Kasuari: Physics Education Journal 8(1) (2025) 272-284
P-ISSN: 2615-2681
E-ISSN: 2615-2673

Kasuari: Physics Education Journal (KPEJ)
Universitas Papua
website: https://journalfkipunipa.org/index.php/kpej

A Reduction in Undergraduate Misconceptions on AC Circuits through Interactive Simulations

Defrianto Pratama
Department of Electrical Engineering, Politeknik Negeri Bandung, Indonesia
Corresponding author: defrianto.pratama@polban.ac.id

Abstract: *Misconceptions are a major barrier in physics learning, particularly in abstract concepts such as alternating current (AC). This study aimed to reduce the number of students experiencing misconceptions on AC topics through PhET-assisted learning. The method used was a quasi-experimental one-group pretest-posttest design, involving 152 Electrical Engineering students enrolled in an Applied Physics course. The instrument employed was a four-tier test developed for six key AC concepts. Pretest results showed that 32.1% of students on average experienced misconceptions, with the highest found in the concept of resonance (50.0%). After instruction using PhET simulations, the average misconception rate dropped to 7.8%, with an average reduction of 24.3%. McNemar's test confirmed that the reduction was statistically significant ($p < 0.05$) across all concepts. PhET simulations proved effective by providing dynamic visualizations, enabling interactive exploration, and triggering cognitive dissonance that encourages conceptual revision. This study recommends the integration of interactive simulations in physics instruction, especially for abstract and dynamic topics.*

Keywords: *alternating current, four-tier test, misconception, PhET simulation, physics learning*

Reduksi Miskonsepsi Mahasiswa pada Konsep Rangkaian Arus Bolak-Balik melalui Simulasi Interaktif

Abstrak: Miskonsepsi merupakan salah satu hambatan utama dalam pembelajaran fisika, terutama pada konsep-konsep abstrak seperti arus bolak-balik (AC). Penelitian ini bertujuan untuk mereduksi jumlah mahasiswa yang mengalami miskonsepsi pada topik arus AC melalui pembelajaran berbantuan simulasi PhET. Metode yang digunakan adalah kuasi-eksperimen dengan desain one-group pretest-posttest, melibatkan 152 mahasiswa Teknik Elektro yang sedang menempuh mata kuliah Fisika Terapan. Instrumen yang digunakan adalah four-tier test yang dikembangkan untuk enam konsep kunci dalam arus AC. Hasil pretest menunjukkan bahwa rata-rata 32,1% mahasiswa mengalami miskonsepsi, dengan miskonsepsi tertinggi pada konsep resonansi (50,0%). Setelah pembelajaran berbasis simulasi PhET, rata-rata miskonsepsi menurun menjadi 7,8%, dengan reduksi rata-rata sebesar 24,3%. Uji McNemar menunjukkan bahwa penurunan miskonsepsi signifikan secara statistik ($p < 0,05$) pada seluruh konsep. Simulasi PhET terbukti efektif karena mampu menyajikan visualisasi dinamis, memungkinkan eksplorasi interaktif, dan memicu disonansi kognitif yang mendorong revisi konseptual mahasiswa. Penelitian ini merekomendasikan integrasi simulasi interaktif dalam pembelajaran fisika, khususnya untuk konsep yang bersifat abstrak dan dinamis.

Kata kunci: arus bolak-balik, miskonsepsi, *four-tier test*, pembelajaran fisika, simulasi PhET

INTRODUCTION

A strong understanding of fundamental physics concepts is essential for first-year students in engineering programs, including Electrical Engineering. At this early stage of vocational education, students are expected not only to master theoretical knowledge but also to relate it to practical applications in the industrial world (Khaharsyah et al., 2024). However, in practice, the learning process often encounters obstacles in the form of deeply rooted and persistent misconceptions in students' thinking (Hatika et al., 2022; Wati, 2024). These misconceptions are incorrect understandings of scientific concepts that are formed before or during instruction, yet are retained by students despite having received formal explanations from lecturers (Resbiantoro et al., 2022). For example, students may believe that electric current in an AC circuit flows in one direction as it does in a DC circuit, or that voltage and current are always in phase in all types of AC circuits (Frans & Wasis, 2022; Olaogun et al., 2023). Such incorrect beliefs are not only difficult to correct through conventional lectures, but are also often unrecognized by students themselves, allowing them to persist into more advanced topics in subsequent semesters. This situation presents a serious challenge in engineering education because misconceptions can affect how students think, analyze, and even design or troubleshoot electrical systems.

Students often struggle to understand how AC current and voltage behave, how root mean square (rms) values are determined, and how the phase relationship between current and voltage affects power in a circuit. In addition, concepts such as impedance, inductive and capacitive reactance, and phasor diagrams are often learned only mathematically without sufficient visual representation. The mismatch between symbolic teaching and concrete experience contributes to the formation of misconceptions that are difficult to detect through conventional tests.

Previous studies have shown that traditional, expository teaching methods are not sufficient to address misconceptions, especially among first-year students who lack a strong cognitive foundation in physics (Listianingrum et al., 2024). Therefore, a visual, interactive, and exploratory learning approach is needed to help students build a more comprehensive conceptual understanding. One such approach that is increasingly being used is the implementation of PhET Interactive Simulations, a computer-based simulation tool developed by the University of Colorado Boulder. PhET allows students to manipulate physical parameters and observe the logical consequences in the form of animations, graphs, and direct measurements within simulations, thereby providing a more immersive and contextual learning experience.

Several studies have demonstrated the effectiveness of PhET simulations in reducing misconceptions in physics concepts. Saudelli et al. (2021) stated that PhET simulations significantly enhance students' understanding and engagement. Research by Hasanah & Wasis (2021) also found that integrating simulations into physics instruction can improve learning outcomes and reduce misconceptions, especially when accompanied by structured discussions and guided exploration. However, there are still few studies that specifically evaluate the effectiveness of PhET use in the context of vocational college students, particularly in Electrical Engineering departments, and in measuring conceptual changes using valid and sensitive instruments such as the Four-Tier Diagnostic Test.

Based on these issues, this study aims to reduce the number of students experiencing misconceptions in the concept of AC circuits through lectures assisted by PhET simulations. The findings are expected to contribute to the development of more effective and contextual physics learning strategies in vocational education settings, especially polytechnics. These findings are also anticipated to serve as a foundation for lecturers to design learning activities that focus not only on mastering formulas but also on fostering strong conceptual understanding from the beginning of the course.

METHOD

This study employed a one-group pretest-posttest design, which is a quasi-experimental design where a single group of subjects is given tests before and after the treatment to measure the impact of the intervention. This design allows researchers to compare students' conceptual understanding before and after the learning process, as well as to observe the shift from misconceptions to scientific understanding (Maggin, 2022; Schneider & Rohmann, 2021). The research subjects were 152 first-year students from the Department of Electrical Engineering, consisting of five classes enrolled in the Applied Physics course.

The research procedure was carried out in three stages: pretest, learning intervention, and posttest. In the pretest stage, students were asked to complete a Four-Tier Test instrument to identify their initial misconceptions. The next stage was the learning intervention, which was conducted over two sessions in the form of interactive lectures assisted by the PhET AC Circuit Construction Kit simulation. In these sessions, students were guided to explore AC current concepts through interactive visualizations, virtual experiments, and structured discussions. The simulations used covered fundamental aspects such as the relationship between voltage and current, differences among resistive, inductive, and capacitive circuits, and the phase dynamics between current and voltage. The lecturer acted as a facilitator who helped students reconstruct their understanding through direct observation of the phenomena presented in the simulation. After the learning phase, students were again asked to complete the same diagnostic test during the posttest stage to assess changes in understanding and reductions in misconceptions.

The Four-Tier Test is a type of diagnostic instrument used to identify conceptual misunderstandings (misconceptions) experienced by students (Istiyono et al., 2023; Önder Çelikkanlı & Kızılcık, 2022). This test consists of four levels of questions. At the first level, participants are presented with a multiple-choice conceptual question with five options. At the second level, they are asked to indicate their confidence in the answer selected. The third level provides four reasoning options corresponding to the first-level choices. At the fourth level, students assess their confidence in the reasoning provided (Kaniawati et al., 2021).

The Four-Tier Test has several advantages in identifying possible misconceptions. One of its strengths is its ability to differentiate between students' confidence in their chosen answer and the reasoning behind it. This enables deeper assessment of conceptual understanding and more detailed analysis of misconceptions. In addition, the Four-Tier Test is also effective in identifying parts of the material that require further conceptual reinforcement (Dirman et al., 2022). This method is useful for planning more effective instructional approaches to prevent students' misconceptions. The results of the diagnostic test were then analyzed based on the misconception classification criteria using the Four-Tier Test, as shown in Table 1.

Table 1. Classification criteria for conceptual understanding using the Four-Tier Test (Kaniawati et al., 2021)

Tier 1	Tier 2	Tier 3	Tier 4	Category
Incorrect	Confident	Incorrect	Confident	Misconception
Correct	Confident	Correct	Confident	Scientific understanding

Tier 1	Tier 2	Tier 3	Tier 4	Category
Correct	Not confident	Correct	Not confident	Partial understanding
Correct	Confident	Correct	Not confident	
Correct	Not confident	Correct	Confident	
Correct	Not confident	Incorrect	Not confident	
Incorrect	Not confident	Correct	Not confident	
Incorrect	Not confident	Correct	Confident	
Correct	Confident	Incorrect	Confident	
Incorrect	Confident	Correct	Confident	
Correct	Confident	Incorrect	Not confident	
Incorrect	Not confident	Incorrect	Not confident	Lack of understanding
Incorrect	Confident	Incorrect	Not confident	
Incorrect	Not confident	Incorrect	Confident	
No response in all tiers				Unclassifable response

To test the significance of the change in the proportion of students experiencing misconceptions before and after the intervention, the McNemar test was used. This is a non-parametric statistical test for paired nominal data with two categories (in this case: misconception and no misconception). This test is appropriate for evaluating treatment effectiveness in studies that involve pre-post measurements on the same subjects (Achour et al., 2025; Diola & Mistades, 2021). The McNemar test compares the proportion or frequency of two binary variables measured at the same time on the same sample—in this study, coded as 0 for no misconception and 1 for misconception.

Table 2. 2x2 Table for McNemar Test Calculation

	Posttest Misconception (1)	**Posttest No Misconception (0)**
Pretest Misconception (1)	*a*	*b*
Pretest No Misconception (0)	*c*	*d*

McNemar Test Formula Used:

$$\chi^2 = \frac{(b-c)^2}{b+c} \tag{1}$$

where: *b* is the number of students who had a misconception in the pretest but not in the posttest (indicating improvement), *c* is the number of students who did not have a misconception in the pretest but did in the posttest (indicating regression) (Wulansari, 2023).

The McNemar test was conducted for each test item (concept) with degrees of freedom (df) = 1 and significance level α = 0.05. The computed test statistic was compared to the critical table value of 3.84. If the calculated value exceeds the table value, the null hypothesis is rejected, indicating a significant change in the proportion of students with misconceptions. All data analysis was conducted using Microsoft Excel for tabulation and data visualization purposes.

RESULTS AND DISCUSSION

The initial diagnostic test (pretest) was administered before students engaged in virtual experiments using PhET simulations to map their conceptual understanding of six key concepts related to AC circuits. The diagnostic instrument consisted of six Four-Tier Test items designed to assess students' comprehension of AC circuit concepts. Examples of these diagnostic questions are shown in Table 3.

Table 3. Example of Four-Tier Diagnostic Test Items on AC Circuit Topics

Tier	Content
Tier-1	A student builds a series RLC circuit with a constant AC voltage source and gradually increases the source frequency. What happens to the current? A. The current always increases B. The current always decreases C. The current may increase or decrease D. Current stays the same
Tier-2	Are you confident with your answer? A. Confident B. Not Confident
Tier-3	What is your reason for the answer? A. Current depends on the circuit's natural resonance frequency B. When frequency increases, the impedance always increases, causing the current to decrease. C. Higher frequency means more energy, so more current D. Only resistance affects current
Tier-4	Are you confident with your reasoning? A. Confident B. Not Confident

Table 3 presents an example of a diagnostic test item constructed using the Four-Tier Test format on the topic of alternating current (AC) circuits. This item is designed to identify the presence and nature of student misconceptions in a more detailed manner. Tier-1 consists of a multiple-choice question that assesses students' understanding of the effect of increasing source frequency on the current in a series RLC circuit. Tier-2 asks students to indicate their confidence in the answer selected in Tier-1 by choosing either "Confident" or "Not Confident." In Tier-3, students are required to choose a conceptual reason that supports their Tier-1 response. The reasoning options are intentionally crafted to include both scientifically accurate explanations and common misconceptions—for example, the belief that increasing frequency always leads to more current. Tier-4 then evaluates the student's confidence in the reasoning selected in Tier-3. Through these four tiers, the instrument not only identifies incorrect answers but also reveals the consistency of students' reasoning and their level of certainty, allowing for a more accurate and comprehensive diagnosis of misconceptions.

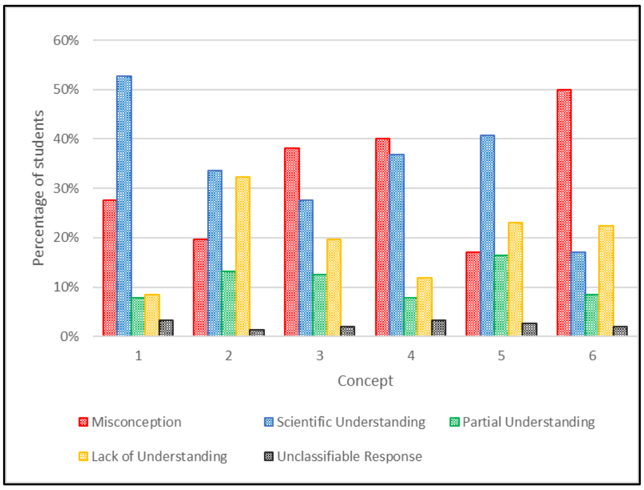

Figure 1. Pretest Diagnostic Mapping of Student Misconceptions

Figure 1 presents the mapping results of student misconceptions from the pretest. It reveals that misconceptions occurred in all tested concepts. On average, 32.1% of students experienced misconceptions across the six AC circuit concepts, while only 34.8% of students demonstrated true conceptual understanding. The pretest results reveal that a considerable proportion of students experienced misconceptions across all six AC circuit concepts, with the highest occurring in Concept 6 (Resonance) at 50%, followed by Concepts 4 and 3 at 40% and 38%, respectively. In contrast, the proportion of students with scientific understanding was relatively lower in those same concepts, particularly in Concept 6, where only around 18% demonstrated correct understanding. The data also show notable levels of lack of understanding and partial understanding, indicating fragmented or incomplete conceptual frameworks. These findings suggest that before the intervention, students struggled to construct accurate mental models of alternating current behavior, especially in more abstract concepts such as phase relationships and resonance. A detailed summary of misconceptions for each concept is presented in Table 4.

Table 4. Types of Student Misconceptions Identified

No.	Concept	Misconception	Scientific Concept
1	Nature of AC voltage and current	Students believe that AC voltage and current are constant like DC.	AC voltage and current vary periodically (typically sinusoidal) over time.
2	Voltage/current reading on multimeter	Students assume the displayed value is the average.	Multimeters display the effective (RMS) value of AC voltage and current.
3	Phase relationship between V and I	Students think voltage and current are always in phase.	In AC, phase shifts depend on circuit elements (resistive, inductive, capacitive).
4	Power calculation in AC circuits	Students use the DC formula P = VI without phase consideration.	Real power in AC is calculated using $P = VI\cos\phi$, where ϕ is the phase angle.
5	Frequency of current in RLC circuits	Students think current frequency can differ from voltage frequency.	L and C affect amplitude and phase, not the frequency of current.

No.	Concept	Misconception	Scientific Concept
6	Resonance in series RLC circuit	Students assume increasing frequency always increases current.	Current peaks only at resonance; beyond it, current may decrease.

Pretest data analysis using the Four-Tier Test instrument revealed that misconceptions still dominated students' understanding of most concepts related to alternating current (AC). The percentage of students with misconceptions ranged from 17% to 50%, depending on the concept tested.

The concept with the highest level of misconception was Concept 6 (resonance in series RLC circuits), with 50% of students exhibiting misconceptions. This indicates that half of the students did not understand that resonance only occurs at a specific frequency, and increasing the frequency does not always lead to increased current. This is likely due to a lack of exploratory experiences in observing how current responds dynamically to frequency changes in RLC circuits.

Concept 4 (AC power calculation) also showed a high misconception rate of 40%, typically resulting from the improper transfer of DC concepts ($P = VI$) to AC contexts without considering the phase angle between current and voltage. The real power in AC is given by $P = VI \cos\phi$, and neglecting this factor is a common conceptual error.

In Concept 3 (phase relationship between voltage and current), 38% of students still held misconceptions. Many were unaware that inductive or capacitive elements cause voltage and current to be out of phase. This misunderstanding could impede further learning in advanced topics like complex impedance or reactive power.

In Concept 1 (nature of AC voltage and current), although 53% of students demonstrated correct understanding, 28% still held misconceptions, thinking AC voltage and current behave like DC—remaining constant. This reflects the persistence of intuitive but incorrect reasoning about AC waveforms.

Concept 2 (RMS value on a multimeter) had a 20% misconception rate, with students commonly misinterpreting the multimeter reading as an average rather than an effective (RMS) value. This shows a weakness in understanding representative values in periodic signals.

The lowest misconception rate was found in Concept 5 (frequency of current in RLC circuits) at 17%, though it still highlights that some students misunderstood that current frequency equals the source frequency and that only amplitude and phase are affected by L and C elements.

These data indicate that misconceptions are a major barrier to conceptual understanding in AC circuits, particularly regarding aspects that are not directly observable in daily experience, such as phase relationships, power, and resonance.

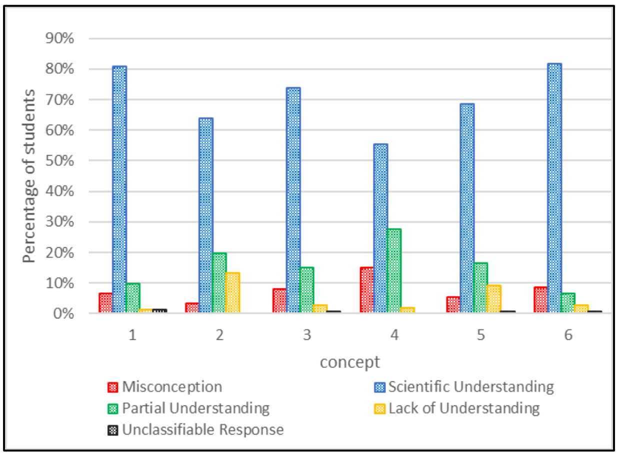

Figure 2. Posttest Diagnostic Mapping of Student Misconceptions

Figure 2 shows the posttest results, indicating a significant decrease in the percentage of students with misconceptions and a notable increase in the percentage of students with scientific understanding across all tested concepts. The graphs and data reflect a positive trend in the success of the instructional intervention.

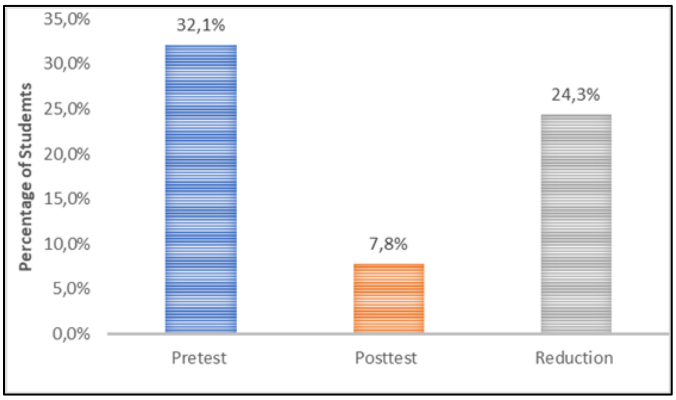

Figure 3. Average Reduction in the Number of Students Experiencing Misconceptions

After participating in PhET-assisted lectures, the proportion of students experiencing misconceptions decreased significantly. According to the posttest results, the average misconception rate dropped to 7.8%, representing an average reduction of 24.3%, as illustrated in Figure 3. This decline illustrates the positive impact of using interactive PhET simulations in teaching alternating current (AC) concepts. The simulations enabled students to directly observe electrical phenomena dynamically, allowing them to revise their prior misconceptions. The graph clearly demonstrates that simulation-based learning is not only effective in enhancing conceptual understanding but also plays a crucial role in reducing pre-existing misconceptions among students.

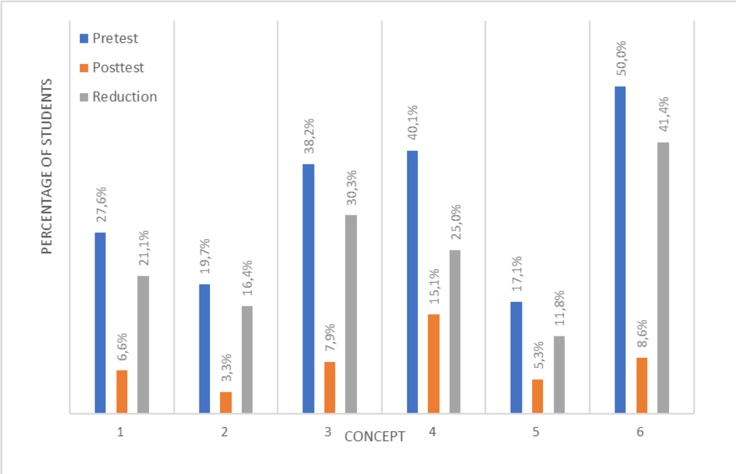

Figure 4. Misconception Reduction Profile for Each Concept

Figure 4 highlights the most significant reduction in Concept 6, from 50.0% to 8.6% (a 41.4% reduction), showing the simulation's high effectiveness in helping students understand that resonance only occurs at a specific frequency—not always with increasing frequency. Similarly, Concept 3 showed a 30.3% reduction in misconceptions, as the visual representation of the phase relationship between current and voltage could be directly observed in the simulation. In Concept 4, although 15.1% of misconceptions remained, there was still a significant improvement (25.0% reduction), indicating that the simulation helped students grasp the concept of power in AC circuits involving a phase angle.

Conversely, basic concepts such as Concept 1 (nature of AC voltage and current) and Concept 2 (RMS measurement by multimeter) also showed improvement, with misconception reductions of 21.1% and 16.4%, respectively. This shows that even intuitive early misconceptions can be corrected through interactive visual learning. Concept 5 showed the smallest improvement (11.8%), although the final misconception rate was still relatively low (5.3%).

To determine whether the observed changes in students' misconceptions from pretest to posttest were statistically significant, the McNemar test was applied to each concept. This test was appropriate given the paired categorical nature of the data (pretest–posttest) with two categories: misconception and no misconception. Table 5 presents the McNemar test results for each concept.

Table 5. McNemar Test Results

Concept	b (1→0)	c (0→1)	χ^2 Calculated	χ^2 Table ($\alpha = 0.05$)	Significance
1	33	1	30.13	3.84	Significant
2	22	1	19.17	3.84	Significant
3	47	2	41.33	3.84	Significant
4	39	0	39.00	3.84	Significant
5	19	0	19.00	3.84	Significant
6	62	1	59.06	3.84	Significant

Note: b = number of students with misconceptions in the pretest but not in the posttest (indicating improvement), c = number of students with no misconceptions in the pretest but had misconceptions in the posttest (indicating regression). Critical χ^2 value for df = 1 and $\alpha = 0.05$ is 3.84.

All calculated χ^2 values exceeded the critical threshold of 3.84, indicating statistically significant changes in the proportion of students with misconceptions before and after instruction. In other words, the reduction in the number of students with misconceptions following the PhET-based learning intervention is statistically significant across all six concepts. The highest χ^2 value was observed for Concept 6 (resonance) at 59.06, suggesting that the reduction in misconceptions was strongest and most consistent for that concept. Concepts 3 and 4 also demonstrated highly significant improvements, reinforcing the effectiveness of simulations in addressing misconceptions about phase relationships and AC power calculation. Even for Concepts 2 and 5, which initially had lower misconception rates, the test results were still statistically significant, indicating widespread conceptual improvement.

These statistical results confirm that the PhET-assisted intervention produced not only descriptive improvements but also meaningful conceptual change. The use of the McNemar test provides a robust statistical basis to conclude that these improvements are not due to chance or general learning effects, but are directly attributable to the visual, exploratory, and interactive learning approach. The effectiveness of the PhET simulation is rooted in its design, which is based on constructivist and visual-cognitive learning principles, directly targeting conceptual barriers in physics learning (Dantic & Fluraon, 2022). Specifically, in alternating current (AC) material, PhET simulations provide dynamic visualizations, direct manipulation of physical parameters, and real-time feedback—features that significantly contribute to reducing student misconceptions (Maesaroh & Sutikno, 2025; Swandi et al., 2021).

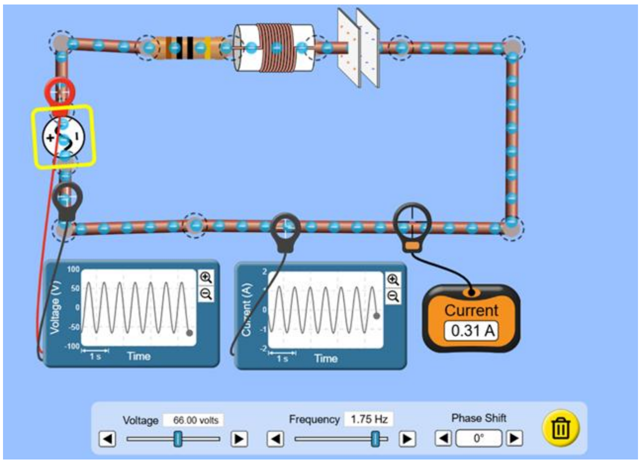

Figure 5. PhET AC Circuit Construction Kit Simulation Showing How Changes in AC Source Frequency Affect Current Amplitude in an RLC Circuit

One of the most significant findings of this study is the success of the PhET AC Circuit Construction Kit in reducing student misconceptions, particularly regarding Concept 6 (resonance in series RLC circuits). Misconceptions related to resonance are common due to the abstract nature of the concept, which cannot be observed directly. Many students incorrectly believe that increasing the AC source frequency will always increase the current in the circuit. PhET offers a solution by enabling interactive visualizations that show real-time changes in current amplitude as the frequency of the source is adjusted. Students can visually observe that the current reaches a maximum only at the resonance frequency, and decreases again if the frequency is increased or decreased beyond that point.

This simulation encourages the occurrence of cognitive dissonance, where students' initial expectations conflict with the observable results, thereby triggering conceptual revision (Heaton & Quan, 2023). The key strength of PhET lies in its ability to bring abstract and unobservable physics phenomena into a manipulable and exploratory learning environment (Wirda et al., 2023). Students can adjust parameters such as inductance (L) and capacitance (C) and directly examine how these affect the resonance peak. Furthermore, PhET presents information through multiple representations—sinusoidal graphs, numerical current values, and circuit visualizations—enhancing conceptual understanding via various cognitive channels.

This approach aligns with constructivist theory, which posits that understanding is actively built through experience, exploration, and reflection on observations. Therefore, it is not surprising that resonance, which previously had the highest misconception rate, became the concept with the most significant improvement after the intervention. This highlights that PhET-based interactive simulations are not merely visual aids, but transformative educational tools capable of reconstructing students' conceptual frameworks in a sustainable and meaningful way.

CONCLUSION AND SUGGESTIONS

This study demonstrates that the use of the PhET AC Circuit Construction Kit simulation can significantly reduce students' misconceptions regarding alternating current (AC) circuits in the Applied Physics course. The pretest results showed that an average of 32.1% of students experienced misconceptions across six main AC concepts, with the highest misconception rates observed in resonance (50.0%), phase relationships between current and voltage (38.2%), and AC power calculation (40.1%).

Following the implementation of PhET-assisted learning, the average misconception rate decreased to 7.8%, with an average reduction of 24.3%. The most significant reduction occurred in Concept 6 (resonance) with a 41.4% drop, followed by Concept 3 (phase relationship) with 30.3%, and Concept 4 (power in AC circuits) with 25.0%. These improvements were confirmed by McNemar tests, which showed statistically significant changes ($p < 0.05$) in the proportion of students experiencing misconceptions across all six tested concepts.

The success of the PhET simulation in reducing misconceptions can be attributed to its ability to provide visual representations of abstract and invisible physical phenomena, offer hands-on exploratory interaction with variables, and trigger cognitive dissonance, encouraging students to revise their prior beliefs. This approach transforms students into active participants in the learning process, supporting the construction of meaningful and lasting conceptual knowledge.

Therefore, PhET-assisted instruction is not only pedagogically effective, but also empirically proven to enhance conceptual understanding of complex and abstract AC electricity concepts among engineering students. These findings suggest the need for integrating interactive simulations such as PhET as part of foundational physics instruction in vocational and engineering education, especially as a systematic strategy to detect and remediate misconceptions early in the learning process.

BIBLIOGRAPHY

Achour, M., Khouna, J., & Tahiri, A. (2025). Can Serious Games Reduce Electric Current Misconceptions among 10 th Grade Moroccan Science Pupils? *International Journal of Information and Education Technology*, *15*(4), 795-802. https://10.0.71.2/ijiet.2025.15.4.2285

Dantic, M. J. P., & Fluraon, A. (2022). PhET Interactive Simulation Approach in Teaching Electricity and Magnetism among Science Teacher Education Students. *Journal of Science and Education (JSE)*, *2*(2), 88–98. https://doi.org/10.56003/jse.v2i2.101

Diola, J. R. G., & Mistades, V. M. (2021). Addressing students' misconceptions in force and motion using interactive simulations. *ICMET*, *21*, 21–23. https://doi.org/10.1145/3468978.3468979

Dirman, H. M., Mufit, F., & Festiyed, F. (2022). Review and Comparison of Four-Tier Multiple Choice and Five-Tier Multiple Choice Diagnostic Tests to Identify Mastery of Physics Concepts. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 1–12. https://doi.org/10.29303/jppipa.v8i1.838

Frans, B. U., & Wasis, W. (2022). Penerapan LKS Berbasis PhET untuk Mereduksi Miskonsepsi Siswa pada Materi Arus Listrik Bolak Balik. *Jurnal Penelitian Pembelajaran Fisika*, *13*(1), 31–40. https://doi.org/10.26877/jp2f.v13i1.11529

Hasanah, D. I., & Wasis, W. (2021). Cognitive Conflict Strategy Assisted by PhET Simulation to Remediate Student's Misconceptions on Wave Material. *Asatiza: Jurnal Pendidikan*, *2*(1), 19–32. https://doi.org/10.46963/asatiz

Hatika, R. G., Daruwati, I., & sohibun. (2022). Idenifikasi Miskonsepsi Mahasisawa Prodi Pendidikan Fisika Universitas Pasir Pengarai Pada Materi Listrik Statis. *Jurnal Ilmiah Wahana Pendidikan,* *8*(23), 393–399. https://doi.org/10.5281/zenodo.7398011

Heaton, R., & Quan, S. C. L. (2023). Managing cognitive dissonance in art teacher education. *Cambridge Journal of Education*, *53*(4), 473–494. https://doi.org/10.1080/0305764X.2023.2175789

Istiyono, E., Dwandaru, W. S. B., Fenditasari, K., Ayub, M. R. S. S. N., & Saepuzaman, D. (2023). The Development of a Four-Tier Diagnostic Test Based on Modern Test Theory in Physics Education. *European Journal of Educational Research*, *12*(1), 371-385. https://doi.org/10.12973/eu-jer.12.1.371

Kaniawati, I., Danawan, A., Suyana, I., Samsudin, A., & Suhendi, E. (2021). Implementation of interactive conceptual instruction (ICI) with computer simulation: Impact of students' misconceptions on momentum and impulse material. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *10*(1), 1–17. https://doi.org/10.24042/jipfalbiruni.v10i1.8375

Khaharsyah, A., Djufri, E., Cahyandaru, P., & Syafiq, A. (2024). Analisis Kemampuan Literasi Informasi Fisika Mahasiswa melalui Pemecahan Masalah pada Materi Energi Kinetik Otomotif. *Jurnal Taman Vokasi*, *12*(1), 27–38. https://doi.org/10.30738/jtvok.v12i1.17439

Listianingrum, S. A., Kuswanto, H., Mundilarto, & Dwandaru, W. S. B. (2024). A Review of Various Misconceptions in Physics Learning. *AIP Conference Proceedings*, *2622*(1), 20028. https://doi.org/10.1063/5.0133832

Maesaroh, N., & Sutikno, P. Y. (2025). Effectiveness of the PhET Simulation Assisted by Songs to Improve Students Critical Thinking Skills in Electrical Circuits. *Jurnal Pijar Mipa*, *20*(2), 356–364. https://doi.org/10.29303/jpm.v20i2.8729

Maggin, D. M. (2022). Group Experimental and Quasi-Experimental Research Designs for Special Education Intervention Validation. In *Handbook of Special Education Research, Volume I* No (pp. 101–114). Routledge.

Olaogun, O. P., Skelton, A., Zafar, M., Hunsu, N. J., & Idowu, I. A. (2023). A Systematic Review of Student Misconceptions about Electricity and Electric Circuit Concepts. *2023 IEEE Frontiers in Education Conference (FIE)*, 1(1), 1–5. https://doi.org/10.1109/FIE58773.2023.10343239

Önder Çelikkanlı, N., & Kızılcık, H. (2022). A Review of Studies About Four-Tier Diagnostic Tests in Physics Education. *Journal of Turkish Science Education*, *19*(4), 1291–1311. https://doi.org/10.36681/tused.2022.175

Resbiantoro, G., Setiani, R., & Dwikoranto. (2022). A Review of Misconception in Physics: The Diagnosis, Causes, and Remediation. *Journal of Turkish Science Education*, *19*(2), 403–427. https://doi.org/10.36681/tused.2022.128

Saudelli, M. G., Kleiv, R., Davies, J., Jungmark, M., & Mueller, R. (2021). PhET Simulations in Undergraduate Physics: Constructivist Learning Theory in Practice. *Brock Education Journal*, *31*(1), 52-68. https://doi.org/10.26522/brocked.v31i1.899

Schneider, V., & Rohmann, A. (2021). Arts in Education: A Systematic Review of Competency Outcomes in Quasi-Experimental and Experimental Studies. *Frontiers in Psychology*, *12*, 623935. https://doi.org/10.3389/fpsyg.2021.623935

Swandi, A., Rahmadhanningsih, S., Yusuf, I., & Widyaningsih, S. W. (2021). Exploring the Compton Scattering Phenomenon with Virtual Learning Under Project Based Learning Model (PjBL). *Kasuari: Physics Education Journal (KPEJ)*, *4*(1), 1–12. https://doi.org/10.37891/kpej.v4i1.159

Wati, W. (2024). Pemetaan Miskonsepsi Mahasiswa Fisika pada Konsep Energi , Kinematika , dan Listrik Statis dengan Tes Disnogtik Four-Tier. *JagoMIPA: Jurnal Pendidikan Matematika dan IPA*, *4*(4), 808–820. https://doi.org/10.53299/jagomipa.v4i4.984

Wirda, W., Mauvizar, E., Lubis, S. P. W., & Muzana, S. R. (2023). Utilization of PhET simulations in replacing real laboratories for physics learning. *Radiasi: Jurnal Berkala Pendidikan Fisika*, *16*(2), 71–79. https://doi.org/10.37729/radiasi.v16i2.3539

Wulansari, A. D. (2023). *Aplikasi Statistika Nonparametrik dalam Penelitian*. Thalibul Ilmi Publishing & Education.