



Use of Artificial Intelligence in the Learning of Newtonian Mechanics: A Didactic Intervention in First-Year Undergraduate Students

Uso de inteligencia artificial en el aprendizaje de la mecánica newtoniana: una intervención didáctica en estudiantes de primer año de licenciatura

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Abstract

This article presents the preliminary effects of a didactic intervention based on the use of artificial intelligence (AI) for teaching Newtonian mechanics concepts to first-year students in the Bachelor of Physics Education program at the University of Guayaquil. This intervention corresponds to the first phase of a quasi-experimental study conducted during the May–August 2024 semester, involving two parallel groups: a control group using traditional peer instruction strategies, and an experimental group using AI-guided activities through a web-based platform supported by ChatGPT. Both groups underwent a diagnostic pre-test, which revealed similar levels of initial conceptual knowledge. Following a structured and differentiated teaching process, a post-test was applied to assess the intervention's impact. The results showed a significant improvement in the conceptual understanding of the experimental group compared to the control group. The findings suggest that integrating AI tools in the classroom can positively impact physics learning by helping students overcome alternative conceptions and fostering a deeper understanding of the fundamental principles of classical mechanics. The study highlights the feasibility of using virtual assistants as a complementary resource in science higher education environments.

Keywords: Artificial Intelligence, Newtonian Mechanics, Physics

Resumen

El presente artículo describe los efectos preliminares de una intervención didáctica basada en el uso de inteligencia artificial (IA) para la enseñanza de conceptos de mecánica newtoniana en estudiantes de primer año de la Licenciatura en Pedagogía de la Física en la Universidad de Guayaquil. Esta intervención corresponde a la primera fase de un estudio cuasiexperimental desarrollado durante el semestre mayo-agosto de 2024, en el que se compararon dos grupos paralelos: uno de control, que trabajó con estrategias tradicionales de instrucción entre pares, y otro experimental, que empleó actividades guiadas mediadas por IA, específicamente utilizando un entorno web con soporte de ChatGPT. Ambos grupos realizaron una prueba diagnóstica previa, cuyos resultados reflejaron niveles similares de conocimiento conceptual inicial. Posteriormente, tras un proceso de enseñanza estructurado y diferenciado, se aplicó una prueba de salida para evaluar el impacto de la intervención. Los datos obtenidos mostraron una mejora significativa en el rendimiento conceptual del grupo experimental en comparación con el grupo de control. Los hallazgos sugieren que la integración de herramientas de IA en el aula puede contribuir positivamente al aprendizaje de la física, facilitando la superación de concepciones alternativas y promoviendo una comprensión más profunda de los principios fundamentales de la mecánica clásica. El estudio destaca la viabilidad del uso de asistentes virtuales como recurso complementario en entornos de educación superior en ciencias.

Palabras clave: Inteligencia Artificial, Mecánica Newtoniana, Enseñanza De La

Introduction

The teaching of physics, especially Newtonian mechanics, represents one of the most complex challenges in university science education. Despite methodological and curricular advances, significant barriers to students' conceptual learning persist. One of the main obstacles is the presence of alternative conceptions, that is, intuitive ideas constructed from everyday experiences that contradict the principles of formal physics (Flores-García et al., 2008; Chi, 2005). These deeply rooted ideas are resistant to change even after formal instruction and hinder the development of a structured and meaningful understanding of key concepts such as force, motion, and inertia.

International studies have highlighted this problem in multiple contexts. For example, the use of the Force Concept Inventory (FCI), a widely validated instrument for measuring understanding of classical mechanics, has revealed low levels of understanding even after physics courses in higher education. In Latin America, research conducted in Mexico, Colombia, Chile, and Argentina reports levels of conceptualization that rarely exceed 70%, placing most students at an average level of content assimilation (Artamónova, Mosquera-Mosquera & Mosquera-Artamónov, 2017; Budini et al., 2019). These results suggest that formal education, although necessary, does not always succeed in bringing about profound conceptual change.

Ecuador is no stranger to this situation. Research conducted in university settings has shown that students have levels of conceptual assertiveness in Newtonian mechanics between 38% and 43%, with recurring difficulties in interpreting problems and applying appropriate formulas (Varas, Villalva & Nieto, 2018). In particular, a study of students in the Experimental Science Education program at the University of Guayaquil showed that, after traditional classes, students were unable to understand projectile motion or correctly apply the principles of vector analysis, obtaining average grades below 4 out of 10 (Amaguaya & Castro, 2022). These deficiencies compromise not only academic performance but also the future teaching practice of these students.

Faced with this situation, the educational community has explored various teaching strategies aimed at improving conceptual understanding in physics. Among these, peer instruction has shown encouraging results. This approach, developed by Eric Mazur (1997), is based on discussion among students to confront ideas, justify answers, and collectively arrive at a more solid understanding. Several studies have shown that this methodology not only promotes active learning but also contributes significantly to conceptual change by exposing students to cognitive conflicts in a collaborative environment (Crouch & Mazur, 2001; Smith et al., 2009).

However, even active methodologies can have limitations if they are not adapted to the individual characteristics of the student. In this regard, artificial intelligence (AI) has emerged as a promising tool in the field of education. Thanks to its natural language processing, pattern analysis, and learning personalization capabilities, AI can offer adaptive environments that respond in real time to the cognitive needs of each user (Woolf, 2010; Chen, Chen & Zhijian, 2020). These environments have the potential to transform the teaching of abstract concepts such as those in classical mechanics, providing explanations, examples, exercises, and feedback in an immediate and contextualized manner.

The application of AI in science education has begun to spread worldwide. Tools such as intelligent tutors, adaptive learning systems, and virtual assistants are being used to improve conceptual understanding and reduce barriers to learning (VanLehn, 2011; Kasinathan, Mustapha & Medi, 2017). For example, platforms such as DreamBox and Labster have proven effective in personalizing learning in mathematics and natural sciences, allowing students to explore at their own pace, make mistakes, and receive personalized guidance.

In the particular case of Newtonian mechanics, these technologies allow for the simulation of dynamic scenarios, guided questions, and the generation of visualizations of complex physical phenomena. In this way, students not only access explanations, but also interact with the content, explore their hypotheses, and correct their mistakes,

which is key to the development of structured scientific thinking (Rosales & Sulaiman, 2020).

At the regional level, Latin America has begun to explore the use of artificial intelligence in education with initiatives that are still disparate. Countries such as Brazil and Chile are leading projects that incorporate intelligent tutoring systems, adaptive learning platforms, and educational simulations at different levels of the education system (Gómez, Del Pozo, Martínez & Martín del Campo, 2020). In these countries, results have shown improvements in students' conceptual understanding, particularly in areas such as mathematics and science, and an increase in content retention thanks to more personalized interactive environments.

In contrast, other countries such as Mexico and Argentina are in the early stages of implementation. Although platforms offering personalized recommendations or academic performance prediction systems already exist, limitations remain in terms of access to technological infrastructure and teacher training in the pedagogical use of these tools (Peñaherrera, Cunuhay, Nata & Moreira, 2022).

The case of Ecuador reflects similar challenges, but also opportunities. Although there are isolated efforts in some higher education institutions, such as the University of Guayaquil and the National Polytechnic School, the adoption of AI in classrooms is still in its infancy (Castillo, Tapia, Placencia & Pavón, 2024). Limited connectivity in rural areas, a lack of adequate technological devices, and poor teacher training in the use of AI-based resources hinder systematic implementation. Despite this, the growing availability of accessible platforms, the presence of educational digitization initiatives, and academic interest in pedagogical innovations constitute fertile ground for progress in this direction.

In this context, tools such as ChatGPT, a language model developed by OpenAI, have begun to be used as virtual assistants in the educational process. Its ability to offer detailed explanations, answer open-ended questions, propose contextualized exercises, and generate immediate feedback makes it a powerful resource for promoting autonomous learning. Its potential does not lie in replacing teachers, but in complementing the teaching process, facilitating access to knowledge outside the classroom, and allowing for more individualized attention to students (Moreno, 2019; Peñaherrera et al., 2022).

In this sense, the integration of AI-based tools such as ChatGPT into physics teaching may represent a viable solution to persistent problems of conceptual understanding, especially in an environment where the number of students per classroom makes personalized attention and the timely identification of conceptual errors difficult. If appropriate AI-mediated teaching activities are designed, students can actively

interact with the content, verify their answers, receive explanations tailored to their level, and, above all, reconstruct their misconceptions through dialogue with a system that responds immediately.

Thus, there is a need to investigate how this type of intervention can affect students' actual learning, especially in populations with a history of low performance in physics. Based on the above, the objective of this study is to evaluate the effect of guided activities mediated by artificial intelligence on the level of conceptual knowledge of Newtonian mechanics in first-year students of the Bachelor's Degree in Physics Education at the University of Guayaquil during the May-August 2024 semester, comparing the results obtained with those of a control group that received traditional peer instruction.

Materials and methods

This study was developed using a quantitative approach and a quasi-experimental design with a non-equivalent control group, which allowed us to evaluate the effects of an artificial intelligence (AI)-mediated teaching intervention on the learning of Newtonian mechanics. The purpose of this first phase, corresponding to the May-August 2024 semester, was to measure the variation in students' conceptual knowledge after applying a specific teaching sequence, comparing the performance between a control group and an experimental group.

The quasi-experimental design was selected due to the impossibility of randomly assigning participants to groups. Instead, two parallel courses within the same university degree program were used, which made it possible to reduce the effects of external variables without altering the existing academic structure (Hernández, Fernández & Baptista, 2014).

The population consisted of first-year students in the Bachelor's Degree in Physics Education at the University of Guayaquil. For this phase of the study, two parallel groups were used:

- The control group, made up of 33 students from the morning course, received traditional peer instruction.
- The experimental group, made up of 30 students from the afternoon class, participated in guided activities using AI through a web platform based on ChatGPT.

Both groups shared similar characteristics in terms of age (between 17 and 20 years old), previous education, and institutional context. In addition, all participants were taking the Physics I course, which focused on the fundamentals of classical mechanics.

Two multiple-choice written tests were used to assess conceptual knowledge: a diagnostic test (pre-test) administered at the beginning of the semester and an exit test (post-test) at the end of the semester. Both tests were adapted from the Force Concept Inventory (FCI) instrument, which has demonstrated validity and reliability in measuring the understanding of key concepts in Newtonian mechanics (Hestenes, Wells & Swackhamer, 1992).

Each test consisted of 30 items covering the following topics:

- Newton's laws of motion
- Net force and acceleration
- Uniformly accelerated rectilinear motion
- Free fall and projectile trajectory
- Conservation of linear momentum

The answers were coded numerically and the scores were normalized to facilitate subsequent statistical analysis. In addition, a sociodemographic survey was administered to characterize the study population.

During the May–August 2024 semester, the intervention was implemented in the experimental group. It consisted of a guided teaching sequence composed of five thematic modules, each accompanied by interactive exercises, simulations, and virtual assistance via ChatGPT. The AI tool was used as a personalized tutor, available to answer questions, clarify concepts, and provide immediate feedback at any time during the process.

Each module addressed a fundamental theme of Newtonian mechanics, with a structure based on:

- Initial diagnosis: trigger question or preliminary simulation.
- Theoretical exploration: guided reading + open-ended questions directed to ChatGPT.
- Practical application: contextualized exercises and problem solving.
- Automatic feedback: immediate review of answers with justification.
- Metacognitive reflection: final questions to identify conceptual changes.

The control group, meanwhile, developed the same content, but through face-to-face sessions focused on the peer instruction model (Mazur, 1997), where students discussed their answers in small groups under the teacher's guidance. The study was conducted in three phases:

- Diagnostic phase: application of the pretest and sociodemographic survey in both groups.

- Intervention phase: implementation of differentiated teaching strategies for 14 weeks.
- Evaluation phase: application of the posttest and comparative analysis of the results.

The data were analyzed using SPSS software. Normality tests (Shapiro-Wilk), descriptive measures (mean and standard deviation), and t-tests for independent samples with a significance level of $\alpha = 0.05$ were applied to determine significant differences between the two groups.

Results

This section presents the findings obtained after applying the AI-mediated teaching intervention during the May-August 2024 semester. The analysis focuses on comparing the levels of conceptual knowledge in Newtonian mechanics between the experimental group, which worked with ChatGPT as a virtual assistant, and the control group, which followed a traditional peer-to-peer instruction model.

Pretest results (diagnostic test)

The pretest results showed that both groups started from similar levels of conceptual understanding. The mean score obtained by the experimental group was 4.18/10 (SD = 1.01), while the control group achieved a mean score of 4.10/10 (SD = 1.05). The independent samples t-test yielded a value of $t(61) = 0.30$; $p = 0.76$, indicating that there were no statistically significant differences between the groups at the beginning of the training process.

These initial results corroborate the homogeneity of the groups in terms of prior knowledge and validate the subsequent comparison based on the effects of the intervention.

Post-test results (exit test)

At the end of the semester, the exit test was administered to measure the impact of the differentiated teaching strategies. The results show a clear improvement in both groups, although more pronounced in the experimental group.

The experimental group obtained an average of 7.72/10 (SD = 0.94), representing an increase of 3.54 points compared to the pretest.

The control group obtained an average of 5.60/10 (SD = 1.02), increasing by 1.50 points on average.

The independent samples t-test applied to the post-test results revealed a statistically significant difference between the two groups ($t(61) = 8.31$; $p < 0.001$), indicating that the use of guided activities with artificial intelligence had a considerable positive effect on conceptual learning.

Complementary qualitative analysis

During the intervention, it was observed that students in the experimental group used the virtual assistant to clarify concepts and verify their answers in real time. The most frequently asked questions were related to the interpretation of acceleration and velocity graphs, the analysis of forces in systems with friction, and the understanding of the principle of inertia. This continuous interaction with the AI system seemed to favor more autonomous and reflective learning.

In addition, greater motivation and active participation were evident in the experimental group. The availability of a resource that responded immediately and adaptively gave students the confidence to take on complex conceptual challenges without fear of making mistakes.

Conclusions

The results of this first phase of the quasi-experimental study provide clear evidence of the potential of artificial intelligence (AI) as a teaching resource for improving conceptual learning in Newtonian mechanics in university settings. In particular, the integration of ChatGPT into a sequence of guided activities allowed students in the experimental group not only to achieve better scores on the exit test but also to develop a more autonomous, reflective, and meaningful learning process. From a pedagogical point of view, the substantial improvement observed in the experimental group compared to the control group can be attributed to several key factors. One of these is the personalization of learning. AI provided immediate responses tailored to each student's level of understanding, allowing for constant feedback that is difficult to achieve in traditional environments with high student density (VanLehn, 2011; Woolf, 2010). This personalized support is essential in teaching content such as classical mechanics, which often generates high rates of misunderstanding due to the presence of persistent alternative conceptions (Chi, 2005; Flores-García et al., 2008).

In addition, AI acted as a facilitator of conceptual change by allowing students to confront their own ideas, reformulate hypotheses, and test their reasoning in real time. These opportunities for interaction increased the depth of learning, as Rosales and Sulaiman (2020) have also pointed out in similar studies on AI-assisted physics teaching.

Another important finding was the higher level of motivation and participation observed in the experimental group. Continuous access to a virtual assistant gave students a sense of control over their learning process, reducing academic anxiety and strengthening their self-confidence in tackling new problems. This is in line with recent studies that highlight the positive emotional impact that the use of AI can have in education, provided that it is mediated by appropriate pedagogical strategies (Chen, Chen & Zhijian, 2020; Moreno, 2019).

The comparison with the control group is also revealing. Although students in this group participated in an active modality through peer instruction—a strategy that has been shown to be effective in various studies (Mazur, 1997; Smith et al., 2009)—learning outcomes were significantly lower. This does not invalidate the effectiveness of the traditional model, but rather suggests that the use of AI can complement and enhance existing strategies, creating hybrid environments where opportunities for conceptual interaction and metacognition are maximized.

At the methodological level, the application of diagnostic and exit tests, together with a quasi-experimental design, allowed for the control of external variables and ensured the validity of the results. The similarity of initial scores between the two groups confirms that the improvement observed in the experimental group is not due to prior differences, but to the direct effects of the intervention.

However, this study also faces limitations that should be considered in future research. The duration of the intervention, restricted to a single semester, prevents the evaluation of long-term effects. In addition, the sample was limited to a specific institution and degree program, so the results should be generalized with caution. Dependence on connectivity and access to technology is another critical factor, especially in contexts such as Ecuador, where significant digital infrastructure gaps still exist (Peñaherrera et al., 2022).

Despite this, the findings allow us to conclude that artificial intelligence, when integrated in a planned manner into the teaching process, can be an effective tool for improving conceptual learning in physics. In particular, its use with first-year undergraduate students helps to overcome initial cognitive barriers, strengthen critical thinking, and promote active and personalized learning.

This study not only confirms previous results in international contexts, but also provides local evidence on the feasibility of applying AI in higher science education in Ecuador. It is therefore suggested that teachers consider the progressive incorporation of AI-based tools as a complement to their teaching strategies, especially in areas where conceptual abstraction represents a persistent difficulty. Finally, the results obtained open up new lines of research. Future studies could

explore the emotional impact of interaction with AI systems, analyze the individual learning trajectories that these systems allow to be traced, and design hybrid methodologies that integrate the best of traditional teaching with the advantages of intelligent and adaptive learning.

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