technical Reasoning (CTR); and (3) conceptually, by formulating the Diagnostic Analytical Framework (DAF) a structured cognitive framework from pattern recognition to normative benchmarking, which requires interpretive convergence of at least two test parameters as the basis for diagnostic validity, thereby formalizing the heuristic practices of experienced technicians into vocational pedagogy.

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CONCLUSION

Fundamental Finding: The study's core finding is that the diagnostic application serves as a catalyst for a fundamental pedagogical shift, moving students from passive recipients of theoretical knowledge to active participants in contextualized, data-driven problem-solving. This transformation is not merely reflected in statistically significant performance gains, but more importantly, in the cultivation of applied analytical skills and confidence. These are the core competencies that directly address the well-documented gap between academic learning and professional industry demands.

Implications: The research provides empirical evidence that targeted software can be a vital pedagogical tool to bridge the gap between classroom theory and practical, industry-required competencies. For vocational institutions, it offers a scalable and cost-effective method to provide students with semi-practical experience, thus enhancing the quality and employability of graduates. For educators, it facilitates a more engaging, case-based teaching approach.

Limitations: The primary limitation is the study's quasi-experimental design, which lacks a control group. This makes it difficult to attribute the observed improvements solely to the application, as other factors like natural student development or instructor style could have had an influence. Furthermore, the findings have limited generalizability as the research was conducted with a small sample of students from a single institution.

Future Research: To build upon these findings, future research must take a more comprehensive approach that addresses methodological rigor, technological advancement, and strategic collaboration. Methodologically, it is essential to employ a more rigorous design, such as a randomized controlled trial, to isolate the application's specific impact, complemented by a longitudinal study to assess the long-term retention of analytical skills. In terms of technological development, the application itself should be enhanced with more advanced features; recommendations include an instructor customization module for bespoke case studies, an adaptive feedback system to guide students in real-time, and an expansion of diagnostic modules to cover more complex analyses. Finally, to ensure broader validation and relevance, these efforts should be embedded within strategic collaborations, including multi-institutional studies to test the application across diverse contexts and partnerships with industry to integrate real-world failure data, thereby keeping the learning experience dynamically aligned with professional practice.

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