Integration of Augmented Reality and Flipped Classroom in the Learning of Linear Kinematics in Engineering Students

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Currently, engineering education faces continuous challenges to improve the effectiveness of learning and understanding of complex concepts, such as linear kinematics. This paper describes the integration of Augmented Reality and the Flipped Classroom strategy in engineering students for the teaching-learning process of linear kinematics topics. The aim of the research is to identify how the use of augmented reality and flipped classroom enhances the learning of linear machine kinematics topics. This study provides a critical view of how technological innovation and teaching-learning strategies can be used to improve the quality of education in technical and scientific fields, particularly in the area of mechanics.

Keywords: Augmented Reality, Flipped Classroom, Linear Kinematics.

Introduction

Linear kinematics, a fundamental pillar in engineering education, is crucial to understanding motion, machine design, and mechanisms. This discipline, which encompasses the study of motion without taking into account the forces that produce it, is essential for engineering students, particularly in branches such as mechanics, robotics, and industrial design, among others. However, the inherent complexity of linear kinematics concepts and their abstract nature pose significant challenges to their effective teaching and learning. Traditional methods, which often rely on theory and graphical representation, may not be sufficient to facilitate a deep and practical understanding (McDermott, 1998).

In this context, Augmented Reality (AR) and the Flipped Classroom strategy emerge as promising educational innovations (Herrera et al., 2023; Núñez, 2023a). AR, which overlays digital information onto the user's physical environment, offers an interactive and visually appealing way to explore complex concepts, providing an immersive learning experience. By visualizing mechanisms and movements in real-time, students can gain a better understanding of the abstract and complex concepts of kinematics.

Traditional education in the context of engineering and science has historically been characterized by an approach in which the teacher is the main transmitter of knowledge through lectures, while students play a mainly passive role, receiving information and performing practice tasks outside the classroom (Bonilla et al., 2015). In contrast, the Flipped Classroom revolutionizes this traditional approach to teaching, offering a methodology that promotes greater student engagement. Rather than focusing on lectures in the classroom and completing homework assignments, this methodology invites students to study the theoretical material independently before class and then apply the knowledge in an interactive classroom environment (Núñez, 2023b). Not only does this approach encourage greater interaction between students and teachers, but it also allows for a practical application of knowledge, thus facilitating a deeper understanding of concepts.

The combination of these two educational innovations promises to transform the teaching of linear kinematics, offering a more dynamic, interactive, and comprehensive learning experience. The purpose of this study is to compare the effectiveness of two teaching methods, specifically the flipped classroom with augmented reality and traditional teaching, in the context of linear machine kinematics learning among undergraduate students during the pandemic period (Pardo Alean et al., 2021).

In the present work, the quantitative research method is applied to determine the effectiveness of using an augmented reality application in the teaching of machine kinematics. This method makes it possible to compare the educational outcomes of two sets of students: one who employs the augmented reality application and one who adheres to conventional methods of instruction. This strategy makes it possible to collect and analyze numerical information to make an objective assessment of the impact of augmented reality on the understanding of concepts.

The focus group of this study is composed of 250 engineering students from a higher education institution. The convenience sample size consisted of 40 biomedical and mechatronics engineering students, divided into a control group and an experimental group. The control group received traditional teaching methods, while the experimental group experienced the augmented reality flipped classroom approach.

By comparing the learning outcomes and performance of both groups, this research aims to determine the effectiveness of the flipped classroom in conjunction with augmented reality compared to traditional teaching methods. Previous studies have shown that flipped classrooms can significantly improve the teaching-learning process and positively impact students' academic performance (Arriaga & Medina-Talavera, 2018). This study aims to further explore these findings and contribute to the ongoing discussion on the best teaching methodologies for undergraduate students, with the difference that the study was conducted in the pandemic period.

By examining differences in student perceptions and performance, this study aims to provide valuable insights into the potential benefits and drawbacks of each method, ultimately contributing to the ongoing conversation about the future of education and pedagogy (Pardo Alean et al., 2021).

Frame of reference

In this research, the conceptualization of 'traditional teaching' will be adopted as a pedagogical model centered on the teacher, where lectures predominate for the transmission of knowledge, relegating students to a receiving and passive role. Assessment under this model often involves standardized tests and individual assignments, performed outside of the classroom setting (Arredondo et al., 2014; Benítez Muñoz et al., 2005; Chavez, 2011). This approach is contrasted with active learning methodologies, such as the Flipped Classroom and the application of emerging technologies, in this case augmented reality.

Traditional teaching methodology has been prevalent in educational settings for many years, with a focus on teacher-centered learning methods (Gonzales et al., 2023). However, recent advances in technology and pedagogy have led to the emergence of alternative teaching approaches, such as the flipped classroom model, which aims to modify the roles of teachers and students within the teaching-learning process (Carreño & Carreño, 2019). This shift in focus from teacher-centered learning to student-centered learning is supported by empirical evidence suggesting that the flipped classroom model pays more attention to students' individual learning needs (Gonzales et al., 2023).

The flipped classroom methodology has been compared to traditional teaching methods in several studies, and the findings indicate that students who participate in this model exhibit better performance and understanding. For example, a comparative study conducted by Arriaga et al. analyzed the results of flipped classroom methodology and traditional methodology in Spanish, English, and math classes (Arriaga & Medina-Talavera, 2018). The results of this study demonstrated that the flipped classroom model was more effective in promoting successful learning outcomes for students in different subject areas (Arriaga & Medina-Talavera, 2018). In addition, Serrano's research on students' perception of learning from traditional classroom methodologies versus the flipped classroom model further supports the efficacy of this innovative teaching method (Pardo Alean et al., 2021).

Augmented reality (AR) has been increasingly recognized as a valuable tool in education, particularly for teaching complex concepts such as linear machine kinematics (Banoy Suárez, 2020). AR allows students to interact with virtual objects in their real-world environment, providing a more immersive and engaging learning experience compared to traditional teaching methods (Gonzales et al., 2023). Understanding the effectiveness of AR in conjunction with flipped classroom teaching approaches is crucial to determining the best strategies to improve college students' learning outcomes.

The flipped classroom is an innovative teaching approach that focuses on student-centered learning by shifting the traditional lecture-based structure to a more active and participatory environment (Gonzales et al., 2023). In this model, students are expected to review conference materials and resources before attending class, allowing class time to be spent on discussions, problem-solving, and other interactive activities (Pardo Alean et al., 2021). Numerous studies have shown the benefits of the flipped classroom approach, including increased student engagement, increased engagement, and better overall learning outcomes (Chuquimbalqui-Maslucán, 2021; Arriaga & Medina-Talavera, 2018).

Comparisons have been made between the flipped classroom and traditional teaching methods in various academic disciplines, shedding light on the potential advantages and limitations of each approach (Arriaga & Medina-Talavera, 2018; Dehghanzadeh & Jafaraghaee, 2018; O'Flaherty & Phillips, 2015; Palazón-Herrera & Soria-Vílchez, 2021; Prieto et al., 2021). For example, a study by Carreño found that the teaching procedure significantly influenced students' knowledge construction in a sample of 50 students, highlighting the importance of selecting the most effective teaching strategies (Carreño & Carreño, 2019). By combining AR technology with the flipped classroom approach, educators can create even more immersive and engaging learning experiences for their students, ultimately fostering a deeper understanding of complex topics such as linear machine kinematics.

Linear machine kinematics occupies a central place in university engineering education, essential to the understanding of motion in mechanical systems. In response to the growing need to adopt more effective educational strategies (Hernández Hechavarría et al., 2021), this study emphasizes the importance of innovating in pedagogy, particularly through the integration of the Flipped Classroom model and augmented reality (AR) technology. This approach revolutionizes traditional learning by transforming the classroom into an interactive space where students apply previously reviewed concepts in a practical way autonomously (Faúndez et al., 2017). The effectiveness of these modern methodologies, contrasted with conventional ones, highlights their potential to significantly improve student understanding in complex areas such as linear kinematics, fostering more immersive, participative learning adapted to the individual needs of each student.

The study of linear machine kinematics is a crucial aspect of university engineering education, as it involves understanding the motion of components in mechanical systems. To impart this knowledge effectively, various teaching methodologies have been employed. One such approach is the flipped classroom, which is a method that changes the traditional roles of teachers and students in the teaching-learning process (Pardo Alean et al., 2021). By using this method, students are expected to come prepared for class by interacting with the learning materials beforehand, allowing class time to be used more effectively for interactive discussions, problem-solving, and collaborative activities.

The importance of learning linear machine kinematics in university studies cannot be underestimated, as it provides students with a solid foundation in mechanical engineering concepts (Gonzales et al., 2023). By employing effective teaching methods, such as the flipped classroom, educators can help ensure that students gain a deeper, more progressive, and more meaningful understanding of the subject matter (Rojas, n.d.). Some benefits of using the flipped classroom methodology in teaching linear machine kinematics include: -

Increased student engagement and participation (Arriaga & Medina-Talavera, 2018) - Improved problem-solving and critical thinking skills (Rozo García, 2016) - A more student-centered learning environment - Personalized learning opportunities and differentiated instruction (Rozo García, 2016) Overall, the use of flipped classroom methodology in teaching linear machine kinematics has the potential to significantly improve the learning experience of college students, leading to better retention and understanding of the subject matter (Arriaga & Medina-Talavera, 2018).

Flipped Classroom as an Alternative to Traditional Teaching

The traditional teaching approach has long been the predominant method of imparting knowledge in educational settings. However, recent advances in technology and pedagogy have led to the development of alternative teaching strategies, such as the flipped classroom with augmented reality (AR) (Gonzales et al., 2023).

To compare the AR flipped classroom with traditional teaching, it is essential to first define and explain the traditional teaching approach. Traditional teaching typically involves a teacher-centered environment, where the instructor imparts knowledge through lectures and students are expected to passively absorb the material (Arriaga & Medina-Talavera, 2018). This approach often focuses on direct instruction, with limited opportunities for active learning or collaboration among students. Consequently, traditional teaching methods can leave some students disengaged or struggling to grasp complex concepts, which can hinder their overall academic progress.

In contrast, the flipped classroom methodology aims to improve student engagement and understanding by modifying the roles of teachers and students in the teaching-learning process (Carreño & Carreño, 2019). This approach involves providing students with pre-recorded lectures or other learning materials to review before class, allowing classroom time to be spent on more interactive activities, such as discussions, problem-solving exercises, and group work (Arriaga & Medina-Talavera, 2018). The integration of augmented reality into the flipped classroom further enhances the learning experience by immersing students in a virtual environment that simulates real-world scenarios or processes, thereby facilitating a deeper understanding of the subject matter (Banoy Suárez, 2020). Several studies have reported positive outcomes associated with the flipped classroom approach, including increased student engagement, improved learning outcomes, and higher levels of satisfaction (Gonzales et al., 2023; Pardo Alean et al., 2021). However, it is crucial to conduct a systematic review to determine the overall effectiveness of the AR-flipped classroom compared to traditional teaching methods in the context of linear machine kinematics.

Flipped Classroom with Augmented Reality

Understanding the level of difficulty in learning linear machine kinematics is essential for educators to develop effective teaching methods that meet the diverse needs of college students (Gonzales et al., 2023). Linear kinematics is a complex subject, and students often struggle to grasp the concepts and apply them in real-life situations. Traditional teaching methods may not be sufficient to address these challenges, leading educators to explore alternative approaches to improve student learning outcomes (Roig-Vila, 2016).

The flipped classroom with augmented reality (AR) is an innovative teaching approach that combines the benefits of flipped classroom methodology and AR technology (Carreño & Carreño, 2019). In this method, students are encouraged to study the course material before attending class, allowing them to participate in interactive activities, discussions, and problem-solving sessions during class time (Arriaga & Medina-Talavera, 2018). Augmented reality adds an immersive learning experience by overlaying digital information onto the physical environment, helping students better visualize and understand complex concepts in linear machine kinematics (Chuquimbalqui-Maslucán, 2021). This approach aims to transform the traditional teacher-centered classroom into a collaborative, more student-centered learning environment (Gonzales et al., 2023).

The flipped classroom with AR offers several advantages and disadvantages compared to traditional teaching methods. Some of the key benefits include: - Improved student engagement and participation (Cárdenas Yánez & Gavilanes López, 2023; Gonzales et al., 2023) - Improved understanding of complex concepts through AR visualization (Chuquimbalqui-Maslucán, 2021; Quiñónez & Sanchez, 2023) - Increased collaboration and peer-to-peer learning opportunities (Barroso, 2022; Carreño & Carreño, 2019). However, there are also some drawbacks to consider: - The need for adequate technological infrastructure and access to AR devices (Chuquimbalqui-Maslucán, 2021) - Potential challenges in implementing the flipped classroom model for educators who are unfamiliar with the approach (Pardo Alean et al., 2021) - The potential for students not to effectively use self-directed learning opportunities outside of the classroom (Domínguez-Torres et al., 2021).

Methodology

To evaluate the effectiveness of flipped classroom methodology in teaching linear machine kinematics, researchers have employed various data collection methods and instruments (Pardo Alean et al., 2021). A commonly used method involves comparing the performance of students in flipped classrooms with that of students in traditional classrooms (Arriaga & Medina-Talavera, 2018). By analyzing student participation, performance, and engagement, researchers can determine the impact of flipped classroom methodology on student learning outcomes (Gonzales et al., 2023). In addition, studies may include qualitative data obtained through interviews, questionnaires, and observations to learn more about students' experiences and perceptions of the flipped classroom approach (Carreño & Carreño, 2019).

In recent years, there has been a growing interest in the efficacy of augmented reality and flipped classroom methodologies in education. Several studies have explored the use of these innovative teaching approaches to improve student learning and engagement. For example, Gonzales (2023) He stressed the importance of analyzing the flipped classroom method, focusing on student participation and performance. Similarly, other researchers have compared flipped classroom methodology to traditional teaching methods and concluded that it offers a more interactive and student-centered learning experience. Pardo Alean et al. (2021) He further emphasized the importance of understanding students' perceptions of learning through the flipped classroom and the flipped classroom. Methodologies.

Development

The augmented reality (AR) application was developed specifically for this study with the purpose of improving the understanding of linear machine kinematics. The app allowed users to visualize models of mechanisms and machines in an AR environment, making it easier for these models to interact in real-time. Mainly these models were taken from the first chapters of the book of Machines & Mechanisms by David H. Myszka (Myszka, n.d.). The students could observe the movement of the mechanisms through animations embedded in an application developed for Android operating systems, thanks to the design with Unity and Vuforia software (specific for these applications). This tool was designed to be accessible, ensuring that students could focus on kinematics concepts without the barrier of a technological learning curve.

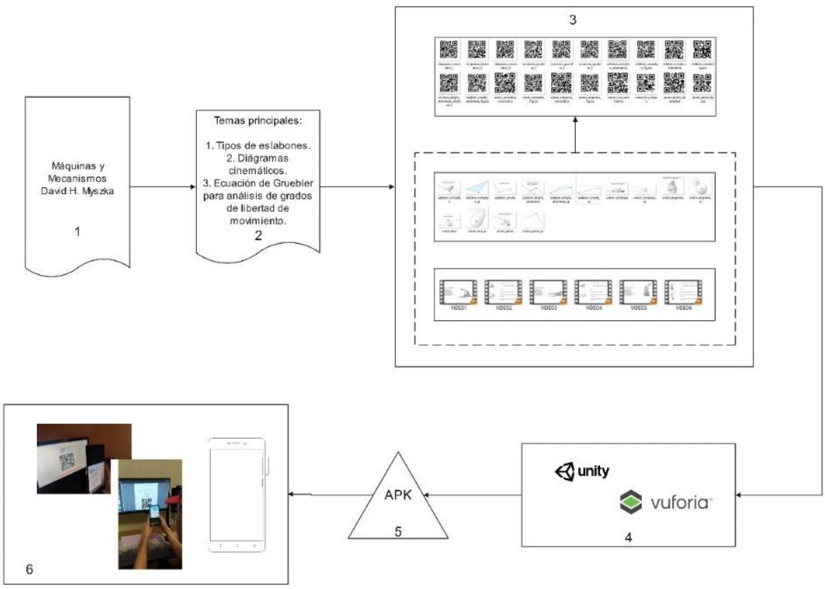

Figure 1. Diagram to building blocks of the augmented reality application.

Figure 1 shows a block diagram, which is described as follows: 1) As a basis for the development of the augmented reality application, the book "Machines and Mechanisms" by David H. Myszka was taken as a reference. It is important to mention that; 2) Only topics related to link types, kinematic diagrams and Gruebler's equation for the analysis of degrees of freedom of movement in machines were taken into account for the development of the application. These topics focus on the analysis of the linear kinematics of machines, which are essential for more advanced analyses, such as speed, acceleration and actuator installation. 3) From these themes, 2D animations and images were created, which were stored in the cloud using Vuforia. Unity was used as the environment for the development of the application, whereby; 4) Animations and images were imported from the Vuforia cloud to each QR code. 5) Using the Unity software, the augmented reality application developed in APK format was exported, which is compatible with mobile devices operating under the Android system. 6) This integration culminated in the development of the application, which was used by the students as a complementary tool to the flipped classroom method.

Didactic Sequence to Integrate Flipped Classroom and the Augmented Reality Application

The flipped classroom methodology was implemented to complement the use of the AR app. Students under the "traditional" class scheme are instructed with study material that includes readings and exercises. This material provided them with the theoretical foundations necessary for the practical class that followed. On the other hand, with the didactic sequence developed under institutional format, the students of the experimental group, during their flipped classroom sessions, learned the concepts of linear kinematics, actively applying them – together with the students of the control group – in the days dedicated to the resolution of practical exercises focused on the analysis of the linear kinematics of machines. This approach fostered classroom discussion, teamwork, and deeper understanding through direct experimentation and problem-solving.

Computer, projector1. Detailed didactic design of the machine kinematics course.

weeks	Session	Duration	Learning objectives	Description of activities	Didactic materials	Tools and Instruments
1	Theory (Day 1)	2 hours	Introduce the course and objectives of the research	Framework of the course, explanation of the methodology and objectives of the research	Course guide, PowerPoint presentation	Computer, projector
	Exercises (Day 2)	2 hours	Evaluate students' prior knowledge	Pretest application and its qualification to establish a baseline	printed pretest, answer sheets	Pencil, paper
2	Theory (Day 1)	2 hours	Understand the types of linkages	Presentation and discussion on fundamental concepts of linkages	Control group: Guide text, illustrative diagrams	Whiteboard, markers
	Exercises (Day 2)	2 hours	Identify linkages in practical examples	Practical exercises to identify linkages in different machines	Experimental group: Augmented reality application developed.	Pencil, paper
3	Theory (Day 1)	2 hours	Learn to create kinematic diagrams	Explanation and demonstration of kinematic diagrams	Printed exercises, machine examples	Computer, projector
	Exercises (Day 2)	2 hours	Develop skills in making kinematic diagrams	Practice creating kinematic diagrams from machine examples	Worksheets, machine examples	Pencil, paper, ruler
Week	session	Duration	Learning Objectives	Description of Activities	Teaching Materials Experimental group: Augmented reality application developed.	Tools & Instruments
	Theory	2 hours	Introduces the	Course setting,	Course Guide,	Computer,

	(Day 1)		course and objectives of the research	explanation of the methodology and objectives of the research	PowerPoint Presentation	projector
5	Exercises (Day 2)	2 hours	Assess students' prior knowledge	Applying Pretest and Grading to Establish a Baseline	Printed Pretest, Answer Sheets	Pencil, paper
	Theory (Day 1)	2 hours	Understanding the Types of Linkages	Presentation and discussion on fundamental concepts of linkages	Control group: Guide text, illustrative diagrams Experimental	Blackboard, markers

Table 1 details the design and structure of the course focused on machine kinematics, highlighting how both traditional teaching methods and technological innovations, such as augmented reality, were incorporated to enhance the learning experience. Over the course of five weeks, theoretical and practical sessions are described, each with specific learning objectives, planned activities, teaching materials used and the tools and instruments necessary for their implementation.

In the first week, the introduction of the course and its research objectives is done through a general framework and explanation of the methodology, using a course guide and a PowerPoint presentation as teaching materials, and a computer and a projector as tools. The second day focuses on assessing students' prior knowledge through a pretest.

Week two is dedicated to the study of the types of linkages, differentiating between the control group, which uses guide texts and diagrams (instructed by the professor), and the experimental group, which takes advantage of an augmented reality application. The practical exercises in this module seek to identify links in real examples of machines.

In week three, students learn how to create cinematic diagrams, with the control group using a PowerPoint presentation and printed examples, while the experimental group uses the augmented reality app. The exercise session focuses on developing practical skills in creating these diagrams.

Week four addresses Gruebler's equation, explaining how to calculate degrees of freedom of movement, again differentiating between the materials and methods used by the control and experimental groups. The practical exercises are designed to apply this equation in specific cases. Finally, week five includes an institutional exam to assess student learning, followed by a feedback session where grades and comments on the exam are provided, using computers and projectors as tools to facilitate review.

Comparison with Traditional Teaching Methods

To evaluate the effectiveness of these educational innovations, a direct comparison with traditional teaching methods was carried out. The control group consisted of students who were taught using conventional approaches, which included classroom lectures, standard demonstrations, and paper-based problem-based assignments. The assessment of students' learning and comprehension was carried out through a pre-test and a post-test, which were applied uniformly to both groups.

This methodology provided a solid foundation for determining whether the integration of augmented reality and the flipped classroom approach could offer a significant improvement in linear kinematics students' learning and understanding compared to traditional teaching methods.

The traditional teaching approach has certain advantages and disadvantages that impact the learning process of students. In the traditional classroom, teachers serve as the primary source of information and students passively receive knowledge (Carreño & Carreño, 2019). This method has the advantage of providing a structured learning environment and a coherent curriculum. However, it also has several drawbacks, such as limiting student participation and engagement, encouraging a passive learning style, and discouraging individualized learning experiences (Pardo Alean et al., 2021). As a result, the effectiveness of traditional teaching methods in promoting deep and meaningful learning has been increasingly questioned.

To analyze the data and compare the effectiveness of this type of implemented approach and traditional teaching methods in learning linear machine kinematics, researchers have employed various data analysis methods, such as comparative studies and systematic reviews (Pardo Alean et al., 2021). For example, one study compared flipped classroom methodology with traditional teaching methods in Spanish, English, and math classes, examining learning outcomes and student engagement (Arriaga & Medina-Talavera, 2018). Another study focused on the self-directed learning aspect of the remote flipped classroom, which is an alternative to the conventional flipped classroom, and found that it does not compromise students' self-directed learning (Domínguez-Torres et al., 2021). By employing these data analysis methods and examining the results, researchers can better understand the overall effectiveness of these approaches compared to traditional teaching methods in learning the linear kinematics of machines by college students.

As mentioned above, the target population was 40 engineering students (biomedical and mechatronics) from a private higher education institution in the state of Jalisco, Mexico, through selection at convenience, since, in each annual four-month period, specifically in the September-December periods, fourth-semester students are the ones who mainly study the subject of mechanisms in their study plans. To do this, the students were identified by the acronyms: IBIO for biomedical engineering students and IMEC for mechatronics engineering students. The consecutive number identified each of them, and at the end, a letter C to identify the students in the Control group and a letter E for the students in the Experimental group.

On the second day of ordinary classes, the entire group was given a pretest, which is designed to evaluate the knowledge prior to the start of the topics of the subject of mechanisms. These results – from the pretest – can be seen in Table 2.

3.782. Grades obtained in the pretest by each of the students.

Grupos			
Exercises (Day 2)	2 hours	Identify links in practical examples	Practical exercises to identify links in different machines
Printed	Pencil, paper	3	Theory (Day 1)

Exercises, Machine Examples			
2 hours	Learn how to create kinematic diagrams	Explanation and Demonstration of Kinematic Diagrams	Control group: PowerPoint presentation, diagram examples Experimental
Computer, projector	5.75	Exercises (Day 2)	2 hours
Develop skills in making kinematic diagrams	Practice creating kinematic diagrams from machine examples	Worksheets, Machine Examples	Pencil, paper, ruler
4	Theory (Day 1)	2 hours	Understanding the Gruebler Equation
Presentation and explanation of Gruebler's equation for calculating degrees of freedom of movement	Control group: Study guide, PowerPoint presentation Experimental	Blackboard, markers	5.45
Exercises (Day 2)	2 hours	Apply Gruebler's equation in practical exercises	Exercises to Calculate Degrees of Freedom of Movement Using Gruebler's Equation
Worksheets, calculator	Pencil, paper	5	Exam (Day 1)
2 hours	Assess student learning	First midterm exam to assess the understanding and skills acquired	Paper Exam, Answer Sheets
Pencil, paper	5.10	Feedback (Day 2)	2 hours
Provide feedback and improve learning	First Midterm Exam Feedback & Grade Delivery	Copies of the exam with comments, list of scores	Computer, projector
IMEC3C	4.25	IMEC9E	0.00
IBIO10C	6.95	IBIO24E	5.45
IBIO11C	5.70	IMEC10E	0.00
IBIO12C	2.40	IBIO25E	Groups
Control	Pre-test qualification	Experimental	Pre-test qualification
IBIO1C	7.25	IBIO15E	0.00
IBIO2C	6.65	IBIO16E	4.85
IBIO3C	5.75	IBIO17E	4.50
IBIO4C	5.75	IMEC7E	3.30
IBIO5C	6.00	IBIO18E	5.15

After the intervention using the methodology proposed in this article, both control and experimental groups were given a post-test designed to evaluate the topics addressed during the experimentation. The results of both groups can be seen in Table 3.

7.983. Grades obtained in the post-test by each of the students.

IBIO6C			
5.75	IBIO19E	5.45	IBIO7C
5.75	IMEC8E	5.75	IBIO8C
7.55	IBIO20E	4.85	IBIO9C
4.20	IBIO21E	3.30	IMEC1C
5.10	IBIO22E	0.00	IMEC2C
3.00	IBIO23E	4.80	IMEC3C
4.25	IMEC9E	0.00	IBIO10C
6.95	IBIO24E	5.45	IBIO11C
5.70	IMEC10E	0.00	IBIO12C
2.40	IBIO25E	6.05	IBIO13C
6.35	IMEC11E	3.35	IBIO14C
4.85	IBIO26E	5.45	IMEC4C
6.00	IBIO27E	4.25	IMEC5C
5.15	IBIO28E	3.65	IMEC6C
6.35	IMEC12E	5.45	Average
5.54	Average	3.78	10.00
IBIO13C	6.90	Groups	Control
Exam Qualification	Experimental	Exam Qualification	IBIO1C
8.70	IBIO15E	5.40	IBIO2C
9.10	IBIO16E	8.80	IBIO3C
8.10	IBIO17E	6.90	IBIO4C
10.00	IMEC7E	5.10	IBIO5C

Results and discussion

With the above results, statistical tests were carried out, Kolmorov-Smirnov and Saphiro-Wilk, which is applicable for this type of case studies with a small number of students. These results can be seen in Table 4.

The Kolmogorov-Smirnov and Shapiro-Wilk tests are two statistical methods used to assess the normality of a data set, that is, to determine whether a sample comes from a population that follows a normal distribution (Berger & Zhou, 2014; Shapiro & Wilk, 1965). In the context of this research, these tests are crucial tools to analyze the results obtained from groups of students, thus allowing to determine the applicability of certain statistical techniques that assume the normality of the data.

The Kolmogorov-Smirnov test is a non-parametric test that compares the cumulative distribution of a sample with a theoretical distribution (in this case, the normal distribution), or the comparison between two samples (Berger & Zhou, 2014). The null hypothesis (H0) of the Kolmogorov-Smirnov test holds that the sample comes from a population with the specified theoretical distribution. A significant result (low p-value) indicates that the null hypothesis should be rejected, suggesting that the sample does not follow the distribution in question.

The Shapiro-Wilk Test is specifically designed to test the normality of a sample. By comparing the order of the data with what would be expected from a normal sample, the

Shapiro-Wilk test calculates a W-statistic that indicates how likely it is that the sample was drawn from a normally distributed population (Shapiro & Wilk, 1965). As in the Kolmogorov-Smirnov test, a null hypothesis (H0) states that the sample has a normal distribution. A low p-value in the Shapiro-Wilk test suggests rejecting H0, indicating that the data are not normally distributed.

Therefore, the Kolmogorov-Smirnov and Shapiro-Wilk tests are applied to the pre- and post-intervention outcomes of the control and experimental groups to assess the normality of the grade distributions. The results of these tests help to determine whether additional statistical techniques, which assume the normality of the data, can be correctly applied in the subsequent analysis. For example, normality is a requirement for applying parametric tests such as the t-test for comparisons of means.

0.09754. Pre- and Post-Intervention Test Results (Kolmogorov-Smirnov and Shapiro-Wilk).

8.40	IBIO18E	9.70	IBIO6C	9.40
IBIO19E	7.60	IBIO7C	6.60	IMEC8E
9.70	IBIO8C	10.00	IBIO20E	7.50
IBIO9C	6.90	IBIO21E	6.30	IMEC1C
10.00	IBIO22E	8.10	IMEC2C	7.50

A KS statistic close to 1 and a very low p-value in all groups suggests strong evidence against normality. This indicates that the grade distributions do not follow a normal distribution. The p-values of SW are mixed. In the control groups (both pretest and post-test), the p-values are greater than 0.05, which implies that the hypothesis of normality is not rejected. However, in the experimental groups, the p-values are less than 0.05, indicating a deviation from normal. These results suggest that both before and after the intervention (pretest and posttest), the scores in the experimental groups are not normally distributed. This could be due to the variability in how students interact and learn with augmented reality, possibly reflecting differences in the ease of use or pedagogical effectiveness of the tool, or the impact that the pandemic generated at the time.

In contrast, the control group shows a greater tendency towards normality, especially in the post-test, which may indicate a more even distribution of academic performance in this group. This might suggest that traditional teaching methods offer a more consistent or predictable learning experience, though not necessarily more effective. Due to the results shown above and assuming that there is no normality in the results of the control and experimental groups, a Mann-Whitney U test was performed for the groups before and after the intervention, having the results in Table 5 and Table 6, respectively. The Mann-Whitney U test, also known as the Wilcoxon rank sum test for independent samples, is a nonparametric statistical method used to compare two independent groups to determine if they come from the same distribution (McKnight & Najab, 2010). Unlike t-tests, the Mann-Whitney U does not assume normality in the distribution of data or homogeneity of variances, which makes it particularly useful when those assumptions are not met.

The main goal of the Mann-Whitney U test is to assess whether there is a significant difference in the median between the two groups. To perform the test, all the values from the two groups are combined into a single dataset, and then sorted from lowest to highest. Each value is assigned a rank, with the smallest being rank 1. If there are ties, each is assigned the average of the ranks they would have occupied.

0.00235. Results of the Mann-Whitney U test for the pre-intervention groups.

IBIO23E	9.40	IMEC3C	9.10	IMEC9E	7.20
IBIO10C	8.10	IBIO24E	6.90	IBIO11C	8.70
IMEC10E	7.20	IBIO12C	10.00	IBIO25E	10.00

The value of the U statistic is 313.0. This value, on its own, tells us little until we compare it to the p-value. The p-value is 0.0023, which is less than the commonly used threshold of 0.05. This indicates that there is a statistically significant difference in the distributions of scores between the control group and the experimental group in the pretest.

The statistical significance found suggests that the scores between the two groups before the intervention (pretest) are not equal. Since this is the pretest, i.e., prior to the implementation of any educational intervention, this difference may reflect underlying variables in the groups that are not related to the intervention itself, such as differences in the level of prior knowledge, learning skills, or motivation.

In the context of evaluating the impact of an augmented reality application on the teaching of machine kinematics concepts, it is important to note that these differences existed prior to the intervention. This means that any changes observed in the post-test need to be considered in light of these initial differences. The effectiveness of the educational intervention should be evaluated not only in terms of improving grades but also by taking into account the initial level of the students.

0.30846. Results of the Mann-Whitney U test for the groups after the intervention.

IBIO13C	6.90	IMEC11E	7.50	IBIO14C	6.90
IBIO26E	9.40	IMEC4C	7.85	IBIO27E	9.70
IMEC5C	9.70	IBIO28E	7.20	IMEC6C	8.10

The Mann-Whitney U-statistic is 238.0, and the associated p-value is 0.3084, which is higher than the conventional threshold of 0.05. This indicates that there is no statistically significant difference in the distributions of scores between the control group and the experimental group in the post-test.

Although the mean and median are slightly higher in the control group, the lack of statistical significance suggests that these differences are not marked enough to be considered statistically relevant. Both groups show variability in their scores, although the experimental group has a slightly higher standard deviation, indicating greater dispersion in scores.

These results show a not-so-significant difference in the control and experimental groups after the intervention, however, to verify more thoroughly, Hake's conceptual gain analysis was performed in each of the groups after the experimental intervention (Table 7), to validate and contrast the results shown above. Hake's gain provides a way to assess how much students learned relative to how much they could have learned, taking into account their initial level of knowledge. A value of g Close to 1 (or 100%) indicates a very high improvement, where students, on average, achieved almost all the possible knowledge they could have acquired according to the test. A value of g close to 0 indicates little or no improvement in learning (Hake, 1998). This is calculated using the following formula:

$$g = \frac{\text{posttest} - \text{pretest}}{100 - \text{pretest}}$$

Where:

g is the normalized gain ranging from 0 to 1 (0% to 100% when expressed as a percentage)

Posttest is the student's grade point average after the educational intervention.

Pretest is the student's grade point average before the educational intervention.

This measure is particularly useful for comparing the effectiveness of different teaching approaches, as it takes into account the student's starting point and allows for a more equitable analysis of improvement. For example, in studies comparing traditional teaching methods with more active or innovative approaches, such as problem-based learning or the use of technologies such as augmented reality (as in the case of this research), Hake's conceptual gain may reveal how effective these methodologies are in promoting a deeper understanding of concepts.

67.52%7. Results of the application of the Hake profit factor.

IMEC12E	10.00	Average	8.50	
Average	7.98	8.50	Media	66.44%
Experimental	3.78	7.98	Media	67.52%

The results of the conceptual gain analysis using the Hake factor provide an interesting perspective on the effectiveness of the educational intervention in both groups. Let's discuss these results in the context of the study:

In the control group, the mean in the pretest was 5.54, and in the posttest it increased to 8.50, resulting in an average gain of 66.44%. This indicates a significant improvement in grades after the educational intervention. In the experimental group, the mean in the pretest was 3.78, and in the posttest it increased to 7.98, with an average gain of 67.52%. This improvement is slightly higher than that of the control group, indicating that students experienced an increase in their conceptual understanding.

Both groups showed significant improvements in their grades, suggesting that both traditional teaching methods and augmented reality intervention were effective in improving students' conceptual understanding of machine kinematics. Although the average gain of the experimental group is slightly higher than that of the control group, the difference is minimal. This could be interpreted to mean that the application of augmented reality is as effective as traditional teaching methods in terms of improving conceptual understanding. However, it is important to consider that the experimental group started from a lower baseline, which could have allowed for more room for improvement.

Since the experimental group started with lower scores on the pretest, the larger gain could be partially influenced by a "floor effect." In other words, when students start with a lower level of knowledge, they have more room to improve.

While grades and conceptual gain are important indicators, they do not fully capture the impact of augmented reality on aspects such as student engagement, motivation, critical thinking ability, and practical application of knowledge. These aspects should also be evaluated to gain a full understanding of the effectiveness of the intervention.

The results suggest that incorporating innovative technologies such as augmented reality can be an effective strategy to improve conceptual understanding on complex topics such as machine kinematics. However, it is crucial to balance the use of new technologies with traditional teaching methods to maximize learning. It would be valuable to further investigate how different teaching strategies affect various aspects of learning and how these methods can be combined or adapted for different learning styles or levels of prior knowledge.

Conclusions

Based on the analysis of the data and the results obtained through various statistical tests and evaluation methods, several significant conclusions can be reached regarding the effectiveness of teaching machine kinematics concepts, in particular in relation to the use of an augmented reality application compared to traditional teaching methods.

Effectiveness of Teaching Methods:

- Significant improvements in both groups: Both the control group (traditional methods) and the experimental group (augmented reality) showed notable improvements in their scores from pretest to post-test. This indicates that both methods are effective in improving students' conceptual understanding.
- Baseline Differences and Their Impact: The experimental group started with a lower level of knowledge compared to the control group, as evidenced by the pretest scores. Despite this initial disadvantage, the experimental group showed slightly greater improvement (according to Hake's factor), suggesting that augmented reality may be particularly effective for students starting with a lower knowledge base.
- Statistical Significance and its Interpretation: The Mann-Whitney U test revealed statistically significant differences in pretest scores, but not in post-test. This underscores the importance of considering the initial level of students when evaluating the impact of educational interventions.

Implications for Teaching Machine Kinematics:

- Balance between Technology and Traditional Methods: The results suggest that the integration of innovative technologies such as augmented reality, together with traditional teaching methods, can be an effective strategy. Technology can offer more interactive and engaging learning experiences, but it shouldn't completely replace traditional approaches.
- Consideration of Miscellaneous Factors in Educational Assessment: While grades are an important indicator of academic success, other factors such as commitment, motivation, and the ability to apply knowledge in practical ways are also crucial. It is important to conduct a holistic assessment that includes these aspects in order to fully understand the impact of any educational intervention.
- Conducting the study during the COVID-19 pandemic adds an extra layer of complexity and relevance to the findings. This particular context impacts not only the logistics and methodology of teaching, but also the experience and performance of the students. Let's consider this factor in the conclusions:

Adaptation and Resilience in Education:

- Flexibility in Teaching Methods: The pandemic forced educators and students to adapt to distance learning methods. In this context, augmented reality and other digital technologies have proven to be valuable tools to maintain the continuity and quality of education, overcoming the physical barriers imposed by confinement.
- Importance of Educational Technology: The implementation of augmented reality has been particularly pertinent during the pandemic. It offers an interactive and engaging way to learn remotely, which is crucial when face-to-face interactions and hands-on experiences are limited.

Psychological and Emotional Impact of the Pandemic:

- Student Well-Being and Academic Performance: The pandemic had a significant impact on students' mental health, which can affect their academic performance. Technologies that increase engagement and provide a more engaging learning experience can help mitigate some of these negative effects.
- Distance Learning Challenges: Distance learning, while necessary, can present challenges such as a lack of direct interaction and support from peers and teachers. Augmented reality tools can help create a more immersive experience and compensate for some of these limitations.

Educational Evaluation and Effectiveness in Times of Crisis:

- Assessment of Learning in Exceptional Circumstances: Assessments of students during the pandemic must consider the unique challenges they face. This includes limited access to resources, variations in the learning environment at home, and additional stress due to the global situation.
- Potential of Augmented Reality in Educational Crises: The pandemic has highlighted the potential of augmented reality and other educational technologies in crisis situations. They offer a viable alternative to maintain the quality of education when traditional face-to-face methods are not possible.

Recommendations for Post-Pandemic Education:

- Preparedness for Future Crises: This study underscores the importance of integrating flexible and resilient educational technologies into curriculum planning. These technologies are not only useful in times of crisis, but they can also enrich the educational experience in normal times.
- Innovation and Continuous Development: The pandemic has accelerated the adoption of educational technologies. It is crucial to continue to develop and integrate these tools into education, building on lessons learned during the pandemic to improve teaching and learning.

Recommendations for Future Educational Research and Practices:

- Additional Research on Teaching Methodologies: Further studies exploring how different methods affect different types of learners, especially those with different levels of prior knowledge or learning styles, would be valuable.
- Developing Personalized Educational Strategies: Educators should consider adapting their strategies to address the individual needs of students, using a combination of

technology and traditional methods to provide a richer and more effective learning experience.

- Incorporation of Continuous Assessments: To gain a more detailed understanding of the impact of educational interventions, it is crucial to implement continuous and diversified assessments that can measure not only conceptual knowledge, but also practical and cognitive skills.

In summary, the results of the study suggest that both augmented reality and traditional methods are effective in teaching machine kinematics, each with its unique strengths. The key to effective education in this field seems to lie in the balanced combination of innovative technologies and traditional pedagogical approaches, tailored to the individual needs of students and assessed through a holistic and continuous approach.

The COVID-19 pandemic presented unprecedented challenges in education, but it also offered an opportunity to explore and validate the efficacy of innovative methodologies, such as augmented reality. Not only have these technologies proven to be effective in improving conceptual understanding in the teaching of machine kinematics, but they have also provided means to overcome some of the barriers imposed by distance education. Looking to the future, it is essential that educational institutions continue to adopt and adapt these technologies to improve the resilience and quality of education, both in times of crisis and in normal times.

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