JPPIPA 11(9) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

The Effect of Hybrid Learning Method Assisted by Artificial Intelligence Camera Controller and Student Engagement on Learning Outcomes

Agus Fajar Hariadi[1*], I Nyoman Sudana Degeng[1], Punaji Setyosari[1], Saida Ulfa[1], Faiqul Faris Alhakim[2]

[1] Department of Instructional Technology, Universitas Negeri Malang, Malang, Indonesia.
[2] Mining Engineering, School of Engineering, University of Western Australia, Australia.

Received: June 06, 2025
Revised: August 11, 2025
Accepted: September 25, 2025
Published: September 30, 2025

Corresponding Author:
Agus Fajar Hariadi
agusfajarh@gmail.com

DOI: 10.29303/jppipa.v11i9.12034

Abstract: The COVID-19 pandemic disrupted education, causing learning loss due to reduced teacher-student interaction during distance learning. Digital methods often failed to improve engagement and outcomes due to remote monitoring difficulties. A hybrid learning approach integrating offline and online methods was introduced, supported by an Artificial Intelligence Camera Controller (AICC), allowing 50% of students in-person participation while others joined online. This study investigated AICC-supported hybrid learning's impact on student engagement and mathematics outcomes using a quasi-experimental 2x3 factorial design with non-equivalent control groups. The participants of this study consisted of an experimental group of 64 students and a control group of 62 students. Data were collected through observations, questionnaires, and tests, analyzed using Two-Way ANOVA. Results showed AICC-supported hybrid learning significantly improved outcomes compared to hybrid learning without AICC. Findings revealed: (1) no significant difference between high and medium engagement students; (2) no significant difference between medium and low engagement students; (3) significant differences between high and low engagement students. AICC-supported hybrid learning effectively enhances engagement and academic performance, offering a promising post-pandemic educational strategy. Teachers should adopt this method for improved student competencies.

Keywords: Artificial intelligence camera controller; Hybrid learning method; Learning outcomes; Students engagement

Introduction

The contemporary educational landscape necessitates continuous adaptation to evolving technological and environmental circumstances, particularly evident during significant disruptions such as the global COVID-19 crisis (Amin et al., 2022; Haetami, 2023). Although distance education served as an essential emergency response, it resulted in substantial academic deficits and diminished interpersonal connections among learners, highlighting the critical requirement for innovative pedagogical approaches (Singh et al., 2021). Blended learning models—integrating digital platforms with traditional classroom instruction—have emerged as viable alternatives, facilitating optimal utilization of physical learning spaces while enhancing educational flexibility (Triyason et al., 2020). This pedagogical framework synthesizes the strengths of conventional face-to-face teaching with digital learning methodologies, promoting active student participation and delivering

How to Cite:
Hariadi, A. F., Degeng, I. N. S., Setyosari, P., Ulfa, S., & Alhakim, F. F. (2025). The Effect of Hybrid Learning Method Assisted by Artificial Intelligence Camera Controller and Student Engagement on Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *11*(9), 777–786. https://doi.org/10.29303/jppipa.v11i9.12034

meaningful educational encounters (Gutiérrez-Braojos et al., 2019).

Blended educational approaches encounter significant obstacles, most notably in maintaining meaningful participation among distance learners (Nortvig et al., 2018). This study introduces a novel technological solution—the Artificial Intelligence Camera Controller (AICC)—which represents the first systematic integration of AI-powered dynamic camera tracking with pedagogical theory in hybrid learning environments. Artificial Intelligence Camera Controller (AICC) systems represent an innovative solution designed to address this pedagogical divide by facilitating dynamic instructional interactions and delivering immersive learning environments for remote participants (Jacob et al., 2021; Amin et al., 2023). Unlike existing static camera systems that limit remote learners to passive observation, this research presents the first empirical investigation of how AI-enabled dynamic visual engagement affects the theoretical framework of student engagement across behavioral, emotional, and cognitive dimensions simultaneously.

In contrast to conventional arrangements that restrict online learners to passive observation through fixed camera positions, AICC technology empowers educators with unrestricted mobility throughout the learning space, thereby creating stimulating and participatory educational settings (Panahi & Duraisamy, 2021). Such technological capabilities serve to sustain learner focus and counteract the tedium frequently experienced by remote students, particularly within academically demanding disciplines such as mathematics that necessitate intensive cognitive involvement (Fung et al., 2018). This research contributes novel theoretical insights by proposing an extended engagement-technology interaction model that explains how AI-mediated visual dynamics influence learning outcomes through moderated engagement pathways.

Artificial Intelligence Camera Controller systems utilize sophisticated AI algorithms to optimize blended learning environments, enabling automated camera tracking of instructor mobility while documenting real-time classroom activities comprehensively (Jacob et al., 2021; Ayuni et al., 2024). This technological capacity guarantees that distance learners achieve equivalent visual access and instructional quality comparable to their physically present counterparts (Hekele et al., 2022). Nevertheless, the effectiveness of such implementations relies heavily upon the seamless integration of artificial intelligence solutions with pedagogical strategies specifically adapted to learner requirements, temporal constraints, and institutional resources (Nortvig et al., 2018). Empirical investigations examining AICC's educational effectiveness remain relatively scarce, with this study being the first to employ a factorial experimental design examining the interaction effects between AI-enhanced visual technologies and varying levels of student engagement on mathematics learning outcomes.

The significance of demonstrative instruction within mathematical pedagogy underscores the critical necessity for sophisticated visual presentation mechanisms (Sudiarta & Widana, 2019). Conventional teaching approaches depend upon traditional writing surfaces, which present considerable challenges for replication in virtual learning environments when utilizing standard computer-based recording equipment (Hung et al., 2016). This research presents a methodological innovation by developing and validating a comprehensive AICC system that integrates dual-camera functionality with real-time AI processing, providing the first quantitative evidence of its impact on mathematical problem-solving skills across differentiated engagement levels. AICC technology addresses these pedagogical constraints through the implementation of intelligent camera systems coupled with fixed presentation displays, thereby ensuring optimal visual clarity and sustained learner engagement for distance participants. This multi-camera configuration not only enhances visual-spatial learning experiences but also corresponds with the inherently collaborative and analytical problem-solving characteristics fundamental to mathematical education (Triyason et al., 2020).

The novelty of this research lies in three key contributions: (1) the first systematic integration of AI camera technology with established engagement theory in educational settings, (2) the development of a new theoretical framework explaining technology-engagement-learning outcome relationships, and (3) the introduction of a replicable methodological approach for evaluating AI-enhanced hybrid learning environments. To enhance blended educational experiences, AICC integrates dual essential elements: an artificially intelligent tracking device for monitoring instructor locomotion and a stationary recording apparatus for documenting pedagogical materials such as board-based presentations (Kharisma et al., 2023; Prananta et al., 2023). This technological synthesis, coordinated through an accessible interface system, establishes a responsive and equitable educational setting (Amin et al., 2023). Preliminary research indicates that although sophisticated technological implementations do not invariably ensure superior academic achievements (Bognár et al., 2018), instruments such as AICC target particular deficiencies within integrated learning frameworks by strengthening student involvement and minimizing educational inequalities (Hekele et al., 2022).

This research explores the integration of AICC into hybrid learning, focusing on its impact on student engagement and mathematics learning outcomes. By addressing these challenges, the study aims to contribute to pedagogical advancements that balance technology and effective teaching methods. The findings highlight the potential of AICC to redefine hybrid learning as a sustainable educational model, offering practical insights for educators navigating post-pandemic challenges. The aims of this study are to examine the differences in learning outcomes between students who experience AICC-assisted hybrid learning methods and those who use traditional hybrid methods without AICC, to evaluate the differences in learning outcomes among students with high, medium, and low levels of engagement, and to analyze the interaction between teaching methods and student engagement on learning outcomes.

Method

Research Design

This study utilized a quasi-experimental 2x3 factorial pre-test-post-test design with nonequivalent control groups (See table 1). This design allowed the simultaneous examination of two teaching methods and their interaction with varying levels of student engagement (Creswell, 2016). The factorial structure facilitated the identification of main effects and interaction effects between variables. Pre-tests were conducted to measure initial equivalence between groups, while post-tests assessed the learning outcomes following the interventions.

Table 1. 2 x 3 Factorial Design

Moderator Variable	Independent Variable	
Students Engagement	With AICC (X1)	Without AICC (X2
Hight (Y_1)	X_1Y_1	X_2Y
Middle (Y_2)	X_1Y_2	X_2Y
Low (Y_3)	X_1Y_3	X_2Y

The design involved two independent variables: the learning method (AICC-assisted hybrid learning and traditional hybrid learning) and the moderator variable of student engagement (categorized as high, medium, and low). The dependent variable was students' mathematics learning outcomes. This design was particularly appropriate for addressing external factors that could influence the learning outcomes, as statistical controls were applied to ensure the validity of comparisons between groups.

Variables

This study examined the effects of teaching methods, engagement levels, and their interactions on students' mathematics learning outcomes. The variables are described as follows:

The independent variable in the study was the teaching method. Two approaches were compared: the AICC-assisted hybrid learning method and the traditional hybrid learning method. In the AICC-assisted hybrid learning, Artificial Intelligence Camera Controller (AICC) technology was employed to enable dynamic tracking of the teacher's movements, fostering greater interaction between the teacher and students, both in-person and online. In contrast, the traditional hybrid learning method relied on static webcams, offering less interactivity for online students.

The dependent variable was students' mathematics learning outcomes. These outcomes were assessed through pre-tests and post-tests, which measured students' comprehension of mathematical concepts and problem-solving abilities.

Student engagement served as the moderator variable. Engagement levels were categorized into three groups: high, medium, and low. These levels were determined using a validated engagement questionnaire designed to capture behavioural, emotional, and cognitive dimensions of student involvement in the learning process (Amin et al., 2023).

This framework allowed the study to explore the direct and interactive effects of teaching methods and engagement levels on students' learning outcomes, providing insights into the interplay between instructional strategies and student participation.

Participants

The study population comprised 126 eighth-grade students from SMPIT Insan Permata Malang, selected using purposive random sampling. This sampling ensured the inclusion of classes with diverse engagement levels to maintain internal validity. Students were divided into four classes: A and B (experimental group, n=64) receiving AICC-assisted hybrid learning, and C and D (control group, n=62) receiving traditional hybrid learning. Randomization of class assignments and equivalence testing (homogeneity tests) ensured comparability between groups before the intervention.

Instruments

The instruments used in this study were carefully designed and validated to ensure their effectiveness in measuring the targeted variables. The Student Engagement Questionnaire utilized a 5-point Likert scale adapted from the Student Engagement in Schools Questionnaire (SESQ) developed by Hart et al. (2011). This questionnaire assessed three dimensions of engagement: behavioural, emotional, and cognitive. Behavioural engagement focused on students'

participation and attention during learning activities, emotional engagement measured their interest and enjoyment in learning, and cognitive engagement evaluated their willingness to exert effort in completing tasks. The reliability of this instrument was confirmed, with Cronbach's Alpha scores of 0.813 for behavioral, 0.724 for emotional, and 0.716 for cognitive engagement dimensions.

The mathematics test served as another critical instrument, designed to assess students' mastery of geometry topics such as identifying shapes, calculating perimeters, and solving area problems. The test was developed and validated through expert judgment and trial testing to ensure content validity and reliability. The mathematics test achieved a high Cronbach's Alpha score of 0.922, further verifying its suitability for evaluating learning outcomes. These rigorously developed instruments provided a solid foundation for examining the impact of AICC-assisted hybrid learning on student engagement and mathematics achievement.

Procedure

The study began with the preparation phase, which involved developing lesson plans tailored to both AICC-assisted hybrid and traditional hybrid learning approaches. Instruments, including questionnaires and tests, were validated through expert reviews and pilot testing to ensure their accuracy and reliability. Mathematics teachers received specialized training to implement the AICC-assisted methods effectively, equipping them with the skills needed to maximize the technology's potential.

The implementation phase spanned six weeks, consisting of six sessions for each group. The experimental group utilized AICC technology, which enabled dynamic tracking of teacher movements and enhanced interaction for online students. This setup allowed teachers to move freely around the classroom while maintaining visibility to remote learners. In contrast, the control group relied on static webcams, which limited interactivity and engagement levels for online participants.

Data collection focused on assessing student engagement and learning outcomes. Engagement levels were measured using the SESQ-based questionnaire, which evaluated behavioral, emotional, and cognitive participation in learning activities. Pre-test and post-test scores were recorded to determine the effectiveness of the interventions in improving mathematics learning outcomes.

For data analysis, descriptive statistics were employed to summarize key metrics, including mean scores, standard deviations, and frequency distributions. Two-way ANOVA was conducted to examine the main effects of teaching methods and engagement levels, as well as their interaction effects on learning outcomes. Prior to analysis, statistical assumptions such as normality, homogeneity, and independence were thoroughly tested to ensure the validity and reliability of the results. This systematic approach provided a comprehensive evaluation of the impact of AICC-assisted hybrid learning on student engagement and mathematics performance.

Data Validation

Content validity was ensured through expert judgment, confirming that the instruments adequately measured the intended constructs. Construct validity for the engagement questionnaire was evaluated using Pearson correlation coefficients, with most items surpassing the threshold of 0.3, indicating strong validity. Reliability was also a key focus; the engagement questionnaire displayed high internal consistency, as evidenced by Cronbach's Alpha scores across behavioural, emotional, and cognitive engagement subscales. The mathematics test similarly demonstrated high reliability, with a Cronbach's Alpha score of 0.922, verifying its effectiveness for assessing learning outcomes.

Statistical assumptions were rigorously tested to ensure the suitability of the data for parametric analysis. Normality was assessed using the Kolmogorov-Smirnov test, confirming that the data followed a normal distribution. Additionally, Levene's test was conducted to verify homogeneity of variance, ensuring comparable variances across groups. This comprehensive methodology established a robust framework for analyzing the effectiveness of AICC-assisted hybrid learning and its impact on student engagement and mathematics learning outcomes, thereby validating the study's findings and conclusions.

Result and Discussion

Descripton of Participants

This study involved 129 seventh-grade students from SMPIT Insan Permata Malang, divided into two groups: the experimental group (66 students) using AICC-assisted hybrid learning and the control group (63 students) using traditional hybrid learning without AICC. Both groups alternated between offline and online sessions in a hybrid format, ensuring balanced exposure to both instructional methods. The experimental group comprised two classes, with 33 students per class, while the control group had two classes of 32 and 31 students, respectively.

Engagement Levels

Student engagement was analysed across three key dimensions: behavioural, emotional, and cognitive

engagement. The findings for each group are described as follows:

In the experimental group, behavioural engagement was categorized as high for 78.79% of the students, with a mean score of 3.88, signifying a strong level of participation and involvement in activities. Emotional engagement showed a moderate level, with 40.91% of students demonstrating high engagement and a mean score of 3.50. Meanwhile, cognitive engagement was high for 54.55% of students, with a mean score of 3.68, indicating a strong investment in learning and application of knowledge.

For the control group, behavioural engagement was also high, with 70.60% of students achieving high levels of engagement and a mean score of 3.80. Emotional engagement in this group was comparable to the experimental group, with 41.27% of students showing high engagement and a mean score of 3.48, reflecting a moderate level of emotional connection to learning. However, cognitive engagement was lower in the control group, with only 31.75% of students classified as highly engaged and a mean score of 3.10, reflecting a moderate overall engagement level in this dimension (table 2).

Table 2. Comparative Student Engagement Distribution Between Groups

Engagement Dimension	Group	Low (1.00-2.33)	Medium (2.34-3.66)	High (3.67-5.0)	Mean	Level
	Control	3 (4.75%)	13 (20.63%)	47 (74.60%)	3.80	High
Behavioral	Experimental	2 (3.03%)	12 (18.18%)	52 (78.79%)	3.88	High
	Difference	-1.72%	-2.45%	+4.19%	+0.08	Maintained
	Control	7 (11.11%)	30 (47.62%)	26 (41.27%)	3.48	Medium
Emotional	Experimental	2 (3.03%)	32 (48.48%)	27 (40.91%)	3.50	Medium
	Difference	-8.08%	+0.86%	-0.36%	+0.02	Maintained
	Control	12 (19.05%)	31 (49.21%)	20 (31.75%)	3.10	Medium
Cognitive	Experimental	1 (1.52%)	29 (43.94%)	36 (54.55%)	3.68	High
	Difference	-17.53%	-5.27%	+22.80%	+0.58	Upgraded
	Control				3.46	Medium
Overall Average	Experimental				3.69	High
	Difference				+0.23	Upgraded

Overall, the experimental group demonstrated consistently higher levels of engagement across all dimensions compared to the control group, suggesting the intervention's effectiveness in fostering greater students participation, emotional connection, and cognitive involvement in the learning process.

Learning Outcomes

Learning outcomes were evaluated through pre-test and post-test scores, focusing on the development of students' problem-solving skills in mathematics. In the experimental group, the mean pre-test score was 64.87, which increased significantly to a post-test mean score of 77.56. Statistical analysis revealed a significant improvement in learning outcomes ($F = 7.967$, $p = 0.006$), underscoring the positive impact of the intervention on enhancing students' mathematical problem-solving abilities.

The control group also showed an increase in scores, with a pre-test mean of 66.24 and a post-test mean of 71.93. While the improvement was evident, it was less substantial compared to the experimental group, suggesting that the intervention applied in the experimental group was more effective in facilitating meaningful learning gains (See Figure 1).

These findings highlight the superiority of the experimental approach in improving both engagement levels and learning outcomes, with a particular emphasis on its effectiveness in promoting higher cognitive and behavioural engagement alongside enhanced problem-solving skills.

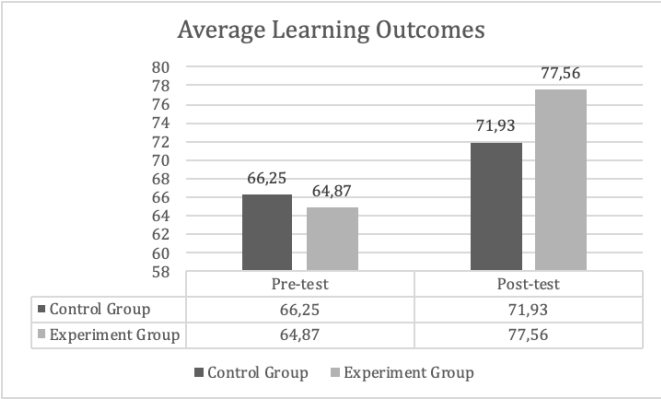

Figure 1. Average learning outcomes of students in the experimental class and control class

Hypothesis Testing

The results of a two-way ANOVA revealed several significant findings related to the effects of teaching methods, engagement levels, and their interaction on learning outcomes.

First, the analysis showed that the teaching method significantly influenced learning outcomes. Students taught using the AICC-assisted hybrid method demonstrated superior learning outcomes compared to

those taught with the traditional hybrid method (F = 7.967, p = 0.006). This indicates that the choice of teaching method plays a crucial role in enhancing students' academic performance.

Second, differences in learning outcomes were observed across varying engagement levels—categorized as high, medium, and low (F = 3.752, p = 0.026). This finding suggests that students' level of engagement significantly impacts their learning outcomes, with higher engagement levels generally associated with better performance.

Furthermore, a significant interaction effect between teaching methods and engagement levels was identified (F = 7.363, p = 0.001). This indicates that the effectiveness of the AICC-assisted hybrid learning method varied depending on students' engagement levels, highlighting the combined influence of teaching methods and engagement on learning outcomes.

Post-Hoc Analysis

Post-hoc analysis provided additional insights into the relationship between engagement levels and learning outcomes. A significant difference was found between students with high and low engagement levels (p = 0.026), with those exhibiting higher engagement achieving better results. However, no significant differences were detected between high and medium engagement levels or between medium and low engagement levels (p > 0.05), suggesting that the distinctions in learning outcomes between these groups were less pronounced.

These results underscore the importance of both teaching strategies and student engagement in achieving optimal learning outcomes. Moreover, the interaction between these factors indicates that their combined effect can further enhance the learning process (Nadrah, 2025).

Summary of Results

The findings confirm that the AICC-assisted hybrid learning method significantly improves student engagement and learning outcomes compared to traditional hybrid methods. Additionally, engagement levels play a moderating role in determining learning success, with the highest outcomes observed in students with high engagement. The interaction between the teaching method and engagement levels further emphasizes the importance of tailored approaches to hybrid learning environments.

Discussion

The Impact of AICC-Supported Hybrid Learning Methods on Learning Outcomes

The present study addresses these challenges through the implementation of AICC technology, which specifically targets the visual clarity and participation equity issues identified in existing literature. Hybrid learning integrates face-to-face and online instruction to improve learning outcomes by combining social benefits with flexibility and accessibility (Alika & Radia, 2021; Gutiérrez-Braojos et al., 2019; Händel et al., 2022). In mathematics education, hybrid approaches enhance conceptual understanding and problem-solving skills (Cahyono & Asikin, 2019; Hidayat et al., 2019), yet challenges persist in maintaining visual clarity and equitable participation. The present study addresses these challenges through AICC technology.

The findings demonstrate that the hybrid learning method supported by Artificial Intelligence Camera Controller (AICC) significantly enhances learning outcomes compared to the hybrid method without AICC (Prananta et al., 2023; Ayuni et al., 2024). The experimental class achieved a higher average score (85.49) compared to the control class (74.26), with a statistically significant difference (F = 7.967, p = 0.006). This aligns with previous studies by Herayanti et al. and Hung et al., which confirmed the effectiveness of hybrid methods in improving students' comprehension (Herayanti et al., 2020; Hung et al., 2016). Furthermore, the observed improvement indicates that leveraging innovative tools like AICC addresses learning disparities and ensures a more equitable learning experience across diverse student groups.

The integration of AICC and the Moodle platform offers distinct advantages, such as seamless interaction and accessibility. Moodle's comprehensive features, including digital classrooms, real-time interaction, and integrated assessments, surpass the capabilities of Google Classroom. The AICC-enabled camera enhances virtual learning by mimicking real classroom dynamics, ensuring equitable participation and engagement for both in-person and remote students. This technology fosters a sense of inclusivity, motivating students to actively participate regardless of their location or mode of access. By combining advanced features like camera tracking and interactive content delivery, the AICC-supported hybrid model demonstrates its potential to transform traditional learning environments (Andriyani et al., 2025).

The AICC-enabled camera system enhances virtual learning by mimicking real classroom dynamics, addressing a critical gap identified by Bedenlier et al in their research on webcam use in synchronous online learning (Händel et al., 2022). Unlike static camera setups that limit visual engagement, the AICC system ensures equitable participation and engagement for both in-person and remote students. This technology fosters a sense of inclusivity, motivating students to actively participate regardless of their location or mode of access, directly supporting the visual engagement pathways

identified in recent literature (Händel et al., 2022; Raes et al., 2020).

The Role of Student Engagement in Learning Outcomes

Student engagement encompasses behavioral, emotional, and cognitive components that significantly influence academic achievement (Fredricks et al., 2016). In hybrid learning contexts, maintaining high engagement presents unique challenges due to varied learning environments and technological mediation (Nortvig et al., 2018; Amin et al., 2023). While technology-enhanced environments can positively impact engagement when properly implemented (Hidayat et al., 2019), the relationship between specific technological features and engagement outcomes requires further investigation.

The study reveals that students' engagement levels (high, moderate, and low) significantly influence their academic performance. Students with high engagement scored an average of 84.59, outperforming those with moderate (79.09) and low engagement levels (69.00). This finding is consistent with previous studies by Raes et al. and Krishnan, emphasizing that active engagement fosters cognitive and emotional involvement, ultimately improving learning outcomes (Krishnan, 2018; Raes et al., 2020; Amin et al., 2023). Moreover, these results underline the necessity of implementing teaching strategies that encourage active participation and nurture intrinsic motivation among students (Amin et al., 2020; Kurniawati et al., 2022).

The study also underscores the importance of self-regulated learning (SRL) in enhancing students' engagement (Kurniawati et al., 2022). Active participation in hybrid classes—both physical and virtual—is linked to students' ability to manage their learning processes effectively. This supports the idea that hybrid learning environments encourage collaborative and independent learning (Bognár et al., 2018; Sudiarta & Widana, 2019). Teachers play a crucial role in fostering SRL by designing tasks that stimulate curiosity, challenge cognitive abilities, and promote sustained engagement over time. The development of SRL skills not only improves academic performance but also prepares students to adapt to future educational and professional demands (Hidayat et al., 2019; Amin et al., 2020). The observed engagement-performance relationship aligns with recent findings by Kahu and Nelson, who emphasized the importance of understanding engagement mechanisms in educational success (Kahu & Nelson, 2018). Our results provide quantitative evidence that technological interventions can influence these mechanisms, particularly when they address specific learning environment limitations such as visual access in hybrid settings.

Interaction Between Method and Engagement Levels

Artificial intelligence integration in educational technology enables personalized and adaptive learning experiences through real-time feedback, content adaptation, and enhanced student engagement (Kavitha et al., 2024; Kharisma et al., 2023; Hwang et al., 2020). Computer vision and automated tracking systems show potential for improving remote learning experiences (Bond et al., 2021), yet limited research has explored AI-powered camera systems' effectiveness in hybrid learning environments (Amin et al., 2022).

The results indicate a significant interaction between the teaching method and student engagement levels ($F = 7.363$, $p = 0.001$). Students with low engagement demonstrated the most improvement when exposed to AICC-supported hybrid learning, supporting findings that technology-enhanced environments can effectively address learning disparities (Nortvig et al., 2018; Singh et al., 2021). This highlights the potential of engaging teaching methods to mitigate the challenges faced by less motivated learners. By employing tools that integrate visual and interactive elements, educators can capture the interest of disengaged students and gradually enhance their involvement in the learning process.

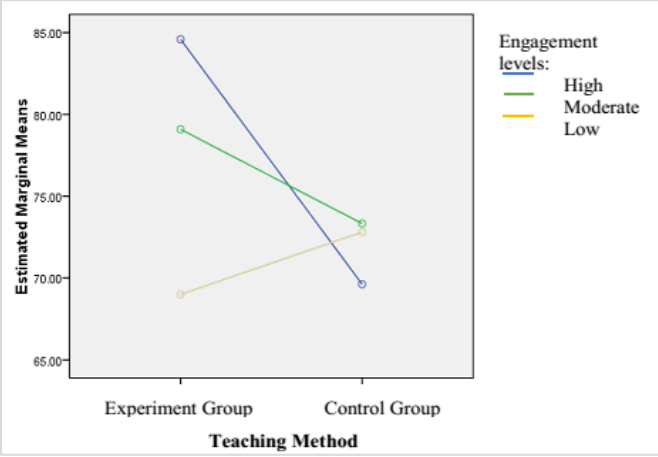

Figure 2. Estimated marginal means of problem-solving skills

Interestingly, the post-hoc analysis revealed no significant interaction between high and moderate engagement levels, suggesting that these groups tend to maintain consistent performance regardless of teaching methods. However, students with low engagement showed substantial improvement when exposed to an engaging and interactive teaching approach, underscoring the importance of adaptive instructional designs (Andriyani et al., 2025). This finding stresses the critical role of identifying at-risk learners and tailoring teaching approaches to address their specific needs, aligning with research on personalized learning approaches (Kavitha et al., 2024; Hwang et al., 2020).

AICC's ability to provide real-time feedback and facilitate virtual interaction allows educators to maintain continuous engagement, thereby reducing the likelihood of academic underachievement among disengaged students. For more details, please see Figure 2.

Figure 2 depicts the estimated marginal means of problem-solving skills across engagement levels and instructional methods. The hybrid learning method demonstrates a more pronounced effect, particularly for students with high engagement (Hendrowati et al., 2025; Zainudin et al., 2023). Students with low engagement demonstrated the most substantial improvement when exposed to AICC-supported hybrid learning, showing an average increase of 15.59 points compared to their counterparts in traditional hybrid learning environments. This finding highlights the potential of engaging teaching methods to mitigate the challenges faced by less motivated learners, supporting the equity-focused goals of educational technology identified by Hollister et al. in their research on online learning during COVID-19 (Hollister et al., 2022; Haetami, 2023).

Conclusion

The AICC-supported hybrid learning method proves to be highly effective in enhancing student engagement and learning outcomes, particularly in mathematics education. The use of advanced technological tools like AICC and Moodle creates a dynamic learning environment that caters to diverse learning needs. Teachers are encouraged to leverage these tools to foster a more inclusive and interactive classroom experience. Additionally, these technologies equip educators with the flexibility to integrate synchronous and asynchronous learning modalities, making education more accessible and adaptable.

Acknowledgments
The authors would like to express their sincere gratitude to SMPIT Insan Permata Malang for providing the research site and facilitating data collection throughout this study. We also extend our appreciation to the Department of Instructional Technology, Universitas Negeri Malang, for their valuable support and resources that made this research possible. Special thanks to all students, teachers, and staff who participated in this study and contributed to its successful completion.

Author Contributions
Conceptualization, A.F.H.; methodology, A.F.H.; software, P.S. and F.F.A.; validation, I.N.S.D.; formal analysis, A.F.H. and P.S.; investigation, A.F.H.; resources, A.F.H.; data curation, A.F.H and F.F.A.; writing—original draft preparation, A.F.H.; writing—review and editing, I.N.S.D. and S.U.; visualization, A.F.H.; supervision, I.N.S.D.; project administration, S.U.; funding acquisition, A.F.H. All authors have read and agreed to the published version of the manuscript.

Funding
This research was conducted independently and was self-funded by the authors. No external funding was received for this study.

Conflicts of Interest
The authors declare no conflicts of interest. This research does not have any conflicts of interest with regard to any individual or particular group.

References

Alika, O., & Radia, E. H. (2021). Development of Learning Media Based on Cross Puzzle Game in Science Learning to Improve Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 173–177. https://doi.org/10.29303/jppipa.v7i2.667

Amin, S., Sumarmi, S., Bachri, S., Susilo, S., & Bashith, A. (2020). The Effect of Problem-Based Hybrid Learning (PBHL) Models on Spatial Thinking Ability and Geography Learning Outcomes. *International Journal of Emerging Technologies in Learning (iJET)*, *15*(19), 83–94. Retrieved from https://www.learntechlib.org/d/217900/

Amin, S., Sumarmi, S., Bachri, S., Susilo, S., Mkumbachi, R. L., & Ghozi, A. (2022). Improving Environmental Sensitivity through Problem-Based Hybrid Learning (PBHL): An Experimental Study. *Jurnal Pendidikan IPA Indonesia*, *11*(3), 387–398. https://doi.org/10.15294/jpii.v11i3.38071

Amin, S., Sumarmi, S., & Prasad, R. R. (2023). Social science education students' preparedness for problem-based hybrid learning. *Journal of Education and Learning (EduLearn)*, *17*(1), 76–84. https://doi.org/10.11591/edulearn.v17i1.20652

Andriyani, L. P. Y., Tika, I. N., & Artawan, P. (2025). The Effect of TGT (Team game tournament) type Cooperative Learning Model Assisted by Interactive Wordwall Media on the Interests and Science Learning Outcomes of Junior High School Students. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 553–560. https://doi.org/10.29303/jppipa.v11i7.11519

Ayuni, R. T., Jaedun, A., Zafrullah, Z., & Ramadhani, A. M. (2024). Trends in the Use of Artificial Intelligence in Science Education: Bibliometric & Biblioshiny Analysis (1975-2024). *Jurnal Penelitian Pendidikan IPA*, *10*(10), 740–756. https://doi.org/10.29303/jppipa.v10i10.7846

Bognár, L., Fáncsikné, É. H., Horváth, P., Joós, A., Nagy, B., & Strauber, G. (2018). Improved learning environment for calculus courses. *Journal of Applied*

Technical and Educational Sciences, 8(4). https://doi.org/10.24368/jates.v8i4.59

Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2021). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education, 18*(1), 50. https://doi.org/10.1186/s41239-021-00282-x

Cahyono, A. N., & Asikin, M. (2019). Hybrid learning in mathematics education: How can it work? *Journal of Physics: Conference Series, 1321*(3), 032006. https://doi.org/10.1088/1742-6596/1321/3/032006

Creswell, J. W. (2016). *Research Design Pendekatan Metode Kualitatif, Kuantitatif, dan Campuran*. Pustaka Pelajar.

Fredricks, J. A., Filsecker, M., & Lawson, M. A. (2016). Student engagement, context, and adjustment: Addressing definitional, measurement, and methodological issues. *Learning and Instruction, 43*, 1–4. https://doi.org/10.1016/j.learninstruc.2016.02.002

Fung, F., Tan, C. Y., & Chen, G. (2018). Student Engagement and Mathematics Achievement: Unraveling Main and Interactive Effects. *Psychology in the Schools, 55*(7), 815–831. https://doi.org/10.1002/pits.22139

Gutiérrez-Braojos, C., Montejo-Gamez, J., Marin-Jimenez, A., & Campaña, J. (2019). Hybrid learning environment: Collaborative or competitive learning? *Virtual Reality, 23*(4), 411–423. https://doi.org/10.1007/s10055-018-0358-z

Haetami, H. (2023). Analysis Hybrid Learning on Learning Motivation Students and Mental Disorders as Moderator Variables During COVID-19. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6648–6658. https://doi.org/10.29303/jppipa.v9i8.4847

Händel, M., Bedenlier, S., Kopp, B., Gläser-Zikuda, M., Kammerl, R., & Ziegler, A. (2022). The webcam and student engagement in synchronous online learning: Visually or verbally? *Education and Information Technologies, 27*(7), 10405–10428. https://doi.org/10.1007/s10639-022-11050-3

Hart, S. R., Stewart, K., & Jimerson, S. R. (2011). The Student Engagement in Schools Questionnaire (SESQ) and the Teacher Engagement Report Form-New (TERF-N): Examining the Preliminary Evidence. *Contemporary School Psychology: Formerly 'The California School Psychologist', 15*(1), 67–79. https://doi.org/10.1007/BF03340964

Hekele, F., Spilski, J., Bender, S., & Lachmann, T. (2022). Remote vocational learning opportunities—A comparative eye-tracking investigation of educational 2D videos versus 360° videos for car mechanics. *British Journal of Educational Technology, 53*(2), 248–268. https://doi.org/10.1111/bjet.13162

Hendrowati, T. Y., Badrun, M., Siswoyo, & Istiani, A. (2025). The Impact of Hybrid Learning on Student Engagement and Academic Performance in Post-Pandemic Science Education. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 154–165. https://doi.org/10.29303/jppipa.v11i4.10701

Herayanti, L., Widodo, W., SusantiNi, E., & Gunawan, G. (2020). The effectiveness of blended learning model based on inquiry collaborative tutorial toward students' problem-solving skills in physics. *Journal for the Education of Gifted Young Scientists, 8*(3), 959–972. https://doi.org/10.17478/jegys.675819

Hidayat, D., Kim, T., Listiani, T., & Setianingsih, A. R. (2019). Adolescence Student Behavioral Engagement In Mathematics Class. *JPI (Jurnal Pendidikan Indonesia), 8*(2). https://doi.org/10.23887/jpi-undiksha.v8i2.16927

Hollister, B., Nair, P., Hill-Lindsay, S., & Chukoskie, L. (2022). Engagement in Online Learning: Student Attitudes and Behavior During COVID-19. *Frontiers in Education, 7*. https://doi.org/10.3389/feduc.2022.851019

Hung, Y. H., Chang, R. I., & Lin, C. F. (2016). Hybrid learning style identification and developing adaptive problem-solving learning activities. *Comput. Hum. Behav., 55*(PA), 552–561. https://doi.org/10.1016/j.chb.2015.07.004

Hwang, G.-J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence, 1*, 100001. https://doi.org/10.1016/j.caeai.2020.100001

Jacob, T. P., Pravin, A., & Rajakumar, R. (2021). An AI-Powered Smart Camera for Object Detection. *2021 6th International Conference on Communication and Electronics Systems (ICCES)*, 1701–1703. https://doi.org/10.1109/ICCES51350.2021.9489064

Kahu, E. R., & Nelson, K. (2018). Student engagement in the educational interface: Understanding the mechanisms of student success. *Higher Education Research & Development, 37*(1), 58–71. https://doi.org/10.1080/07294360.2017.1344197

Kavitha, K., Joshith, V. P., Rajeev, N. P., & S, A. (2024). Artificial Intelligence in Higher Education: A Bibliometric Approach. *European Journal of Educational Research, 13*(3), 1121–1137. https://doi.org/10.12973/eu-jer.13.3.1121

Kharisma, D. B., Sudirman, S., & Edi, F. (2023). Current Trend of Artificial Intelligence-Augmented Reality in Science Learning: Systematic Literature Review.

Jurnal Penelitian Pendidikan IPA, *9*(8), 404–410. https://doi.org/10.29303/jppipa.v9i8.4484

Krishnan, S. (2018). Students' perceptions of learning mode in mathematics. *MOJES: Malaysian Online Journal of Educational Sciences, 4*(2), 32-41. Retrieved from https://mjlis.um.edu.my/index.php/MOJES/article/download/12647/8139

Kurniawati, A., Pardjono, P., Mutohhari, F., Nurhaji, S., & Purnomo, S. (2022). Improving Self Efficacy and Learning Motivation Through Hybrid Learning Based Google Classroom. *JPI (Jurnal Pendidikan Indonesia), 11*(3). https://doi.org/10.23887/jpiundiksha.v11i3.39289

Nadrah, N. (2025). Science Laboratory Environment and Students' Motivation as Predictors on Attitudes Towards Physics Lesson. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 845–854. https://doi.org/10.29303/jppipa.v11i2.9215

Nortvig, A.-M., Petersen, A. K., & Balle, S. H. (2018). A Literature Review of the Factors Influencing E-Learning and Blended Learning in Relation to Learning Outcome, Student Satisfaction and Engagement. *Electronic Journal of E-Learning, 16*(1), 46–55. Retrieved from https://academic-publishing.org/index.php/ejel/article/view/1855

Panahi, A., & Duraisamy, P. (2021). Automated Classroom Engagement Evaluation using Machine Learning for 180 Degree Camera Environment. *International Conference on Computing Communication and Networking Technologies (ICCCNT)*, 01–05. https://doi.org/10.1109/ICCCNT51525.2021.9580041

Prananta, A. W., Susanto, N., Purwantoro, A., & Fuadah, N. (2023). ChatGPT Artificial Intelligence Integration in Science Learning Media: Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA, 9*(7), 315–321. https://doi.org/10.29303/jppipa.v9i7.4386

Raes, A., Detienne, L., Windey, I., & Depaepe, F. (2020). A Systematic Literature Review on Synchronous Hybrid Learning: Gaps Identified. *Learning Environments Research, 23*(3), 269–290. https://doi.org/10.1007/s10984-019-09303-z

Singh, J., Steele, K., & Singh, L. (2021). Combining the Best of Online and Face-to-Face Learning: Hybrid and Blended Learning Approach for COVID-19, Post Vaccine, & Post-Pandemic World. *Journal of Educational Technology Systems, 50*(2), 140–171. https://doi.org/10.1177/00472395211047865

Sudiarta, I. G. P., & Widana, I. W. (2019). Increasing mathematical proficiency and students character: Lesson from the implementation of blended learning in junior high school in Bali. *Journal of Physics: Conference Series, 1317*(1), 012118. https://doi.org/10.1088/1742-6596/1317/1/012118

Triyason, T., Tassanaviboon, A., & Kanthamanon, P. (2020). Hybrid Classroom: Designing for the New Normal after COVID-19 Pandemic. *Proceedings of the 11th International Conference on Advances in Information Technology,* 1–8. https://doi.org/10.1145/3406601.3406635

Zainudin, Hermanto, D., Wijayanti, R., & Hunaepi. (2023). The Effectiveness of the Combination of Problem-Based Learning Models and Hybrid Learning Models to Improve Problem Solving Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11648–11654. https://doi.org/10.29303/jppipa.v9i12.4740