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The Impact of Artificial Intelligence on Flipped Classroom Learning: A Quasi-Experimental Study in Energy Education

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Abstract. This study utilized a quasi-experimental design to assess whether using AI within a flipped structure created added value for physics education focused specifically on energy through the support of personalized resources and activities. In all, sixty second-year baccalaureate students participated in this study divided into two sections of thirty students each. The experimental section, designated as the intelligent learning environment, provided students with a wide array of personalized resources and activities, whereas control section of students used a traditional structure of a flipped approach without any AI implementation. The results of this research demonstrated that students within the AI-supported experimental section had substantially higher levels of growth in their ability to conceptualize energy ($p < 0.001$, $d = 0.92$), while at the same time having a substantially higher level of energy literacy ($p < 0.01$). Additionally, students demonstrated a higher degree of involvement during both their preparatory and classroom time, as compared to those students in the control section. Overall, by customizing learning pathways using AI, it appears there is considerable evidence that this method can strengthen the impact of flipped learning when teaching complex science subjects.

Introduction

Effective energy education is crucial in dealing with global climate change; it is, however, impeded by the conceptual complexity of subjects like nuclear physics and mass-energy equivalence [1,2]. Traditional pedagogies have often fallen short in the building of deep conceptual understanding necessary to improve energy literacy [3,4].

Flipped learning appears to be a promising approach in science education, where class time is reserved for active learning activities, and meta-analysis has indeed supported its effectiveness in improving student achievement [5,6]. This study examines whether an integration of AI will further enhance flipped learning. Whereas AI-driven technologies, such as chatbots, are generally recognized to offer personalized, just-in-time support [7,8], their combined effectiveness with flipped learning within the narrow domain of energy education remains largely uninvestigated [9].

This study seeks to address this question by developing an enhanced flipped classroom with AI to help teach energy concepts to students and hypothesize that an AI-based chat mentor would result in superior learning outcomes and energy literacy and learning engagement than a basic flipped classroom control condition. This empirical investigation of this model will lead to an informed and evidenced-based strategy to harnessing technology as a solution to overcome energy learning and teaching challenges and meet the needs of all learners to make learning equitable and effective [10,11].

Materials and methods

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A quasi-experimental approach was followed in the current research, where a group of 60 second-year baccalaureate students at the age level of 16-17 years was selected and divided into control and experimental groups. A total of 30 students constituted the control group and the other 30 constituted the experiment group. The control group followed a flipped classroom approach in the matter of teaching the physical topic of "Nuclei, Mass, and Energy," whereas the experiment group received an additional support aid involving an AI assistant by the name of Chatbase incorporated into Google Classroom. The variables adopted by the current research are as follows (Table 1).

Table 1. *Study Variables*

Variable Type	Variable Name	Description
Independent	Condition	Control Group vs. AI Group
Dependent	Pre-test-score	Pre-test knowledge score (0-20)
	Post-test-score	Post-test knowledge score (0-20)
	Energy-literacy-pre	Pre-intervention energy literacy score (1-5)
	Energy-literacy-post	Post-intervention energy literacy score (1-5)
	Engagement-time-preclass-min	Time spent preparing for class (minutes)
	Completion-rate-preclass	Completion rate of upstream activities (%)
	Engagement-in-class	Classroom engagement index (1-5)

The effectiveness of the study's intervention was determined through pre- and post-intervention knowledge tests with 20 multiple-choice questions, one energy literacy test with options for ratings on the 5-point Likert scale, and observing the level of engagement in the classrooms with the use of the structured observation protocol. The study utilized statistical tools such as SPSS version 28 after performing independent and paired t-tests to conduct Pearson correlation.

Results and discussion

The experimental group assisted by the AI technology was found to have remarkably better achievements in all aspects than the control group. Table 2 presents a holistic summary of the descriptive statistics pertaining to the two groups (Table 2).

Table 2. *Descriptive Statistics for Control and Experimental (AI) Groups*

Variable	**Control Group (Mean ± SD)**	**Group AI (Mean ± SD)**
Pre-test	7.63 ± 1.79	8.10± 2.08
Post-test	9.95 ± 2.39	11.88 ± 2.46
Score gain	2.32 ± 1.41	3.78 ± 1.74
Pre-literacy	2.81 ± 0.59	2.86 ± 0.55
Post literacy	3.10 ± 0.65	3.67 ± 0.72
Literacy gain	0.29 ± 0.36	0.80 ± 0.30
Commitment time (min)	34.05 ± 10.24	42.52 ± 8.07
Completion rate (%)	77.72 ± 9.28	89.36 ± 7.12
Classroom engagement	3.13 ± 0.58	3.82 ± 0.60

The most striking result is the learning gain, which was 63% higher in the AI group. This difference was statistically significant ($t(58) = -3.561$, $p < .001$) and represented a large practical effect ($d = 0.92$), as visualized in Figure 1.

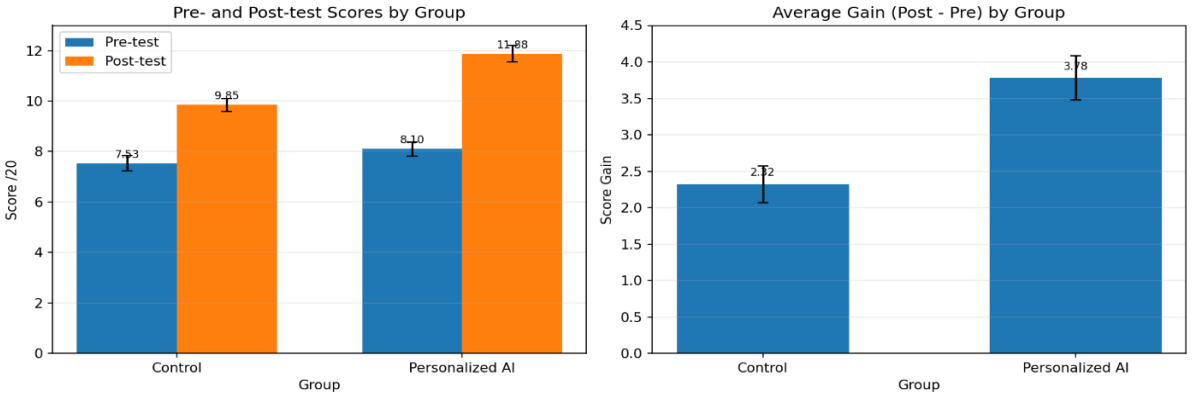


Fig. 1: *Comparison of average pre- and post-test scores and gains*

Nevertheless, more fundamentally, this intervention also contributed to the development of learning equity indeed, in a vital fashion. As interesting information, it might be noted as well that the association between the pre- and post-test results for the group with the AI assistance was actually weaker than for the group with the Control assistance, where ($r = .812$), as opposed to the group with the AI assistance where ($r = .716$). Toward accomplishing this, as can even be noted now, it allowed all the students to advance regardless of their pre-existing capacities.

The studies have shown specific support for the idea that the integration of AI with the flipped classroom approach is best used in the teaching of complex concepts in the specific domain of science. In this context, the support provided by the AI agent in the form of a chatbot seems to have provided the most crucial support to the students in their learning of specific concepts before venturing into other complex learning processes. This is supported by the idea that the learning

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abilities of the students in the specific domain of STEM can improve through the integration of AI [12,13].

Recent meta-analyses also confirmed the high performance of AI chatbots in terms of enhancing the learning outcomes of the students across different educational situations [14,15]. Even as the study, which employed a non-experimental approach, must be well noted as having a particular context, the results, nevertheless, clearly reveal the capability of this particular approach in shaping better, more engaging, as well as more effective teaching situations in the field of energy.

Group AI shows significantly higher post-test scores and average gains. There was an average improvement of 1.93 points for group AI (from 8.10 to 11.88), compared with 2.32 points for the control group (from 7.63 to 9.95). This difference of 1.46 points in favour of group AI is statistically significant ($p < 0.001$).

Distribution of Score Gains.

The median and interquartile range are higher for the AI group, with a statistically significant difference ($p < 0.001$). The box plot reveals that the majority of students in the AI group achieved gains of more than 2.5 points, while the control group shows a more dispersed distribution with several extreme values. This visualisation confirms that the AI intervention benefited the vast majority of students.

Energy Literacy

The AI group showed a significantly greater improvement than the control group. Energy literacy, which measures understanding of energy concepts and awareness of energy issues, increased by 0.80 points in the AI group compared to only 0.29 points in the control group. This difference of 0.51 points is statistically significant ($p = 0.0022$), suggesting that AI not only reinforced factual knowledge but also promoted a deeper understanding and awareness of energy issues (Fig.2).

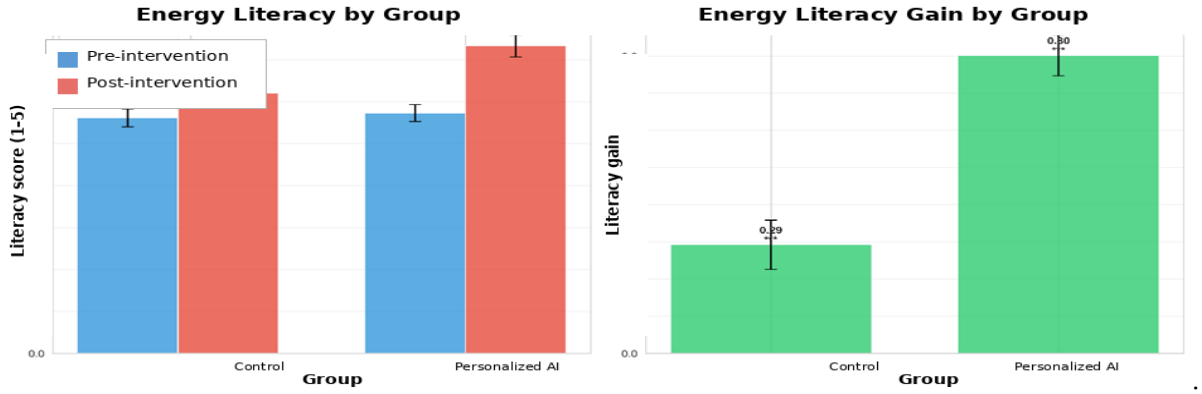


Fig. 2: *Change in energy literacy.*

Engagement

Among the pre-class activities, Group AI students spent more time completing activities and had a higher percentage of completion than the Control Group. Students in the AI Group averaged 42.52 minutes per pupil of time spent on the pre-class activities, compared to the Control Group, who spent an average of 34.05 minutes per student, an additional average of 8.47 minutes for Group AI students compared to their Control Group counterparts. Furthermore, there is evidence to suggest that Group AI students were able to complete the activity at a significantly higher percentage (89.38%) than control group students (77.72%). The evidence suggests that the personalised learning environment used in this study provided an environment that enhanced student engagement.

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Classroom Engagement

The Class Engagement Index for the Group AI was 3.82 on a scale of 1 to 5 compared to a score of 3.13 for the control group. A difference of 0.69 points is statistically significant and has a p-value less than .001 indicating that the use of personalised preparation helped to prepare students in group AI to engage actively and collaborate efficiently in face-to-face classroom activities.

Correlation matrices

In the control group, the association between the rate of completing the course and the involvement in class is moderately strong (r = 0.405). While this correlation is nearly nonexistent in the AI group (r = 0.081). Likewise, the link from pretest score to posttest score, stronger in the control group than the AI group (r = 0.812 vs r = 0.716), indicates that AI has promoted a more equitable learning atmosphere in which learners at all ability levels have experienced relatively consistent growth in skill (Fig.3).

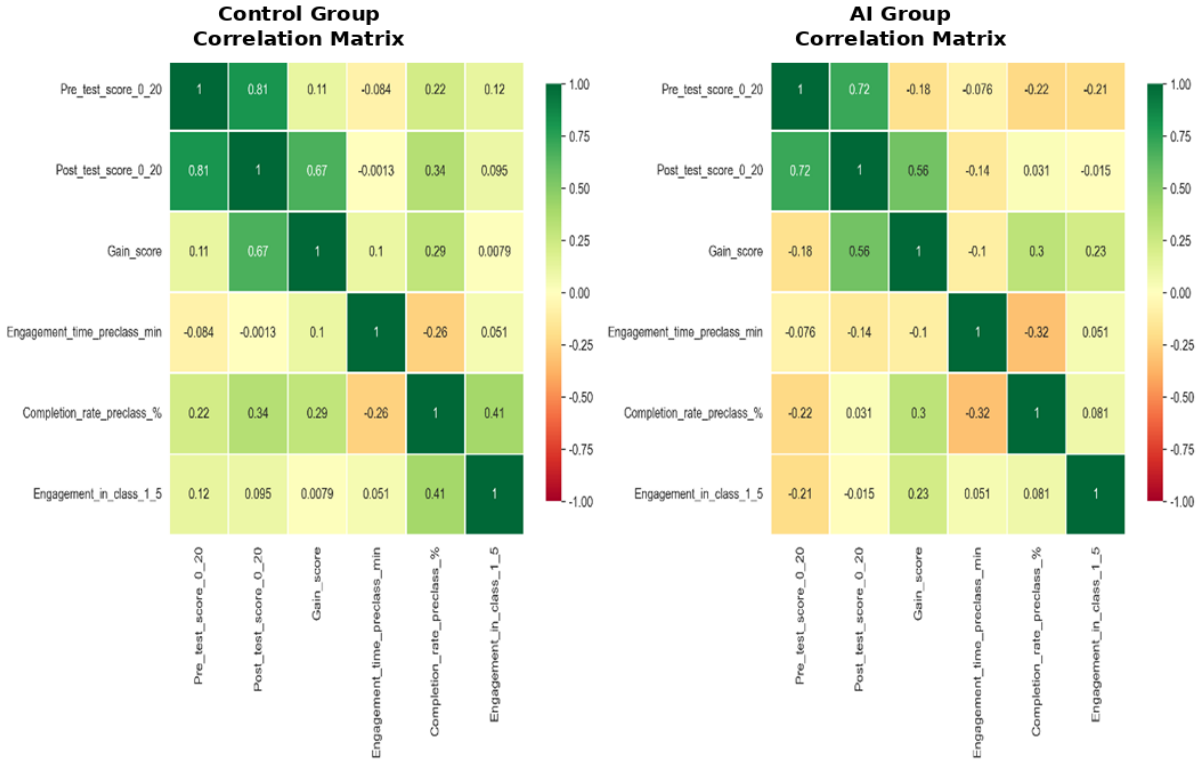


Fig. 3: *Pearson correlation matrices for the two groups.*

Engagement vs Performance

Both groups have little to no correlation between numbers of hours of pre-test activities completed and post-test scores. Scatterplots of both groups show that there is very weak (or no) correlation between time allocated toward completing the pre-test activities, and post-test scores, as for the Control group (r = -0.001) and AI group (r = -0.139). As such, it would appear that, while the quantity of time engaged in pre-test activities may not be as meaningful as previously thought, the quality of engagement and the individualised (or personalised) relevance of content must be considered in the overall effectiveness of AI. This finding reaffirms (or supports) the ability of AI to effectively personalise the learner's journey, by making targeted, individualised recommendations, rather than simply adding more work for the learner.

Conclusion

This study confirmed that the integration of an AI-powered chatbot in a flipped classroom significantly enhances learning results within the complex domain of energy education. The rationale for this research was based on the critical need to enhance energy literacy given the challenge of climate change, which few contemporary approaches seem to address properly. Empirical confirmation of a pedagogical model applying AI for personalized student support was our most important objective.

Under a quasi-experimental design approach, an AI-supported experiment group and a control group with a conventional flipped classroom approach are comparatively studied. The approach that guides the research aims at assessing the results in terms of learning, energy literacy, and engagement.

The findings were unambiguous. The performance of the AI-supported group was significantly superior in terms of gain circa the entire sample ($d = 0.92$), improved energy literacy, as well as engagement rates. Most importantly, the AI-supported group produced an equitable education environment where the knowledge gap between all learners was closed.

The aforementioned findings can be seen as a validation of the power of the application of AI in the design of learning experiences that are both adaptive, effective, as well as student-centered in nature in the context of learning in the science education arena.

While the need for conducting more studies on the long-term effects of the application of AI in learning has been established in the context of the aforementioned paper published in the Journal of Educational Data Mining, its emerging framework can be seen as a validation of the potential benefits that can be harnessed by educators in their bid to effectively confront the energy challenges.

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