

## The Effectiveness of Clicker-Assisted Peer Instruction on Improving High School Students' Understanding of Electromagnetism Concepts

Doni Nurdiansyah<sup>1\*</sup>, Chaerul Rochman<sup>2</sup>, Anna Permanasari<sup>3</sup>  
Universitas Pakuan, Indonesia<sup>1,3</sup>

Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia<sup>1</sup>

Email: doninurdians86@gmail.com<sup>1\*</sup>

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### Abstract

Electromagnetism is a fundamental yet challenging topic in high school physics, as students often struggle to develop deep conceptual understanding through conventional lecture-based instruction. This study aims to examine the effectiveness of clicker-assisted Peer Instruction (PI) in improving students' understanding of electromagnetism concepts. A quasi-experimental pretest–posttest control group design was employed involving two intact grade-11 classes (N = 58). The experimental group was taught using Peer Instruction supported by clickers, while the control group received conventional lecture-based instruction over a four-week period. Data were collected using a 25-item conceptual test with a reliability coefficient (KR-20) of 0.82. Data analysis included descriptive statistics, independent-samples t-test, ANCOVA with pretest scores as covariates, and effect size calculation using Hedges' *g*. The results show that the experimental group achieved a significantly higher normalized gain ( $\langle g \rangle = 0.62$ ) compared to the control group ( $\langle g \rangle = 0.35$ ). Statistical analysis revealed a highly significant difference between groups ( $p < 0.001$ ) with a very large effect size (Hedges  $g = 1.64$ ). The findings indicate that clicker-assisted Peer Instruction not only enhances conceptual understanding but also reduces performance variability among students. In conclusion, the integration of clickers within the Peer Instruction framework is highly effective in improving students' conceptual mastery of electromagnetism. This approach is recommended as an alternative instructional strategy to promote active learning and meaningful engagement in physics education.

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### Keywords:

*peer instruction; clicker; electromagnetism; normalized gain; high school*

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## INTRODUCTION

Understanding the concept of electromagnetism is one of the important aspects of physics education at the high school level. Electromagnetism is not only part of the curriculum, but it is also the basis for many applications of modern technology, such as telecommunications and electrical energy (Doane & Seward, 2011). In everyday life, we can see the application of electromagnetism in a variety of devices, from the phones we use to the electrical systems in the home. However, many students have difficulty understanding the basic concepts of electromagnetism, which can impact their academic achievement (Molin, 2022). This difficulty is often caused by the complexity of the material that involves understanding the magnetic field, electric current, and the interaction between the two. According to research by (Hake, 1998) the application of active learning methods such as Peer Instruction can significantly improve concept understanding. Peer Instruction, introduced by (Crouch & Mazur, 2001) at Harvard University, engages students in group discussions after they answer questions using

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clickers. In this way, students not only play the role of receivers of information, but also as concept digging through interaction with their peers (Dancy et al., 2016).

Traditional learning methods often focus on one-way lectures, which can leave students passive and less engaged in the learning process. In situations like this, students tend to just listen to explanations without really understanding or pondering the material being presented. This has the potential to lead to a low understanding of in-depth concepts. A study by (Freeman et al., 2014) showed that active learning methods, including Peer Instruction, can significantly improve student learning outcomes compared to traditional methods. In the study, it was found that students who engaged in active learning were able to overcome challenges in understanding complex physics concepts, including electromagnetism. Therefore, this study will explore how clicker-assisted Peer Instruction can be used to address the problem of understanding the concept of electromagnetism among high school students (Cirilli et al., 2019).

In this context, clickers serve as a tool to collect student responses in real-time, allowing for more interactive and responsive teaching. The use of clickers not only facilitates data collection, but also creates a more dynamic learning environment. Research by (Kay & LeSage, 2009) shows that the use of clickers can increase student engagement and provide direct feedback to teachers regarding student understanding. For example, when students answer a question via clicker, teachers can immediately see the percentage of correct and incorrect answers, which allows them to immediately identify areas that need clarification. This is especially important in the context of learning complex concepts such as electromagnetism, where a deep understanding is required to solve further problems. With quick feedback, teachers can adjust their teaching approach directly, increasing learning effectiveness (Partanen, 2018).

The novelty of this study lies in three main aspects. First, it specifically examines the effectiveness of clicker-assisted Peer Instruction in the context of high school electromagnetism, a topic known for its abstractness and persistent misconceptions (Magfirah, 2024). Second, it combines the Peer Instruction cycle with real-time clicker feedback in a quasi-experimental classroom setting, allowing a direct comparison with conventional lecture-based teaching. Third, the study emphasizes normalized gain, effect size, and ANCOVA-based comparison to provide a more robust measurement of conceptual improvement, rather than relying only on raw score differences. In this way, the research offers a more focused empirical contribution to physics education, especially at the senior high school level (Wattimena & Batlolona, 2024).

Against this background, this study is expected to provide deeper insight into the effectiveness of clicker-assisted Peer Instruction in improving the understanding of electromagnetism concepts in high school students (Febriansyah et al., 2024). This research also aims to provide recommendations for educators in implementing this method in the classroom. By understanding how Peer Instruction can improve student engagement and understanding, it is hoped that educators can design a more engaging and effective learning experience. In addition, the recommendations resulting from this research are expected to help schools integrate learning technologies in a way that supports better mastery of physics concepts (Nainggolan et al., 2025).

Overall, the application of active learning methods such as clicker-assisted Peer Instruction has great potential to improve students' understanding of electromagnetism. By creating an interactive and responsive learning environment, students not only become more engaged, but also better able to understand and apply the concepts they learn. This research is expected to make a significant contribution to the development of physics teaching methods that are more effective and relevant to the needs of students in the modern era.

## METHOD

This study was structured as a *pretest–posttest control group type quasi-experiment* because the researcher could not randomize students individually without disrupting the existing classroom structure. Two parallel classes of MIPA XI were selected intact; one was used as an experimental group (Peer Instruction + clicker) and one as a control group (conventional lecture). The class was selected after the homogeneity analysis of the previous semester's physics scores (Levene test  $p > 0.05$ ) and the mean difference test (u-test  $p > 0.05$ ) to ensure initial equivalence.

During the four weeks (8 hours lessons) of electromagnetism topics, the experimental class underwent a full cycle of Peer Instruction: the teacher came up with the *ConceptTest*, the students gave an anonymous response via clicker, the distribution of the answer was directly projected, followed by a 90–120 second discussion in pairs, re-voting, and conceptual clarification by the teacher. The control class received exposure to the material through interactive lectures, oral questions, and written question exercises without clickers.

The pre-test and post-test used the same instrument (25 conceptual items; KR-20 reliability = 0.82) so that the change in score could be directly attributed to the intervention. The main analyses included (1) descriptive, (2) *independent* t-test & ANCOVA for post-test scores with pre-test as covariate, and (3) Hedges effect measures  $g$ . Assumptions of normality (Shapiro–Wilk) and homogeneity of variance (Levene) were examined before parametric tests; if violated, transformation or robust test (*bootstrapped* ) ANCOVA) considered. Internal validity is improved through the use of standard instruments, teaching time control, and teacher training so that the procedures of the two classes run consistently.

Independent variables are operationalized as "learning methods" with two levels distinguished by the existence of a Peer Instruction cycle and the use of clickers. To ensure consistency, the experimental teachers were trained to run the five components of PI (concept question, 1 vote, discussion, 2 vote, feedback) and use an equivalent clicker device between sessions. The main dependent variable is the understanding of the concept of electromagnetism which is reflected in the pre-test score, post-test score, and normalized gain  $\langle g \rangle$  calculated through the Hake equation:

$$\langle g \rangle = \frac{S_{postes} - S_{pretest}}{100 - S_{pretest}}$$

The rationalization of  $\langle g \rangle$  lies in its ability to adjust to individual starting point differences, so that the comparison of achievement becomes fairer among heterogeneous groups. Pre-test is also treated as a covariate in ANCOVA to purify the impact of the treatment.

## RESULTS AND DISCUSSION

### Descriptive Pre-test, Post-test, Gain, and Normalized Gain Scores

**Table 1. Analysis Description**

Groups	n	Pre-test	Post-test	Absolute Gain	$\langle g \rangle$
Controls	30	43,49	63,79	20,29	0,35
Experiment (PI + Clicker)	30	45,10	79,86	34,76	0,62

Source: Processed research data by the author, 2026

The experimental group's average post-test score increased  $\approx 16$  points above the controls, while the average  $\langle g \rangle$  jumped from the medium category (0.35) to the high (0.62)

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category. At the starting point, the two classes are at a comparable level of ability. The average pre-test controls were  $43.5 \pm 7.2$  and the experiments were  $45.1 \pm 7.9$  different by less than 2 points—differences that were still covered by standard deviations and within the 95% confidence interval each ( $\approx \pm 2 \cdot SE$ ). An almost identical median signifies a symmetrical and equal initial distribution.

Post-intervention, there was a striking divergence. The average post-test score of the experimental class jumped to 79.9 with an SD of only 6.4, while the control class stopped at 63.8 with a wider dispersion (SD 9.3). The score range (66.6–97.2) in the experimental class showed that even the bottom students surpassed the midpoint of the control class; This indicates an equalization effect, not just an increase in the average.

The absolute increase (Gain) illustrates the same story: 34.8 points for the experiment versus 20.3 points for the control. It was also seen that the distribution of experimental gain was more close—the median of 36.1 was very close to the mean—reflecting the relatively consistent impact of the intervention between students.

The key measure of conceptual effectiveness, *normalized gain*  $\langle g \rangle$ , corroborates the findings. According to the classification of (Hake, 1998),  $g < 0.3$  is categorized as "low", 0.3–0.7 "moderate", and  $> 0.7$  "high". The control class was located at the lower limit of the "medium" category (0.35) while the experimental class was comfortably perched at 0.62—almost double and close to the upper edge of the "medium" category. This means that the experimental students made use of more than 60% of the conceptual "learning space" that was still available after the pre-test, while the control took only a third.

Furthermore, the range of  $\langle g \rangle$  in the experimental class (0.31–0.95) indicates that all students, including those with low pre-test scores, still gain substantial gains. In contrast, the control class had a very small lower tail  $\langle g \rangle$  (0.03), and there were even students who experienced *absolute negative gain* (–5.7) due to concept confusion or exam fatigue.

A *small standard error* ( $\approx 0.03$ –0.04) resulted in a 95% confidence interval that did not overlap between the groups for both the post-test and  $\langle g \rangle$ , providing preliminary statistical evidence prior to formal inferential testing that the difference was very unlikely to occur randomly.

### Statistical Inference

**Table 2. Statistical Inference**

Analysis	Statistics	p	Effects
T-test	$t(48) = -6.42$	$3.7 \times 10^{-8}$	Hedges $g = 1.64$ (very large)
ANCOVA post-test score*	$F(1, 57) \approx 33.0$	$< 0.001$	partial $\eta^2 = 0.37$ (large)

Source: Processed research data by the author, 2026

The results of the two-tail t-test showed a very significant difference between the PI+ clicker group and the lecture group ( $p \ll 0.001$ ). Hedges  $g = 1.64$  place the intervention effect in the "very large" range—more than one and a half standard deviations above the control. With  $n = 29$  per group and  $\alpha = 0.05$ , *post-hoc* analysis calculates power  $(1 - \beta) > 0.99$ , so the risk of failing to detect such a strong effect is negligible. A narrow confidence interval ( $\pm 0.09$ ) shows high estimation accuracy thanks to the relatively small  $\langle g \rangle$  variant in both groups.

The ANCOVA model includes pre-test scores as covariates to eliminate the residual bias of the initial ability. The *interaction pre  $\times$  method* ( $p = 0.22$ ) proved to be insignificant, meeting the homogeneous slope requirement. After correction, the learning method explained 37% of the post-test score variance (partial  $\eta^2 = 0.37$ ), well above the *large effect threshold* (0.14 according to Cohen). The adjusted mean ( $\pm SE$ ) was  $80.1 \pm 0.8$  for the experiment and  $64.1 \pm$

0.8 for the control—a net difference that was almost identical to the *t-test* results on  $\langle g \rangle$ , confirming that the PI + clicker advantage was not an artifact of baseline difference.

To guard against the violation of hidden assumptions, the  $\langle g \rangle$  data was analyzed with Mann-Whitney U. U values = 98 ( $p \approx 2 \times 10^{-7}$ ) confirmed the convergence of the results. The magnitude of the effect  $r = 0.66$ , equivalent to  $g \approx 1.6$ , reinforces the claim of a large effect. In addition, ANCOVA bootstrapped 5 000 iterations resulted in an average difference  $\langle g \rangle 0.27$  with a bias-corrected CI of 0.19–0.37, identical to parametric estimates.

The consistency of the three lines of analysis—*t-test*, ANCOVA, and non-parametric tests—provides strong confidence that the improvement in conceptual understanding of electromagnetism in the PI + clicker group is real, large, and robust. The very high magnitude of the effect also lowers the likelihood that these findings are only relevant in a limited sample; Practically, teachers can expect an average spike of 15–17 points on a scale of 0–100 or an additional utilization  $\pm 30\%$  of conceptual "learning spaces" when this strategy is implemented.

Thus, the inferential analysis validates previous descriptive findings and provides a strong statistical basis for deducing the significant effectiveness of clicker-assisted Peer Instruction in the realm of high school-level electromagnetism teaching.

### In-Depth Discussion

The results of this study confirm that the integration of **Peer Instruction (PI) assisted by clickers** is able to significantly increase the understanding of the concept of electromagnetism with effect sizes that are in the *very large category* (Hedges  $g \approx 1.64$ ). These findings do not stand alone; he constructed, affirmed, and in some respects expanded the canon of research on PI in science education (Zebua, 2024).

The effect of  $\langle g \rangle = 0.62$  achieved by the experimental class is in line with the range of 0.55–0.70 reported by (Crouch & Mazur, 2001) on the topic of mechanics, as well as recent physics research that highlights how PI facilitates *knowledge construction* in the area of abstract concepts (gjerde et al, 2024). In the realm of electromagnetism—a topic that is often more challenging than mechanics—the PIDAM study by (Kola, 2020) showed  $\langle g \rangle \approx 0.58$  when PI was integrated with dialogical arguments (Kola et al, 2021); our results were slightly higher, suggesting that clicker support has the potential to provide additional boost.

Interestingly, a meta-critical analysis by (Anthony, 2025) warns that PI can "fail" on highly counter-intuitive physics questions if the discussion is unstructured (ospanbekov et al, 2024). The fact that the study still recorded a large increase suggests that the combination of clicker and scaffolding questions (ConcepTest focuses on Lorentz-force misconceptions, induction, and flux) successfully mitigates the pitfalls.

The *cognitive conflict model* explains that changes in conception occur when students become aware of a mismatch between the initial prediction and the emerging evidence (in this study: the clicker histogram). Instant visualization triggers dissonance, and then a two-minute discussion serves as an arena for *conceptual negotiation*. Recent neurocognitive research shows that the PI negotiation phase activates the *anterior network of the cingulate cortex*—the brain region that assesses conflicts and errors—as well as the *dorsolateral prefrontal cortex* that plays a role in *working memory* (Gjerde et al., 2025). This is in line with field data: 42% of students who initially chose the wrong one switched to the correct answer after the discussion.

The interactive lecture variant still allows an increase in  $\langle g \rangle \approx 0.35$  (the "medium" category). However, a gap of  $\sim 0.27$  points between the groups shows that PI+clickers double the *learning leverage*. The smaller variance of the experimental post-test score ( $SD = 6.36$ ) than the control ( $SD = 9.31$ ) indicates that PI not only raises the distribution center but also closes the spread—a phenomenon supported by a large-scale study in molecular biology that notes homogenization of achievement when clickers are applied (Watts et al., 2022).

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Clickers lower affective barriers by providing anonymity, so students who are usually reluctant to ask questions still participate. This is important in the context of Indonesia's relatively hierarchical learning culture. PhysPort sources stated that a sense of security to "get it wrong" is the key to the success of PIs in the big class. Our observational participation logs showed an engagement rate of  $> 85\%$  in the experiment, comparable to a chemistry class study of 350 college students that reported a two-fold increase in willingness-to-answer when clickers were used compared to handshakes (Caldwell et al., 2017).

Although the effect is strong, generalizations need to be careful. First, the four-week duration has not tested long-term retention; The literature shows *the decay* of the concept of electromagnetism is quite sharp after 8–10 weeks without amplification. Second, the research was conducted in urban schools with technological carrying capacity; replication in suburban schools requires the substitution of clickers with *free web-polling*—an approach that has been successful in a hybrid study by Ng et al. (2023) but with a slightly lower effect ( $g \approx 0.48$ ). Third, the isolation screening reduced the sample to 58; Although the test power remains  $> 0.95$ , a larger population distribution will add to the confidence.

## CONCLUSION

This study conclusively proves that the application of clicker-assisted Peer Instruction (PI) on electromagnetism material in grade XI of high school results in a much higher increase in conceptual understanding than conventional lecture methods. The *average normalized gain* value of the experimental group reached 0.62—close to the upper limit of the "medium" category according to Hake—while the control group was at 0.35. The difference  $\langle g \rangle$  of  $\approx 0.27$  is reinforced by the Hedges effect size  $g \approx 1.64$  and the partial  $\eta^2 \approx 0.37$ , indicating a **very large and substantive pedagogical impact**. ANCOVA's analysis showed that the advantage remained significant after the initial ability was controlled, and the non-parametric sensitivity test confirmed the robustness of the results. The qualitative findings especially the 42% shift of incorrect answers to correct after peer discussion—shed light on the cognitive mechanisms behind the spike in scores. PI + clicker not only raises the average, but also closes the distribution of student performance, creating a more equal class in concept achievement.

Based on these findings, it is recommended that physics teachers integrate clicker-assisted Peer Instruction into classroom practice to enhance student engagement and conceptual understanding. Schools are also encouraged to support the use of interactive learning technologies to facilitate active learning environments. For future research, it is suggested to involve larger sample sizes, explore long-term retention effects, and examine the application of alternative response systems such as mobile-based polling in different educational contexts.

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