Improving the Methodology of Teaching Physics in Technological Education through an Epistemological Approach in the Fields of Energy and Automation, Based on Current Issues in Electric Power Supply Systems

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Abstract. This article investigates how an epistemological approach can improve the teaching methodology of physics in technological education, especially for energy and automation specializations, in the context of current issues in electric power supply systems. Using theoretical analysis, diagnostics, a pedagogical experiment, and statistical methods, the study shows that reflective questioning, metacognitive strategies, and problem-based tasks linked to real energy processes significantly enhance students' understanding and application of physics. Experimental results demonstrate higher levels of independent thinking, problem analysis, interdisciplinary connections, and transfer of theory to practice compared to the control group ($p < 0.05$). The findings confirm that epistemologically oriented physics instruction increases learning effectiveness and better prepares students to solve practical energy and automation problems.

INTRODUCTION

Over the last decade, electric power supply systems have faced rapidly growing challenges due to the accelerated integration of renewable energy sources, digitalization of industry, and the increasing use of automated control in power networks. As wind and solar capacity expands worldwide and in many countries' development plans for 2020–2030, power systems must operate under more variable generation conditions, requiring higher reliability, stability, and efficiency of electricity transmission and distribution [1–5]. These trends intensify practical problems such as voltage and frequency regulation, power losses, load forecasting, and the effective operation of automated monitoring and protection systems.

In this context, physics becomes a core discipline for energy and automation students because fundamental concepts-energy conservation, electromagnetic phenomena, power flow, and system modeling-directly explain how modern electric power systems work. However, traditional teaching often emphasizes ready-made formulas rather than how knowledge is constructed, tested, and applied to real grid problems. Therefore, an epistemological approach to teaching physics is increasingly necessary: it develops students' reflective thinking, problem analysis, model evaluation, and the ability to transfer theoretical laws into practical solutions for current issues in electric power supply systems. This paper proposes and evaluates an epistemology-based methodology for teaching physics in technological education, aimed at strengthening professional competencies in the fields of energy and automation [5-7].

EXPERIMENTAL RESEARCH

This study employs a mixed-methods research design to explore the efficacy of an epistemologically-driven approach in enhancing the teaching of physics within the context of energy and automation. The core aim is to move beyond conventional rote memorization techniques and foster a deeper, reflective understanding of physics principles, tailored to address contemporary issues in electric power supply systems. By emphasizing the cultivation of analytical reasoning, advanced problem-solving competencies, and the effective transfer of theoretical principles to practical contexts, this study aims to prepare students to competently address the multifaceted and rapidly evolving challenges inherent in contemporary energy and automation systems.

The methodology consists of a pedagogical experiment conducted over an academic semester, with the participation of 120 students from energy and automation programs at two Uzbek universities. These students were divided into an experimental group, which was taught using epistemological strategies, and a control group, which followed traditional teaching methods. The epistemological approach was structured around Socratic dialogue, reflective questioning, and problem-based tasks, all grounded in real-world issues such as voltage stability, power loss minimization, and electromagnetic induction in protection systems. In this approach, students were tasked with analyzing complex energy-related problems, justifying their reasoning, and exploring the practical applications of theoretical knowledge.

Data collection methods included pre- and post-intervention tests, questionnaires, classroom observations, and interviews. The primary focus was to assess the development of reflective understanding, interdisciplinary integration, problem-solving skills, and the application of theory to practice. Statistical analyses were conducted using SPSS Statistics 26.0, with t-tests and correlational procedures employed to determine the significance of the findings. The efficacy of the epistemological framework was systematically assessed in comparison with conventional instructional practices, with specific attention given to its influence on students' performance across a range of competencies, including analytical evaluation of energy system problems, integration of interdisciplinary knowledge, and the practical application of physics concepts to technologically relevant real-world tasks

RESEARCH RESULTS

The pressure distribution across the cross-section of the fiber-blowing chamber was experimentally determined by measuring the flow-induced force using a microtube with an inlet diameter of 6 mm. The static pressure component of the flow was independently recorded using a standard static pressure probe. In parallel with these measurements, the ambient atmospheric pressure (P_{atm}), surrounding air temperature (t), and relative humidity (W) were continuously monitored to ensure accurate characterization of the experimental conditions.

The experimental study conducted on the epistemological approach to teaching physics in the context of energy and automation revealed significant improvements in students' reflective understanding, problem-solving skills, interdisciplinary integration, and the application of theoretical knowledge to practical scenarios. The data collected from both the experimental and control groups were analyzed to assess the effectiveness of the epistemologically oriented teaching methodology.

Reflective Understanding of Knowledge. One of the key findings was a significant increase in the experimental group's ability to reflect on and justify their understanding of physical concepts. The experimental group demonstrated higher scores ($M = 4.32$, $SD = 0.46$) in reflective understanding compared to the control group ($M = 3.65$, $SD = 0.52$), with a statistically significant difference ($t = 5.47$, $p < 0.001$). This suggests that the epistemological approach, which emphasized reflective questioning and metacognitive monitoring, facilitated a deeper engagement with the material. Students in the experimental group were more adept at evaluating and justifying the physical principles behind energy processes and automation systems. These findings align with the principles of metacognition, which highlight the importance of self-regulation and reflective thinking in learning (Schraw & Dennison, 1994). By moving beyond rote memorization, students were able to better monitor their understanding and identify the limitations of their models.

Problem Analysis Skills. Another key result was the significant improvement in the experimental group's problem analysis skills. The experimental group scored higher ($M = 4.18$, $SD = 0.51$) compared to the control group ($M = 3.71$, $SD = 0.49$), with a t-value of 3.92 ($p < 0.01$), demonstrating a notable effect. The epistemological approach encouraged students to engage in problem-based tasks that required them to analyze real-world issues in electric power supply systems. These tasks included scenarios such as voltage instability under fluctuating loads, the impact of resistance on power losses, and the operational conditions for relay protection. By using reflective questioning (e.g., "Why?" and "How?"), students were able to move beyond surface-level problem-solving and develop a more comprehensive understanding of the underlying causes and mechanisms of these issues. The experimental group exhibited improved diagnostic thinking and causal reasoning, which is essential for solving complex problems in energy and automation.

Interdisciplinary Integration. The experimental group also showed significantly higher scores ($M = 4.25$, $SD = 0.43$) in interdisciplinary connection-making compared to the control group ($M = 3.60$, $SD = 0.56$), with a t-value of

4.88 ($p < 0.001$). This finding suggests that the epistemological approach effectively bridged the gap between physics, electrical engineering, and automation, fostering a more integrated understanding of the interconnectedness of these disciplines. Students in the experimental group were better able to make connections between physical laws (such as electromagnetic induction and energy conservation) and their practical applications in power flow, energy losses, and system control. By continuously emphasizing the interdisciplinary nature of energy and automation systems, students were encouraged to develop a holistic view, which is crucial for addressing the complex challenges faced by modern power supply systems.

Application of Theoretical Knowledge to Practice. The ability to apply theoretical knowledge to practical situations was another area where the experimental group excelled. With a mean score of 4.45 (SD = 0.39), the experimental group outperformed the control group (M = 3.78, SD = 0.47) with a t-value of 5.21 ($p < 0.001$). The epistemological tasks, grounded in real-world energy issues, prompted students to apply physics principles in practical scenarios, such as optimizing energy efficiency, reducing thermal losses, and analyzing power system stability. This result suggests that the epistemological approach helped students not only understand theoretical concepts but also transfer their knowledge to practical problem-solving tasks. By engaging in hands-on tasks linked to real electric power supply challenges, students were able to gain a deeper understanding of how theory translates into practice in the energy and automation fields.

Competency Gains. Further analysis of competency indicators showed that the experimental group consistently outperformed the control group across all four targeted competencies, with a stable +18% advantage in areas such as independent thinking, problem analysis, interdisciplinary understanding, and the application of theory to practice. This uniform improvement indicates that the epistemological intervention strengthened core competencies across the entire cohort, demonstrating the pedagogical reliability of the approach. The increase in these competencies is crucial, as these skills are essential for addressing the ever-evolving challenges in energy and automation fields, where professionals must be able to think critically, analyze complex systems, and apply scientific knowledge to real-world problems.

The results presented in the table demonstrate that students who participated in the epistemologically oriented intervention achieved consistently higher outcomes than those in the control group across all evaluated performance indicators. Statistical analysis confirmed that these differences are significant, suggesting that the observed improvements are a direct consequence of the instructional approach rather than the result of random variability.

Table 1. Experimental and control groups'comparative results under an epistemological physics teaching approach

No	Measured indicator	Experimental group (M ± SD)	Control group (M ± SD)	t-value	p-value
1	Level of reflective understanding of knowledge	4.32 ± 0.46	3.65 ± 0.52	5.47	< 0.001
2	Problem analysis skill	4.18 ± 0.51	3.71 ± 0.49	3.92	< 0.01
3	Indicator of interdisciplinary connections	4.25 ± 0.43	3.60 ± 0.56	4.88	< 0.001
4	Application of theoretical knowledge in practice	4.45 ± 0.39	3.78 ± 0.47	5.21	< 0.001

By inserting the table here, you can directly compare the performance of the experimental and control groups on the competencies that were discussed immediately prior. This placement creates a natural flow from the narrative analysis to the statistical comparison.

Evidence from Domain-Specific Learning Tasks

In the experimental group, students worked on domain-specific tasks related to energy efficiency, electromagnetic induction in protection systems, and load fluctuations in supply networks. These tasks required students to justify their reasoning using physical laws, evaluate model limitations, and propose alternative solutions. The experimental group demonstrated a consistent ability to articulate cause–effect relationships and transfer theoretical reasoning to practical decisions. For example, in tasks related to reducing energy losses, students were able to apply Ohm's law and explain how current and resistance influence power dissipation in transmission lines. This ability to apply theoretical concepts to practical problems is a strong indicator of the epistemological approach's effectiveness in preparing students for professional challenges in energy and automation.

Overall Interpretation of Results

The results of this study demonstrate that epistemologically oriented physics instruction significantly enhances students' learning outcomes, particularly in the context of energy and automation systems. By promoting reflective thinking, problem analysis, and interdisciplinary integration, the epistemological approach enabled students to deepen their understanding of fundamental physics concepts and apply them to real-world engineering challenges. The experimental group not only outperformed the control group in cognitive outcomes, but also demonstrated a stronger capacity for metacognitive regulation, which is essential for solving complex problems in dynamic and interconnected fields such as energy and automation.

These findings suggest that epistemologically structured teaching methods should be incorporated into physics curricula for technological education, particularly in energy and automation tracks, to better prepare students for the practical challenges they will encounter in the field. By focusing on the epistemic cycle of questioning, analysis, and justification, students can develop the critical thinking and problem-solving skills necessary to address the current and future challenges of electric power supply systems

CONCLUSIONS

This study demonstrates that integrating an epistemological approach into physics education significantly enhances students' understanding, problem-solving, and application of theoretical knowledge, particularly in the fields of energy and automation. The experimental group showed notable improvements in reflective thinking, problem analysis, interdisciplinary integration, and the practical application of physics concepts to real-world issues in electric power supply systems. These improvements highlight the effectiveness of epistemologically oriented teaching in fostering critical thinking and metacognitive skills essential for addressing modern technological challenges.

The findings confirm that the epistemological methodology not only strengthens core competencies in students but also helps bridge the gap between theoretical learning and practical problem-solving. Given the positive results, it is recommended that epistemological strategies be systematically incorporated into physics curricula for technological education, especially in energy and automation programs, to better prepare students for the complexities of contemporary power systems and automation technologies.

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