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Research Article

Design Thinking in Physics Education: An Innovative Model for the Learning of Circular Motion

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ABSTRACT

This study evaluates the effectiveness of the Design Thinking method in enhancing the learning of circular motion. As part of the research process, students were tasked with designing and constructing an experimental didactic device, which served as a pedagogical tool to foster interactive learning in physics classes focused on circular motion. The research adopted a quantitative descriptive approach, employing a quasi-experimental design with control and experimental groups. Students' performance was assessed using pre- and post-tests to compare results. The study involved 170 high school students from the San Andrés Educational Unit in the Guano canton, Chimborazo province. Data was collected using a questionnaire and performance test. The design and construction of the didactic device enabled students to conduct measurements and analysis in a structured manner, strengthening the connection between theory and practice. Results indicated that while performance levels in the pre-test were similar in both groups, the post-test revealed significant improvements in the experimental group. These findings suggest that the application of the Design Thinking method positively impacted students' understanding of circular motion, promoting conceptual clarity, encouraging active learning, and increasing motivation and interest in physics.

Keywords: experiential learning, educational resources, design thinking method, laboratory experiments, teaching

INTRODUCTION

The need for innovation is more pressing than ever, particularly in the field of education, where innovative pedagogical strategies are essential for developing the skills required by this century, such as creativity, critical thinking, collaboration, and communication among students.

The Design Thinking Education Association presents this methodology as a transformative strategy for problem-solving and project development, emphasizing its potential to reshape traditional teaching models and techniques. Rather than being just a pedagogical approach, Design Thinking provides a structured framework for generating solutions that prioritize the needs of both teachers and students. This approach positions students as active participants in the educational process, fostering collaborative and dynamic learning environments.

In scientific fields, particularly in disciplines such as Biology and Physics, Design Thinking has developed unique characteristics that distinguish it as a method for creating new pedagogical proposals. The association highlights the relevance of this methodology for educational institutions, promoting creativity, innovation, flexibility in teaching, and the search for agile solutions to challenges, all while striving for continuous improvement in educational quality. Additionally, it encourages practical learning, teamwork, creativity, problem-solving, and the development of analytical and critical thinking. Increased student motivation and a drive for self-evaluation have also been observed—key elements for the evolution and effectiveness of the educational process.

Design Thinking (DT) has gained popularity as an innovative teaching method. Recently, DT has been recognized as an unconventional approach to developing problem-solving, creativity, and innovation skills (Briceño et al., 2021). It is an educational model that seeks to maximize students' abilities by guiding them to solve real-life problems. It is a dynamic, non-linear, spiral process that facilitates deep learning (Shiyu & Chengfeng, 2023), increases interest and motivation, sparks creativity and engagement, and ultimately enhances student learning (Howard et al., 2021).

In secondary education, theoretical scores are often the primary criteria for final evaluation, while laboratory work tends to be undervalued. One of the contributing factors is the lack of necessary materials for experiments (Shana & Abulibdeh, 2020). Consequently, students often find experimental physics unappealing, particularly at the university level (Bouquet et al., 2023). Additionally, many physics teachers perceive the subject as difficult and abstract, which further hinders the development of experimental teaching methods and students' interest in physics, thereby impeding the improvement of students' future innovation awareness and their ability to foster creativity.

A poor understanding of physics and frequent misconceptions about the concept of motion are common issues (Puspitasari et al., 2020). Specifically, students struggle with the concept of circular motion due to the inadequacy of traditional teaching and learning methods. Additionally, low levels of critical thinking skills hinder the understanding of uniform circular motion (Faizuna et al., 2023). Another challenge is the authoritarian dynamic between teachers and students, which limits equal interaction and lacks methods to stimulate students' internal motivation (Tu et al., 2018). Misconceptions and a poor understanding of scientific concepts are prevalent, as science and physics teaching is largely reliant on textbooks, which are often the only teaching material used (Shana & Abulibdeh, 2020).

To address the challenges of teaching and learning circular motion, three critical areas should be focused on: innovation in the implementation of current educational methodologies, innovation in teaching approaches, and the expansion of experimental practices. These efforts will encourage students to engage with physics and acquire scientific knowledge more willingly.

Teaching physics at the high school level and cultivating scientific thinking are vital for the comprehensive development of students. Therefore, the objective of this study is to enhance students' creativity and effectively integrate the theoretical and practical aspects of circular motion—a fundamental topic in the curriculum of various undergraduate programs—using the Design Thinking methodology. This approach aims to prepare students to confront future challenges in a world that is increasingly oriented towards science and technology.

MATERIALS AND METHODS

Research Design

This study adopts a mixed-methods approach, integrating both quantitative and qualitative research methods to comprehensively evaluate the effectiveness of the Design Thinking methodology in teaching circular motion. The quantitative component focuses on assessing academic performance through pre- and post-tests, while the qualitative component seeks to understand students' perceptions and experiences using questionnaires and focus groups. This approach allows for a broader analysis, combining numerical data with in-depth insights into the students' learning processes.

Participants and Sampling

The study was conducted at the San Andrés Educational Unit in Guano Canton, Chimborazo Province, Ecuador, involving 170 high school students. Participants were randomly assigned to either the experimental or control group, with each group consisting of 30 students. The experimental group received instruction using the Design Thinking methodology, while the control group followed traditional teaching methods. The study population was carefully selected to represent typical high school students from the region.

Instruments for Data Collection

Two main instruments were used for data collection:

1. **Pre- and Post-Test:** A performance test was designed to assess students' understanding of circular motion. This test consisted of 10 multiple-choice questions based on key concepts related to the topic. The pre-test was administered before the intervention, and the post-test was conducted after the intervention. The test was validated for content and reliability through expert reviews and pilot testing, yielding a Cronbach's alpha of 0.91, indicating strong internal consistency.
2. **Questionnaire:** A six-question Likert-scale questionnaire was designed to capture students' perceptions of the learning process, their engagement, and the impact of Design Thinking on their understanding of circular motion. This instrument aimed to provide qualitative data on students' motivation, the perceived effectiveness of the methodology, and their level of satisfaction.

Research Procedure

1. **Experimental Group:** The experimental group participated in a series of lessons designed using the Design Thinking methodology. This approach includes five stages: empathize, define, ideate, prototype, and test. In the empathize phase, students identified their challenges in learning circular motion. During the define phase, students worked to articulate the core problem to be addressed. In the ideate stage, students brainstormed solutions and collaboratively designed an experimental didactic device. In the prototype phase, students built the device and tested its functionality. Finally, in the test phase, students used the prototype to conduct experiments and analyze data related to circular motion.
2. **Control Group:** The control group followed traditional teaching methods for learning about circular motion, which focused on textbook explanations and teacher-led demonstrations. No experimental materials or innovative teaching strategies were used in this group.

Both groups received the same amount of instructional time, but the teaching methods varied significantly.

Data analysis

Pre- and post-measurement data were analyzed through descriptive and inferential statistics using R Studio software. Regarding conceptual and practical learning about circular motion, mean scores with standard deviation of students were calculated for each group before and after the implementation of design-based learning. The normality of each data set was checked using the Shapiro-Wilk test, since the number of students in each group was less than 50. The results of the Shapiro-Wilk tests indicated that the scores of the control and experimental groups in the pretest and posttest were normally distributed: for the control group $W = 0.97708$, p-value = 0.3176 and for the experimental group $W = 0.98365$, p-value = 0.6006. Consequently, the parametric t student test for paired samples was used to compare the mean scores in both control and experimental groups, before and after the pedagogical intervention.

Ethical Considerations

The study adhered to ethical guidelines, ensuring that all participants provided informed consent before participating. Confidentiality was maintained by anonymizing the data, and students were free to withdraw from the study at any time without consequence. The study also sought approval from the relevant educational authorities.

RESULTS

Implementation of the Design Thinking experience in the learning of circular motion.

Figure 1 shows the five key elements of the Design Thinking method: empathize, define, ideate, prototype and test. This approach allows them to learn from physics, while optimizing procedural and attitudinal competencies. For the implementation of this DT methodology, a strict sequential structure is not always followed; it can move from one phase to another as the creative and analytical process demonstrates the effectiveness of the proposals (Uribe, 2021).

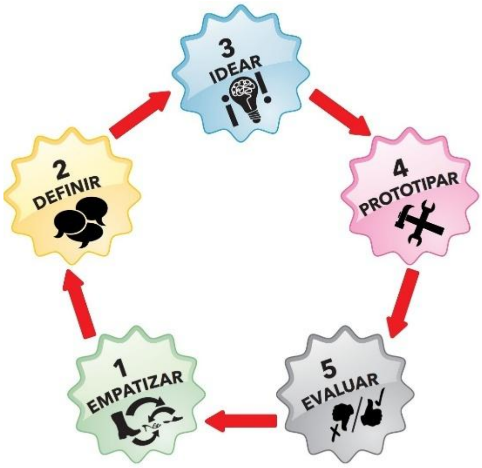

Figure 1. Development stages of the Design Thinking methodology. Taken from (Uribe, 2021)

This methodological approach consists of permanently iterating over five successive stages in order to achieve a novel and satisfactory solution.

User Exploration Stage (Empathize)

The objective of this phase was to gain an in-depth understanding of the students' needs and difficulties in learning circular motion, identifying the factors that influence their understanding and performance.

To this end, it began with a brainstorming session in which students wrote on the board the problems they face when studying circular motion. In addition, an attitude survey was conducted to analyze their perceptions on the topic. Focus groups were organized to identify the factors that motivate and demotivate learning physics, allowing a deeper understanding of their experiences and difficulties. Finally, observations of academic performance were made in order to detect the main challenges in the application of concepts and problem solving.

Definition stage the problem (Define)

It was crucial to clearly identify the specific problem faced by students in learning circular motion. Students had difficulties with understanding how angles relate to velocity and how to apply the formulas correctly in practical situations.

Likewise, among the difficulties identified, the application of mathematical formulas in real contexts was highlighted, which evidenced the need for pedagogical strategies that connect theory with practice in a meaningful way.

Based on these findings, the central challenge of the study was established: How to design an experimental didactic material that facilitates the understanding of circular motion and allows students to apply mathematical concepts in real contexts? This question guided the next stages of the Design Thinking process, ensuring that the proposed solutions responded to the specific needs of the students.

Idea generation stage (Idear)

In this phase, possible solutions to the problem identified in the Define stage were explored, with the objective of developing strategies to improve students' understanding of circular motion. Based on the information gathered in the previous stages, a brainstorming session was held in which students and teachers proposed various alternatives to address the difficulties detected.

During this stage, creativity and critical thinking were encouraged through collaborative work. Students discussed and evaluated different approaches to design an experimental didactic material that would facilitate the visualization and application of the concepts of circular motion. The most viable and effective ideas were prioritized, considering their impact on learning, accessibility and ease of implementation in the classroom.

As a result, an initial plan was established for the construction of the didactic material, ensuring that its design would respond to the identified needs and promote more dynamic and interactive learning.

Through practice and theoretical investigation, students are expected to master the comparison of the velocity of circular motion from linear velocity and angular velocity perspectives, and on this basis, know that velocity and period are also basic methods for comparing the velocity of motion.

Creation and prototyping stage (Prototyping)

The objective of this stage was to design and develop a simple and inexpensive prototype that integrates experimental and theoretical activities, allowing a practical exploration of the concepts of circular motion, transforming the ideas developed in the ideation stage into a tangible resource. To this end, the students worked on the selection of suitable materials, considering aspects such as accessibility, cost and functionality; these are described in Table 1.

Table 1. Materials used for the elaboration of the didactic resource.

Cantidad	Material
1	Pine material
1	MDF wood
1	18 to 22 rpm motor
8	Screw
8	Nails
2	Cables
1	Taipe
1	White glue
1	Lacquer
1	Stain
1	Red, black, blue and white paint
1	Sandpaper N° 240 and N°400
2	Aluminum lugs
4	Nuts

Following a set of technical specifications, a prototype (Figure 2) was designed and built to measure, visualize and analyze phenomena related to circular motion. This process involved the application of physical principles in a practical environment, reinforcing the connection between theory and experimentation.

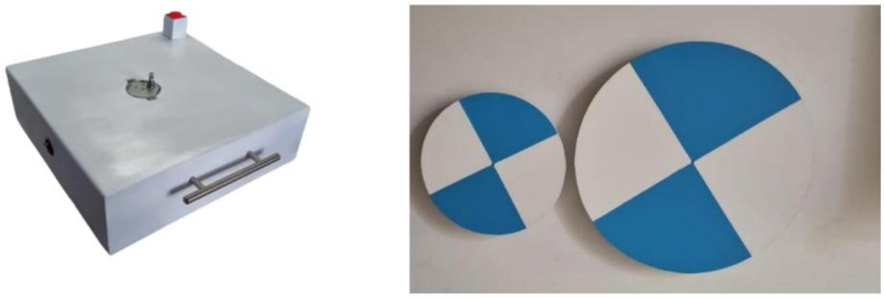

Figure 2. Outline of the experimental teaching material. Own elaboration.

Throughout the prototyping, iterative adjustments were made based on initial observations and tests, ensuring that the didactic material met the pedagogical objectives set. The final result was a functional and dynamic resource that facilitated interactive learning, encouraging the active participation of students in the construction of their own knowledge.

Evaluation and improvement stage (Testing)

In this phase, the functionality and effectiveness of the experimental didactic device was evaluated. For this purpose, test sessions were implemented in physics classes, where students used the didactic device to perform experimental activities, with the following procedure:

- Once the radius of the large disk was measured, it was placed on the axis of rotation of the experimental didactic device. After this, the cable was taken and the connection for the 110 V outlet was made.
- The equipment was turned on with one of the two discs placed on the engine shaft and the count of laps that it gives in a period of time was carried out, the time values obtained were recorded in Table 2.

Table 2. **Data obtained using the didactic material.**

Test,	Radius	Angle rotated	Time	Speed Angular	Speed tangential	Percentage error ω
N°	R(m)	θ (rad)	t(s)	ω(rad/s)	v(m/s)	Error(%)
1	0.100	2π	2.810	2.236	0.224	2.72
2	0.100	4π	5.460	2.302	0.230	0.14
3	0.100	6π	8.220	2.293	0.229	0.23
4	0.100	8π	10.850	2.316	0.232	0.78
5	0.100	10π	13.510	2.325	0.233	1.17
6	0.100	12π	16.250	2.320	0.232	0.94
7	0.100	14π	19.350	2.273	0.227	1.11
8	0.100	16π	21.750	2.311	0.231	0.55
9	0.100	18π	24.610	2.298	0.230	0.03
10	0.100	20π	27.200	2.310	0.231	0.50
	Promedio			**2.298**	**0.230**	**0.82**

- Using equations 1 y 2, the angular and linear speed experienced by this disc was calculated.

$$\omega = \frac{\Delta\theta}{\Delta t} \qquad \text{Ec. 1}$$

$$\omega = \frac{\theta_f - \theta_o}{t_f - t_o} = \frac{(2\pi - 0)rad}{(2.810 - 0)s} = 2.236\ rad/s$$

On the other hand, the linear speed

$$v = \omega \cdot R \qquad \text{Ec 2}$$

$$v = \left(2.236\frac{\text{rad}}{\text{s}}\right)(0.100\ \text{m}) = 0.224\text{m/s}$$

- Using the R studio software, the angular velocity versus time diagram was elaborated.
- Steps 2, 3, 4 and 5 were repeated using the small disk.

During these sessions, the level of interaction, understanding and motivation of the students when applying theoretical concepts in a practical environment was observed.

After obtaining the data with the respective calculations, scientific concepts were formulated with the participation of the students, which is described below:

Teacher: Showing the results of the measurements made, which can be found in Table 2, what patterns can we see?

Student: If in the same time interval, the angle swept by the radius joining the particle with the center of the circle is the same. The arc lengths traveled by the particle would also be the same.

Teacher: Through previous studies. By analogy, how can we compare the speed of the circular motion of an object?

Student: Compare the length of the arc that the particle travels in the unit of time or the angle swept by the line that connects the particle and the center of the circle in the unit of time.

Teacher: Very good! We call linear velocity the relationship between the length of the arc traveled by the two particles and the required time, and angular velocity the relationship between the angle traveled by the line joining the particles and the center of the circle and the required time. Next, let's see in more detail what is the linear velocity of circular motion.

Teacher: Is uniform circular motion really a uniform motion?

Student: No. The physical meaning of a uniform motion lies in the fact that the velocity vector of an object remains constant, which implies that both the magnitude and the direction of the vector do not change. However, in uniform circular motion, although the magnitude of the velocity remains constant, the direction is constantly changing. Therefore, uniform circular motion is not a uniform motion, but a motion with variable speed in direction.

Using experimental didactic material, the students developed thinking skills, practical skills and innovative capacity.

The results of this phase allowed optimizing the prototype and consolidating its applicability in the classroom, ensuring that its use would contribute significantly to the learning of circular motion. Finally, recommendations for future implementations were established, promoting the continuous improvement of the didactic resource.

Finally, evaluation instruments such as questionnaires and performance tests were applied to gather information on the effectiveness of the resource. In addition, iterative adjustments were made to the design and methodology of use of the didactic material, based on the comments and difficulties detected.

Based on the students' responses in class, the experimental process, the post-class exercises and the students' experimental reports, it was found that they had a good understanding of the concepts.

Hypothesis testing

To evaluate the impact of the Design Thinking methodology on the learning of circular motion, the following study variables were considered:

Independent Variable: Application of the Design Thinking methodology (with two levels: with application and without application).

Dependent Variable: Performance in learning circular motion, measured through a performance test.

Definition of the Hypotheses

Null Hypothesis (H_o): The application of the Design Thinking methodology does not have a significant effect on the learning of circular motion.

Alternative Hypothesis (H_1): The application of the Design Thinking methodology has a significant effect on the learning of circular motion.

Significance level specification

The applied significance level $\alpha = 0.05$, and two-tailed hypothesis test.

Setting the decision rule

Where p-value is the probability value and α is the significance level.

If p-value $\leq \alpha$ the null hypothesis is rejected

If p-value $> \alpha$ there is not enough evidence to reject the null hypothesis.

Statistical calculations of hypothesis testing

The paired sample t-test was examined to determine if there were statistically significant differences between the pre- and post-test scores of the control and experimental groups.

To verify the homogeneity of the two groups and to ensure that there were no significant differences in the intellectual preparation of the students before the experiment, their scores were compared through the applied written test.

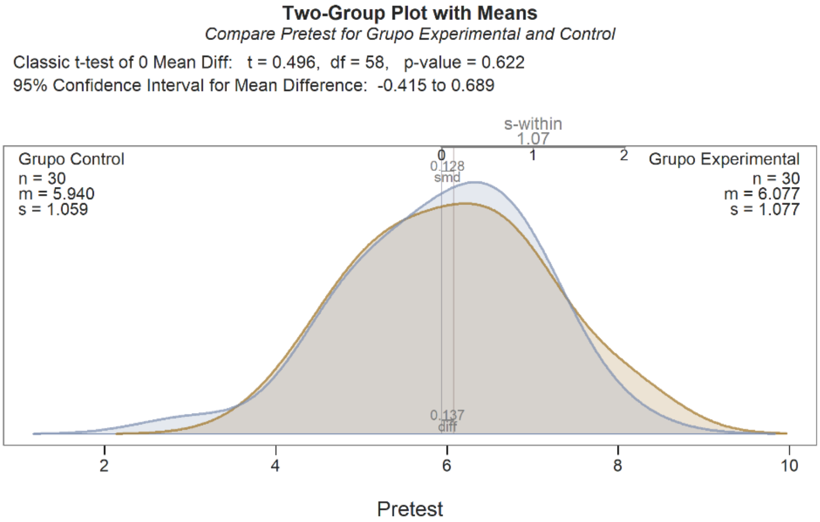

Figure 3. Comparison of means of the control and experimental group (Pretest).

The Figure 3 shows the results of the t-test of paired samples without the application of the Design Thinking methodology in the experimental group (GE) and the control group (GC). The results indicate that there are no significant differences in the means of both groups, which is confirmed by the test statistics ($t = 0.496$, p-value $0.622 > 0.05$). Since the p-value is higher than the significance level ($\alpha = 0.05$), there is not enough evidence to reject the null hypothesis.

In addition, the probability density curves have an approximately normal distribution, with a bell shape and symmetry. Both groups are within the expected range compared to the general population of high school students of the educational unit under study.

In the same way, the main findings and their interpretation of the paired sample t-test on the application of the post-test Design Thinking methodology to both the GE and the GC are presented below.

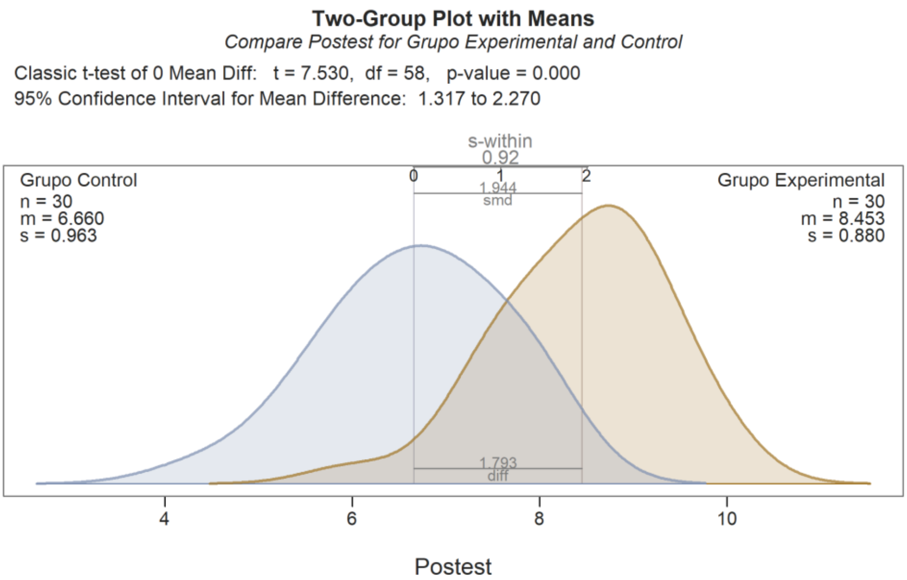

Figure 4. Comparison of means of the control and experimental group (Postest)

Figure 4 presents a comparison of the performance of the control and experimental group (postest), together with an analysis of means, which allows evaluating the impact of an intervention based on the Design Thinking methodology on the learning of circular motion. As can be seen, the experimental group that received teaching using the Design Thinking methodology registered a high score (8.453), compared to the control group that received it in a traditional way (6.660).

There is a significant difference of means in the post-test, through the test statistics ($t = 7.530$, p-value $0.000 < 0.05$) for the control and experimental groups. Since the p-value is lower than the significance level ($\alpha = 0.05$), there is enough evidence to reject the null hypothesis and accept the alternative hypothesis that is: The application of the Design Thinking methodology has a significant effect on the learning of circular motion. In addition, the confidence interval in the post-test data does not include the zero value, which confirms that the improvement in student performance is not a product of chance. This finding suggests that the didactic strategy implemented had a positive impact on the understanding of the subject.

Likewise, a reduction in the dispersion of the data in the experimental group is observed, which implies that the students not only improved on average, but their results were more homogeneous. This lower variability suggests a more consistent understanding of the content, evidencing that the participants consolidated the knowledge acquired after the intervention better.

The density curves show a shift to the right in the experimental group, confirming an improvement in the students' overall performance. The decrease in the standard deviation reinforces this interpretation, since it indicates that the scores obtained were less dispersed, reflecting more uniform learning.

The increase in the average of the experimental group suggests that the application of Design Thinking facilitated a better understanding and performance in the studied topic. Additionally, the reduction in the variability of the results suggests that the students acquired the knowledge in a more structured and uniform way.

These findings support the hypothesis of the research, demonstrating that the methodology implemented has been effective in teaching circular motion.

Once the experimentation with the teaching material was carried out, it was necessary to know the perception of the students about the experimental activities carried out, in the Figure 5 the results of the survey that was applied to the students are presented:

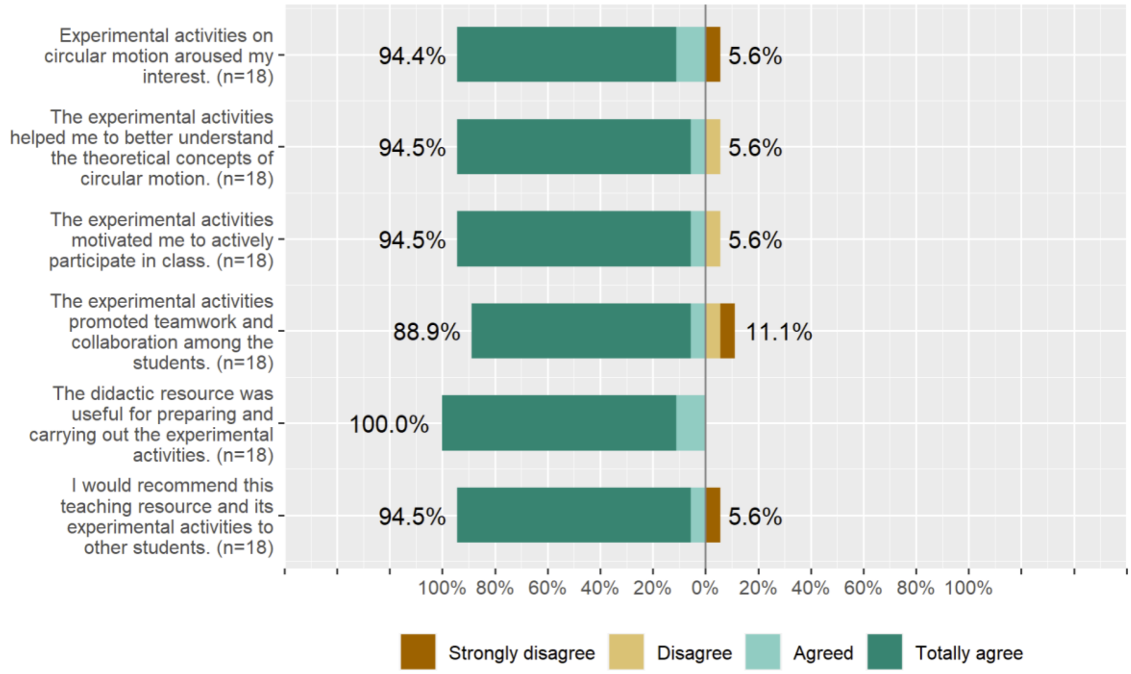

Figure 5. Student satisfaction survey.

Figure 5 presents the results of the survey applied to 18 participants on the perception of the Design Thinking methodology in the learning of circular motion.

In relation to the opinion of students about the effectiveness of the Design Thinking methodology in comparison with traditional teaching to strengthen the ability to detect problems, 94.4% of respondents stated that Design Thinking is more effective for teaching circular motion than traditional teaching.

This result indicates that the methodology used favors the development of analytical skills and the identification of problems in real contexts, promoting more meaningful and interactive learning compared to traditional approaches. In addition, it shows the importance of innovative strategies in the teaching of physics to improve the understanding and application of concepts.

Also, compared to traditional teaching, the Design Thinking method was favorable in generating creative ideas. 94.5% of the participants stated that the experimental activities helped them to better understand the theoretical concepts of circular motion. This suggests that the practical approach facilitated the connection between theory and experience, thus strengthening the construction of knowledge.

In line with the previous results, the motivation to participate in class was also significant. 94.5% of the respondents indicated that experimental activities motivated them to actively participate in class. This result reflects the effectiveness of the didactic design to promote active learning and avoid passivity in the classroom.

On the other hand, regarding teamwork and collaboration, 88.9% of the participants indicated that the Design Thinking methodology has given them more opportunities to interact with colleagues and teachers promoting cooperation among students, while 11.1% showed some reluctance. Although the majority recognized the value of collaborative learning, this result suggests that additional strategies could be implemented to reinforce interaction between students and improve group dynamics.

As for the usefulness of the teaching resource, the results were highly positive. 100% of the respondents agreed that the didactic resource was useful for the preparation and execution of the experimental activities. This finding validates the effectiveness of the material used in the teaching process and reinforces its importance within the educational context.

Finally, regarding the recommendation of the resource to other students, 94.5% of the respondents indicated that they would recommend this teaching resource and its activities to other classmates. This data confirms that the general perception of the material and the methodology is favorable, which suggests its potential replicability in other educational environments.

DISCUSSION

Design Thinking is not just an educational buzzword that has its moment in history; it is a transformative approach that equips students with the skills and mindset needed to solve complex, interdisciplinary problems. Teaching activities that integrate Design Thinking (DT) have the potential to cultivate individual skills (Liu et al., 2023).

Among the most significant results of the application of the Design Thinking method in the experimental group was the decrease in the number of students who had difficulties in differentiating between rectilinear and circular motion. The decrease in the number of students who considered an MRU and an MCU were the same. An increase in the number of students who related an MCU to contextual problems. The decrease in the complications in recognition when the acceleration was centripetal. The decrease in the number of ambiguous responses in RM and MC.

The results of this research are consistent with the study conducted by Yu et al. (2024), on the effects of Design Thinking on student learning. The meta-analytic analysis, based on 25 articles, revealed that the application of Design Thinking had a positive and significant effect on student learning ($r = 0{,}436$, $p < 0{,}001$).

The study Azizahwati et al. (2019) developed a prototype of a learning medium about uniform circular motion, based on the Arduino microcontroller. This study is related to several aspects of the Design Thinking methodology, especially in the problem definition phase, where the difficulties faced by teachers in explaining the concept of uniform circular motion were identified, as well as the limitations of the available teaching material.

The Design Thinking model successfully promoted students' creative self-efficacy, which is related to the results of the study Wei et al. (2023) where a significant difference in creative self-efficacy was found between pretest and posttest in the GE ($p = 0.002 < 0.05$), while no significant difference was observed in the CG ($p = 0.589 > 0.05$). In addition, a significant difference ($p = 0.003 < 0.05$) was found between the GE and the CG on the posttest.

From the above described for Yu et al. (2024) Design Thinking (DT) is becoming an innovative and popular teaching method. Similarly, Tu et al. (2018) points out that the adjusted Design Thinking method can improve students' participation in class, create a classroom atmosphere that attracts students, improve students' willingness to learn and increase the level of interaction between students and teachers.

In the educational field, design thinking contributes to develop students' empathy, enhances the inclusive attitude and collaborative work, and this is corroborated by what people who apply this methodology say: “they develop skills such as observation, analysis, reflection, global and critical perception, empathy, curiosity and creativity”.

In the educational field, design thinking contributes to developing students' empathy, promotes an inclusive attitude and collaborative work, and this is corroborated by Lara et al. (2023) what people who apply this methodology say: “they develop skills such as observation, analysis, reflection, global and critical perception, empathy, curiosity and creativity”.

The answers of the survey applied to the students further validate the integration of the principles of the DT method in the teaching-learning of circular motion; they attribute this to the creativity of the students, improving theoretical understanding, motivating active participation and being useful for the realization of experimental activities.

To guarantee a transition from traditional education to a student-centered one, a set of methods and strategies is needed that respond to the interests, objectives and goals of the school and that encompass the needs and interests of teachers in their teaching and students in their learning.

As a consequence of the above, experimental work in the teaching and learning of science is also important; for this reason, students were encouraged to design and develop an experimental didactic device that facilitates the learning of uniform circular motion, whose purpose was to awaken interest, imagination, motivation and, above all, that learning is centered on the student, where it is easier for him to build his own knowledge, and thus overcome the difficulties encountered.

Physics should be surrounded by practical complement that facilitates better learning (Tu et al., 2018), several authors have shown that laboratory experiments and experimental apparatus can be effectively designed by university students (Smyser et al., 2015). Physics teaching should be based on observation and experimentation that enables students to gain a specific and clear understanding of physical facts, as well as cultivate students' observation and experimentation ability, practical scientific attitude and motivation. Therefore, attention should be paid to enable students to observe relevant phenomena in teaching and vigorously strengthen physics experimental teaching.

Finally, it is worth emphasizing the fact that proper physics teaching is not enough only with the application of laboratory equipment but also requires good motivation and proper methodology so that the teacher can make the best use of the developed laboratory equipment and students can have real physics learning.

Teachers should realize that the important goal of insisting on inquiry activities is to cultivate the ability to understand science. Teachers should use various effective means to stimulate students' enthusiasm for exploration and promptly organize the exchange of information and discussion of problems among students, especially new discoveries and new ideas.

CONCLUSIONS

This study aimed to evaluate the impact of the Design Thinking methodology on the teaching and learning of circular motion in high school physics. Through a mixed-methods approach, combining quantitative and qualitative data, we assessed both the academic performance of students and their subjective experiences with the intervention. The results from the pre- and post-test performance, as well as the qualitative data collected from questionnaires and focus groups, provide compelling insights into the effectiveness of Design Thinking in improving students' conceptual understanding and engagement in physics.

Impact on Academic Performance

The quantitative analysis clearly demonstrates that the application of Design Thinking led to significant improvements in the students' understanding of circular motion. The experimental group, which received instruction using Design Thinking, showed a marked increase in post-test scores compared to the control group, which followed traditional teaching methods. The statistical significance of these differences, as indicated by the paired-sample t-test and the calculated effect size, suggests that Design Thinking is not only effective but has a considerable impact on students' ability to grasp complex physics concepts. These findings support the growing body of literature highlighting the positive effects of innovative teaching methods on student performance (Howard et al., 2021; Shiyu & Chengfeng, 2023). The observed improvements are not merely coincidental, but a direct result of the interactive, student-centered approach of Design Thinking.

Enhancement of Conceptual Understanding

One of the core objectives of this study was to improve students' understanding of circular motion, which is often seen as an abstract and challenging concept. The results suggest that the hands-on, iterative approach of Design Thinking helped bridge the gap between theoretical knowledge and practical application. By designing and building their own experimental devices, students were able to visualize and directly engage with the physical phenomena underlying circular motion. This experiential learning process facilitated a deeper understanding, as it allowed students to actively apply theoretical principles in a real-world context, reinforcing the connection between abstract concepts and practical observations. This approach aligns with educational theories that emphasize the importance of experiential learning and the active construction of knowledge (Kolb, 1984).

Increased Student Motivation and Engagement

The qualitative data, drawn from the student questionnaires and focus groups, revealed that Design Thinking significantly enhanced students' motivation and engagement in the learning process. A substantial majority of students reported feeling more interested in the subject matter, with many citing the interactive nature of the activities and the opportunity to collaborate with peers as key factors contributing to their increased motivation. These findings are consistent with previous research that has highlighted the role of active learning methodologies in promoting student engagement and intrinsic motivation (Liu et al., 2023; Wei et al., 2023). In particular, the ability to participate in the design and prototyping phases of the learning process gave students a sense of ownership over their learning, which in turn fueled their enthusiasm and curiosity.

Development of Critical Thinking and Problem-Solving Skills

Another important outcome of the study is the development of students' critical thinking and problem-solving skills. Through the stages of Design Thinking—empathize, define, ideate, prototype, and test—students were encouraged to approach the problem of understanding circular motion from multiple perspectives, think creatively, and generate innovative solutions. This iterative process of problem-solving, coupled with the collaborative nature of the methodology, enabled students to develop key skills such as critical analysis, collaboration, and creativity, which are essential in today's rapidly evolving world. By integrating these skills into the learning of scientific concepts, the study not only contributed to students' academic success but also helped prepare them for the challenges they will face in their future careers and daily lives.

Limitations of the Study

While the findings of this study are promising, there are several limitations that should be considered. First, the sample size, while adequate for the purposes of this study, was relatively small and drawn from a single educational institution. Future research should replicate this study in a broader range of schools and with larger sample sizes to enhance the generalizability of the results. Additionally, the study focused exclusively on the learning of circular motion in physics, and it remains unclear whether Design Thinking would have the same impact on other areas of the curriculum. Further investigations could explore the applicability of this methodology across different subjects and educational levels, as well as its long-term effects on students' conceptual retention and critical thinking abilities.

Implications for Teaching Practice

The findings of this study have significant implications for teaching practice, particularly in the context of STEM education. The success of the Design Thinking methodology in this study suggests that it should be considered as a viable alternative to traditional teaching methods, particularly for subjects that require deep conceptual understanding and active engagement. Incorporating Design Thinking into the curriculum allows teachers to create more interactive, student-centered learning environments, where students are not passive recipients of knowledge but active creators of their learning experience. This shift towards student-centered pedagogy is essential for fostering the development of critical skills such as creativity, collaboration, and problem-solving, which are increasingly important in the modern workforce.

Recommendations for Future Research

Based on the findings of this study, several avenues for future research emerge. One key area of exploration is the potential for integrating Design Thinking into interdisciplinary teaching. Given the collaborative and problem-solving nature of Design Thinking, it could be beneficial to explore how this methodology can be applied across different subject areas, encouraging students to apply their learning in more holistic, real-world contexts. Furthermore, future studies should examine the impact of Design Thinking on long-term learning outcomes, such as retention of knowledge and the ability to apply concepts to novel problems. Finally, further research could investigate the challenges faced by teachers in implementing Design Thinking, particularly in terms of curriculum adaptation, resource availability, and professional development needs.

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