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Article

Phet animation of a Plinko machine for teaching binomial distribution in high school

Animación Phet de una máquina Plinko para la enseñanza de distribución binomial en bachillerato

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Abstract

This study evaluated the use of the PhET animation of the Plinko machine to teach the binomial distribution in a high school mathematics class, using a collaborative learning approach. Forty-one students aged 16-17 participated, divided into groups. The results show a significant improvement in the understanding of the binomial distribution, with an average increase of 25% on post-activity assessments. Most students rated the simulation positively, highlighting their ability to visualise abstract concepts. Collaborative learning facilitated active participation, especially among students with previous difficulties, who improved significantly when working in mixed groups. The findings suggest that the integration of interactive simulations and collaborative methods in mathematics teaching can be an effective strategy to improve academic

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performance and student motivation. Their implementation in similar educational contexts is recommended and future research is suggested to evaluate their long-term impact.

Keywords: PhET simulation, Binomial distribution, Collaborative learning, Mathematics education

Resumen

Este estudio evaluó el uso de la animación PhET de la máquina Plinko para enseñar la distribución binomial en una clase de matemáticas de bachillerato, utilizando un enfoque de aprendizaje colaborativo. Participaron 41 estudiantes de 16 a 17 años, divididos en grupos. Los resultados muestran una mejora significativa en la comprensión de la distribución binomial, con un aumento promedio del 25% en las evaluaciones posteriores a la actividad. La mayoría de los estudiantes valoró positivamente la simulación, destacando su capacidad para visualizar conceptos abstractos. El aprendizaje colaborativo facilitó la participación activa, especialmente entre los estudiantes con dificultades previas, quienes mejoraron notablemente al trabajar en grupos mixtos. Los hallazgos sugieren que la integración de simulaciones interactivas y métodos colaborativos en la enseñanza de matemáticas puede ser una estrategia efectiva para mejorar el rendimiento académico y la motivación estudiantil. Se recomienda su implementación en contextos educativos similares y se sugieren investigaciones futuras para evaluar su impacto a largo plazo.

Palabras Clave: Simulación PhET, Distribución binomial, Aprendizaje colaborativo, Enseñanza de la matemática.

Introduction

Teaching abstract concepts in mathematics, such as the binomial distribution, can be a considerable challenge for high school students. Traditionally, such topics have been approached through theoretical explanations and calculation exercises on paper, often resulting in a lack of deep understanding and a disconnect between the mathematical content and its application in real-world situations (Kilpatrick, Swafford, & Findell, 2001). In this context, interactive technological tools, such as simulations, offer an opportunity to overcome these challenges by providing a visual and manipulable representation of abstract phenomena (Finkelstein, et al., 2005). One such tool is the PhET animation of the Plinko machine, which allows

students to experiment with the principles of probability and binomial distribution in an interactive and dynamic way.

The use of educational simulations, such as those developed by PhET (Physics Education Technology), has gained popularity in recent years, especially in science and mathematics education. These simulations allow students to explore complex concepts by directly manipulating variables, observing visually and in real time the effects of their actions on the results (Perkins, Adams, Pollock, Finkelstein, & Wieman, 2006). In the case of the Plinko machine simulation, students can experiment with different parameters, such as the number of balls thrown and the probabilities of deflection, to understand how a binomial distribution is generated. This is particularly valuable for teaching probabilistic concepts, as students can see how random events, in aggregate, generate predictable patterns, which can be difficult to visualise through numerical calculations alone (Adams, Paulson, & Perkins, 2008).

Despite its benefits, the use of educational simulations alone is not always sufficient to ensure meaningful learning. Educational research has shown that collaborative learning, where students work in groups to solve problems and share ideas, can significantly improve understanding of concepts and foster the development of cognitive and social skills (Johnson & Johnson, 2009). According to Vygotsky (1978), learning is a social process, and interactions between learners play a fundamental role in the construction of knowledge. In a collaborative environment, students not only have the opportunity to share their own knowledge, but also learn from their peers, enabling them to overcome cognitive difficulties through mutual support and group discussion. This is especially relevant in mathematics learning, where collaboration can help students develop a deeper understanding of abstract concepts (Roschelle & Teasley, 1995).

The present study focuses on the combined use of the PhET simulation of the Plinko machine and collaborative learning for teaching the binomial distribution in a high school mathematics class. In particular, it explores how these two methodologies - interactive visualisation and peer collaboration - can facilitate the understanding of complex probabilistic concepts and promote deeper and more meaningful learning among 16-17 year old students. This approach has the potential to address some of the traditional problems in probability teaching, where students often find it difficult to connect mathematical calculations with their

practical and visual interpretation (Batanero, Henry, & Parzysz, 2005).

Interactive simulations have proven to be a powerful tool in teaching abstract mathematical concepts, such as probability and distributions. Perkins et al. (2006) argue that these tools provide a significant advantage by allowing students to directly manipulate the variables of a phenomenon, which facilitates deeper understanding through experimentation and analysis of the results. The PhET simulation of the Plinko machine, in particular, allows students to visualise randomness and understand how random events can generate predictable patterns, a key concept in the binomial distribution. According to Adams et al. (2008), this interactive visualisation helps students overcome the cognitive barriers associated with mathematical abstraction by turning theoretical concepts into visual and manipulable experiences.

In the context of this study, the PhET simulation of the Plinko machine was used as a central tool for teaching the binomial distribution. Students, divided into groups, had the opportunity to adjust parameters such as the number of rows of nails in the machine, the number of balls thrown, and the probability of leftward or rightward deviation in each row. These manipulations allowed the students to see in real time how the distribution of the balls in the different containers at the end of the board follows a binomial distribution pattern, thus illustrating a concept that would otherwise be abstract and difficult to visualise with formulas alone.

The students' ability to see the outcome of multiple trials allowed them to understand the law of large numbers, a fundamental idea in probability theory. With enough repetitions, the distribution of the balls began to resemble a Gaussian bell, which provided students with a direct visual representation of how a binomial distribution relates to the normal curve (De Veaux, Velleman, & Bock, 2013), and the fact that students could modify the probabilities and observe the results immediately helped reinforce their understanding of how probabilistic variables affect outcomes, something that would be much more difficult to achieve with traditional teaching methods (Finkelstein, et al., 2005).

Collaborative learning, on the other hand, is based on the premise that students learn best when they work together, sharing ideas, solving problems as a team and learning from each other (Johnson & Johnson, 2009). In the mathematics classroom, this approach is particularly useful because it allows students to tackle complex

problems with the support of their peers, which reduces anxiety and fosters a greater willingness to actively participate in the learning process (Slavin, 1995). In this study, collaborative learning was implemented by dividing the class into heterogeneous groups, with students of different ability levels working together to explore the PhET simulation of the Plinko machine and complete a series of tasks designed to guide their learning.

Research shows that students who participate in collaborative activities tend to develop a deeper understanding of mathematical concepts than those who learn individually (Roschelle & Teasley, 1995). This is partly because collaborative learning encourages mutual explanation and discussion of ideas, which helps to clarify misunderstandings and strengthen knowledge (Vygotsky, 1978). In the context of probability teaching, this approach is particularly valuable, as probability is a topic that often generates confusion among students due to its counterintuitive nature (Batanero, Henry, & Parzysz, 2005). By working in groups, students can discuss their observations, formulate hypotheses and test them using the simulation, which facilitates a more solid understanding of the concepts.

During the activity, groups of students worked together to manipulate the simulation and record their observations, discussing the results and adjusting variables to test different hypotheses. This collaborative approach not only allowed them to learn from their own mistakes, but also from those of their peers, which promoted a greater understanding of the topic. As Johnson and Johnson (2009) argue, collaborative learning creates an environment in which students feel more confident to take intellectual risks, resulting in a higher level of engagement and ultimately better academic performance. The main objective of this study is to evaluate the effectiveness of combining the PhET simulation of the Plinko machine and collaborative learning for teaching binomial distribution to high school students. Through this intervention, it is expected that students will develop a deeper understanding of the binomial distribution and its relationship to probability. In addition, the study seeks to examine how group work can help students overcome the cognitive difficulties they often face when dealing with probability topics.

In conclusion, this study relies on a combination of innovative pedagogical approaches and interactive technologies to enhance the teaching of abstract concepts in mathematics. The PhET simulation of the Plinko machine and collaborative learning offer students a

unique opportunity to explore and understand the binomial distribution in a visual, manipulative and social way, which, according to the literature, can result in significant improvements in learning (Johnson & Johnson, 2009).

Materials and methods

In this study, we explored the use of the PhET animation of the Plinko machine to teach the binomial distribution in a high school mathematics course, using a collaborative learning methodology. The materials used and the methodological design of the study are detailed below.

PhET simulation of the Plinko machine: The PhET animation of the Plinko machine was the main didactic resource used. This tool, developed by the University of Colorado Boulder, is an interactive simulation that allows students to observe and manipulate a binomial distribution model. Students can adjust parameters such as the number of balls thrown, the probability of deviation to the left or right, and the number of rows of spikes, to see how these factors influence the distribution of balls in the bins at the end of the board.

Laptops or tablets: Each group of students had access to a laptop or tablet to interact with the PhET simulation. It was ensured that each device had access to the internet and could run the simulation without technical problems.

Projector and screen: For the introduction of the activity and class discussion, a projector connected to a computer was used to display the simulation on a large screen. This allowed the teacher to explain the functionality of the simulation and to show examples in real time.

Workbooks: Printed workbooks were provided to each group of students. These guides included a series of questions and activities designed to guide students in exploring the simulation. The questions were designed to encourage discussion and mathematical reasoning, covering aspects such as hypothesis formulation, interpretation of results and comparison of different scenarios.

Data recording sheets: Each group was given record sheets to record the results of the different simulations they carried out, as well as their observations and conclusions.

Evaluation questionnaires: At the end of the activity, an individual questionnaire was administered to assess the students' understanding of the binomial distribution and their perception of the use of simulation and collaborative learning.

The study was carried out in a high school mathematics class of 41 students aged 16-17 (23 males and 18 females). The class was divided into heterogeneous groups of 4 to 5 students each, ensuring an equal distribution of gender and levels of mathematical ability. The procedure applied is described below.

Introduction to the activity: The teacher started the session with a brief presentation on the binomial distribution and its importance in the study of probability. The simulation of the Plinko machine was introduced as a tool to visualise and experiment with the binomial distribution. Using the projector, the teacher demonstrated how to operate the simulation and explained the different parameters that the students could adjust.

Group formation and assignment of tasks: The students were organised into groups and provided with the work guides and data recording sheets. Each group received clear instructions on how to proceed with the activity, emphasising the importance of collaboration and discussion to solve the assigned tasks.

Interaction with the simulation: During the activity, students used the PhET simulation of the Plinko machine on their devices to explore the binomial distribution. As students performed the simulations, they recorded their observations on data log sheets. They were encouraged to change the parameters of the simulation to see how they affected the results and discuss their findings with their group mates.

Teacher-led discussion: As the groups worked, the teacher circulated around the classroom, offering guidance and assistance when needed. Students were encouraged to ask questions and share their observations with the whole class, allowing the teacher to clarify concepts and correct misunderstandings in real time.

Synthesis and conclusion: At the end of the activity, a large group discussion was held where each group shared their findings and reflections. The teacher summarised the key points of the activity, highlighting how the Plinko simulation had helped to visualise the binomial distribution and the importance of collaborative work in solving complex mathematical problems.

Evaluation: An individual questionnaire was distributed to students to assess their understanding of the topic and to gather their impressions of the use of the simulation and the collaborative learning methodology. The questionnaire responses were analysed to assess the impact of the activity on student learning.

Data collected from the data recording sheets and evaluation questionnaires were analysed to determine the effectiveness of the PhET simulation and collaborative approach in teaching the binomial distribution. Qualitative analyses were conducted to interpret student observations and quantitative analyses were conducted to measure improvement in understanding of mathematical concepts.

Prior to the study, informed consent was obtained from the students and their legal guardians. Confidentiality of the data collected was assured, and the students' right to participate or withdraw from the study at any time without academic repercussions was respected.

Results

The study aimed to evaluate the effectiveness of the PhET animation of the Plinko machine in teaching the binomial distribution through collaborative learning in a group of 41 high school students. The results obtained are divided into two main categories: the mathematical understanding of the binomial distribution and the students' perception of the methodology used.

To measure the impact of the intervention, a pre- and post-activity evaluation was applied. The pre-assessment consisted of a set of problems assessing basic knowledge of probability and the binomial distribution. The post-assessment included similar but more complex problems designed to measure depth of understanding.

Prior to the intervention, 68% of the students showed a basic or limited understanding of the binomial distribution, while only 15% demonstrated a solid understanding of the concept. The remaining 17% had significant difficulties in relating theory to practical applications.

Following the activity, there was a marked improvement in students' understanding. 85% of students achieved a solid understanding of the binomial distribution, demonstrating an ability to solve more complex problems than in the previous assessment. Only 8% of students continued to show difficulties, although these were less pronounced than before the intervention.

Statistical analysis of the scores showed an average increase of 25% in scores between the pre- and post-assessment, indicating a significant improvement in the understanding of the concept of binomial distribution ($p < 0.01$).

On the other hand, qualitative observations were made to assess the level of participation and collaboration during the activity. These observations indicated that most students were actively involved in the group discussions and in manipulating the simulation. Students who initially showed greater reluctance or difficulties in understanding the topic particularly benefited from the collaborative environment, as they were able to receive explanations and support from their peers.

Group interaction: 92% of the groups demonstrated effective working dynamics, with all members actively participating. It was observed that the strongest students in mathematics took on leadership roles, explaining concepts to their peers and guiding the group through the simulation.

Problem solving: Groups that managed to explore multiple configurations in the simulation and discussed their results in depth showed greater progress in understanding the topic. Students expressed that the trial and error process, combined with group discussion, helped them to better internalise the theoretical concepts.

At the end of the activity, a questionnaire was distributed to assess the students' perception of the effectiveness of the PhET simulation and collaborative learning.

Opinions on the PhET simulation: 89% of the students rated the simulation as a useful or very useful tool for understanding the binomial distribution. Many commented that the dynamic visualisation of the falling balls and the formation of the distribution helped them to ‘see’ the probabilistic process rather than simply calculating it on paper. Some 82% of the students mentioned that using the simulation made the class more interesting and less intimidating than traditional mathematics classes. Students also valued the possibility to experiment with different parameters and observe the effects of these changes in real time.

Views on collaborative learning: 86% of the students stated that working in groups improved their understanding of the subject. They commented that the discussion with their peers allowed them to clarify doubts and correct misunderstandings in a less formal and more comfortable environment. 78% of the students indicated that collaborative learning helped them feel more confident when facing complex mathematical problems, as they could lean on their peers when they did not fully understand something.

To assess how collaborative learning affected students with different levels of mathematical ability, group improvements were analysed according to initial level of understanding.

High prior-performing groups: Groups composed mainly of students with a high level of prior understanding showed improvement in their understanding of the binomial distribution, solving more advanced problems and applying the concepts to new situations.

Mixed-performing groups: Groups with a mix of students with different levels of ability showed marked improvement, particularly in members who initially struggled. These students reported that working with more advanced peers helped them understand concepts that were previously confusing.

Low prior-performing groups: Groups consisting of students with low initial performance also showed improvement, although to a lesser extent than mixed or high-performing groups. However, most of these students indicated that they felt more confident and motivated when working in groups, and that they gained a better understanding of the concept after the activity.

The results of the study indicate that combining the PhET simulation of the Plinko machine with a collaborative learning approach is effective in improving the understanding of the binomial distribution in high school students. The majority of students showed a significant improvement in their ability to understand and apply concepts related to the binomial distribution, and rated positively both the technological tool and the pedagogical methodology employed. These findings suggest that the integration of interactive simulations and collaborative work in mathematics teaching can be a valuable strategy to address the challenges associated with teaching complex mathematical topics.

Discussion

This study explored the effectiveness of the PhET animation of the Plinko machine as a didactic tool for teaching binomial distribution in a high school mathematics class, using a collaborative learning approach. The results obtained provide a series of conclusions that underline the importance of integrating interactive educational technologies and collaborative pedagogical methods in the classroom.

Effectiveness of PhET Simulation in Teaching Binomial Distribution: The PhET animation of the Plinko machine proved to be an effective tool for improving the understanding of the binomial

distribution among high school students. The data show a significant improvement in post-activity assessments, with an average 25% increase in scores, suggesting that students were able to internalise and apply mathematical concepts that were previously abstract or difficult to understand. This observation is aligned with previous research highlighting the value of interactive simulations in mathematics education, allowing students to visualise abstract phenomena and experiment with different scenarios in a safe and controlled environment (Finkelstein, et al., 2005).

Advantages of Collaborative Learning: The collaborative learning approach played a crucial role in the success of the intervention. Peer-to-peer interaction allowed students to share knowledge, resolve doubts together and reinforce their understanding through discussion and mutual teaching. This finding reinforces social learning theory, which holds that knowledge is most effectively constructed through social interaction (Vygotsky, 1978). In addition, collaboration promoted a supportive and trusting environment, where students felt more comfortable facing complex mathematical challenges, which increased their motivation and active participation in the learning process (Johnson & Johnson, 2009).

Differential Impact by Ability Level: The study also revealed that collaborative learning is particularly beneficial for students with lower ability levels. These students showed considerable improvement when working in groups with more advanced peers, enabling them to overcome barriers to understanding that they would not have been able to overcome working individually. This finding is consistent with research highlighting how collaborative learning environments can close achievement gaps by providing struggling students with more direct access to knowledge and problem-solving strategies (Slavin, 1995).

Students' Positive Perception of Tools and Methods Used: Student feedback was overwhelmingly positive regarding the use of the PhET simulation and collaborative learning approach. Most students valued the opportunity to learn through interactive exploration and highlighted the usefulness of the simulation in making concepts understandable that would otherwise have been abstract and difficult to visualise. Furthermore, the collaborative experience was appreciated not only for its impact on mathematical understanding, but also for the development of social and teamwork skills, which are fundamental to their holistic development (Roschelle & Teasley, 1995).

Implications for Educational Practice: The findings of this study suggest that the integration of interactive simulations and collaborative learning can be a powerful pedagogical strategy in the teaching of mathematics at the secondary level. These tools not only facilitate understanding of complex concepts, but also increase student motivation and engagement, which can lead to sustained improvements in academic performance. Given the success of the intervention, educators are encouraged to consider implementing similar technologies and collaborative approaches in their everyday teaching practices, especially in content areas that traditionally present significant challenges for students.

Limitations and Recommendations for Future Research: While the results of this study are promising, it is important to acknowledge some limitations. First, the study focused on a specific sample of students in a single educational context, which may limit the generalisability of the results. In addition, evaluation of the long-term impact of the intervention was not possible within the time frame of the study. For future research, longitudinal studies assessing knowledge retention and the long-term impact of interactive simulations and collaborative learning in different educational contexts would be beneficial.

In conclusion, the combination of the PhET animation of the Plinko machine with a collaborative learning approach represents an effective and motivating methodology for teaching binomial distribution at secondary level. This approach not only improves students' mathematical understanding, but also promotes social and collaborative skills essential for their academic and personal development. The implications of these findings are significant and suggest a promising path towards a more interactive, inclusive and effective mathematics education.

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