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Development of "galton sriwijaya board" teaching aid to support students' conceptual understanding of normal distribution

Yudha Mahendra, Tirta Sari Sapitri, Revalina Apriliani Saputri, Rafika Sari, Nashifah Aqilah, Rahma Siska Utari*, Ratu Ilma Indra Putri, Novita Sari, Yovika Sukma
Program Studi Pendidikan Matematika, Universitas Sriwijaya, Palembang, Indonesia
*rahmasiskautari@fkip.unsri.ac.id

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Abstract

This study aims to develop the "Galton Sriwijaya Board" teaching aid to support students' conceptual understanding of the normal distribution. The background of this research is the difficulty students experience in understanding abstract statistical concepts, particularly the normal distribution and the central limit theorem, when learning is limited to theoretical explanations. This study employed a design research approach based on Tessmer's formative evaluation model, comprising preliminary, self-evaluation, expert review, one-to-one, and small-group stages. The participants were first-semester students of Mathematics Education selected through purposive sampling. Data were collected through students' LKPD responses to analyze conceptual understanding, observations, and interviews to identify students' learning processes and difficulties, and practicality questionnaires to evaluate the usability of the developed teaching aid. Students' conceptual understanding was analyzed descriptively using two indicators: interpreting experimental results and generalizing the characteristics of a normal distribution. The results show that the developed teaching aid was validated by two lecturers in the Mathematics Education Study Program who teach Mathematical Statistics, and was categorized as practical based on student responses. In addition, students were able to interpret the results of the Galton Sriwijaya Board experiment and identify the formation of a bell-shaped distribution pattern from repeated random trials. The findings indicate that the "Galton Sriwijaya Board" is valid and practical and provides opportunities for students to construct their understanding of normal distribution through hands-on learning activities. The study suggests that the teaching aid has the potential to be implemented in broader learning contexts and further developed into digital-based learning media.

Keywords: Conceptual Understanding; Galton Sriwijaya Board; Normal Distribution; Teaching Aid

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INTRODUCTION

Statistics plays an important role in education because it supports the measurement of learning outcomes, the analysis of educational research data, and evidence-based decision making. In the context of Industry 4.0 and big data, the ability to process, interpret, and critically evaluate statistical information has become an essential competency for students and prospective teachers (Gacula, 2025; Juarros-Basterretxea et al., 2024; Ritonga et al., 2025).

Statistical literacy involves not only the ability to perform statistical calculations but also the ability to interpret statistical information and understand its meaning in various contexts (Mahmood et al., 2024). Therefore, statistics learning should emphasize the development of students' conceptual understanding, particularly in higher education, where mathematics education students are expected to master statistical concepts and develop the ability to teach data literacy in schools (Pinahayu et al., 2022; Videla-Jiménez, P., Ruz, F. & López-Martín, 2025). Conceptual understanding is a fundamental component of statistics learning because students need to comprehend the meaning behind statistical procedures and recognize relationships among statistical concepts rather than merely applying formulas procedurally (Puspito, 2026; Wulantina et al., 2025). In this study, conceptual understanding refers to students' ability to connect experimental observations with the underlying concept of normal distribution. Specifically, conceptual understanding is examined through two aspects: (1) students' ability to interpret the results of random experiments using the Galton Sriwijaya Board, and (2) students' ability to generalize the characteristics of normal distribution based on experimental data. These aspects reflect students' ability to relate random processes to distribution patterns and construct meaningful interpretations of statistical phenomena.

However, students still experience difficulties in developing conceptual understanding of statistical concepts. Previous studies indicate that many students have difficulty connecting statistical concepts with real-world situations and interpreting statistical information meaningfully (Martiasari & Kelana, 2022). One of the statistical concepts that is often considered difficult to understand is normal distribution (Syarifuddin, 2025). Students frequently perceive normal distribution merely as a bell-shaped graph rather than as a probability model that emerges from repeated random processes (Rizki et al., 2026). This misconception indicates that students need learning experiences that allow them to observe and construct the concept of normal distribution directly.

Normal distribution is a fundamental concept in statistics because it serves as the basis for various inferential statistical procedures and applications involving data analysis and prediction (Saputri et al., 2024; Verlage et al., 2025). Nevertheless, many students still struggle to understand why repeated random events can produce a bell-shaped distribution pattern . This difficulty is often caused by learning approaches that emphasize mathematical procedures and formulas without providing sufficient opportunities for visualization and exploration of statistical phenomena.

One approach that can support students' understanding of abstract statistical concepts is the use of manipulative learning media (Puspito et al., 2026). Previous studies have shown that concrete learning experiences and visualization-based media can facilitate students in constructing mathematical concepts and reducing misconceptions (Setiawan et al., 2023; Wijayanti & Juandi, 2024). One example of manipulative media used to visualize statistical concepts is the Galton Sriwijaya Board, also known as the Quincunx or Bean Machine, which demonstrates how repeated random processes can generate a distribution pattern approaching a normal distribution.

However, existing Galton Sriwijaya Board teaching aids are generally designed as probability demonstrations without emphasizing contextualized learning experiences that connect the experimental process with students' conceptual understanding of normal distribution. Therefore, this study develops the "Galton Sriwijaya Board" by incorporating the local identity of Sriwijaya through the development context at Universitas Sriwijaya, where the teaching aid was designed and implemented, while integrating structured LKPD activities to guide students in interpreting experimental results and generalizing the characteristics of normal distribution.

Although several studies have explored the use of manipulative media and simulation activities in statistics learning, studies focusing on the development of contextual teaching aids specifically designed to support students' conceptual understanding of normal distribution remain limited. Therefore, this study aims to develop the "Galton Sriwijaya Board" as a teaching aid to support students' conceptual understanding of normal distribution. This study also evaluates the validity and practicality of the developed teaching aid through a design research approach.

METHODS

This study employed an Educational Design Research (EDR) approach to develop the "Galton Sriwijaya Board" as a valid and practical teaching aid to support students' conceptual understanding of normal distribution. EDR was selected because it focuses on the systematic development and evaluation of educational products through iterative processes involving analysis, design, implementation, and refinement (Bakker, 2018; McKenney & Reeves, 2020). In this study, the research procedure followed Tessmer's formative evaluation model, which consists of preliminary and prototyping stages. The prototyping stage included self-evaluation, expert review, one-to-one evaluation, and small group evaluation (Easterday et al., 2018;

Tessmer, 1993). However, this study was limited to the prototyping stage because the main purpose was to evaluate the initial validity and practicality of the developed teaching aid before broader implementation. Therefore, the research focused on identifying weaknesses, obtaining expert feedback, and examining students' responses during small-scale trials (Mertasari & Candiasa, 2022; Tessmer, 1993).

The participants were first-semester students of the Mathematics Education Study Program at Universitas Sriwijaya. They were selected through purposive sampling based on their diverse mathematical abilities to obtain varied responses during the formative evaluation process (Sugiyono, 2023). The one-to-one stage involved three students representing high, medium, and low levels of mathematical ability, while the small group stage involved six students divided into two groups. The LKPD and teaching aid were validated by two lecturers from the Mathematics Education Study Program at Universitas Sriwijaya who teach Mathematical Statistics. Their expertise was relevant for evaluating the accuracy of normal distribution concepts, the alignment between learning activities and conceptual understanding indicators, and the clarity of instructional language. The validation results were used as the basis for revising the LKPD and teaching aid before student implementation.

Students' conceptual understanding was analyzed using worksheet-based tasks (LKPD) designed as an assessment instrument. Students' responses in the LKPD were analyzed by the researchers based on the predetermined conceptual understanding indicators to identify students' levels of conceptual understanding. The responses were categorized into three categories of conceptual understanding: correct understanding, partial understanding, and misconception. The LKPD was developed based on two indicators of conceptual understanding: (1) the ability to interpret the results of random experiments using the Galton Sriwijaya Board, and (2) the ability to generalize the characteristics of the normal distribution based on experimental data.

Data were collected through LKPD responses, observations, interviews, and practicality questionnaires. Observations and interviews were used to capture students' learning processes and difficulties during the implementation of the teaching aid, while questionnaires were used to measure practicality in terms of usability and clarity. The stages of the research are presented in Table 1.

Table 1. Stages of Design Research of the Development Study model by Tessmer

No	Stage	Description
1	Preliminary	Literature review, identification of materials and subject requirements, identification of games with cultural contexts relevant to normal distribution materials, and instrument design.
2	Self Evaluation	Independent evaluation of instruments (student worksheets and teaching aids).
3	Expert Review	Instrument validation by expert review in terms of content, construct, and language suitability with mathematical modeling.
4	One to One	Testing on three students with different individual ability levels to obtain initial feedback and identify weaknesses in the instrument.
5	Small Group	Testing of the revised instrument on six students divided into two groups to measure practical aspects including ease of operation, visual appeal, applicability, and usability.

Data analysis used descriptive qualitative and quantitative approaches. Qualitative analysis was conducted by reviewing students' answers, identifying patterns of understanding and misconceptions, and interpreting the learning process from observations and interviews. Quantitative analysis was conducted using practicality questionnaires. The practicality percentage was calculated using the following formula:

$$P(s) = \frac{S}{N} \times 100\%$$

where P is the practicality percentage, T is the total score obtained from the questionnaire responses, and N is the maximum possible score.

Based on this formula, the practicality percentage obtained was then adjusted to the practicality category criteria in Table 2.

Table 2. "Galton Sriwijaya Board" Practicality Category Criteria

Score Interval	Practicality Category
80% ≤ Score ≤ 100%	Very Practical
60 % ≤ Score < 80%	Practical
40 % ≤ Score < 60%	Fairly Practical
20 % ≤ Score < 40%	Less Practical
0 % ≤ Score < 20%	Not Practical

Students' conceptual understanding achievement was analyzed based on their responses to the LKPD during the small group stage. The analysis focused on two indicators: (1) students' ability to interpret the results of random experiments using the Galton Sriwijaya Board, and (2) students' ability to generalize the characteristics of normal distribution based on experimental results. Each response was assessed using a scoring rubric based on these indicators. The achievement percentage of each indicator was calculated using the following formula:

$$CA = \frac{S}{M} \times 100\%$$

where CA represents the conceptual understanding achievement percentage, S represents the total score obtained by students, and M represents the maximum possible score. The obtained percentages were then interpreted based on the achievement category criteria to determine the level of students' conceptual understanding.

RESULTS AND DISCUSSION

Preliminary Stage

At the preliminary stage, the researchers conducted a needs analysis and literature review to design the "Galton Sriwijaya Board" for learning the concept of normal distribution. The analysis indicated that students experienced difficulties in understanding the normal distribution due to its abstract representation and reliance on theoretical explanations. Based on these findings, a manipulative teaching aid was developed to visualize the formation of the normal distribution through repeated marble-drop experiments.

Prototyping Stage

The prototyping stage followed a formative evaluation framework consisting of self-evaluation, expert review, one-to-one evaluation, and small group evaluation. This stage focused on improving the design of the "Galton Sriwijaya Board" and ensuring its validity and practicality in supporting learning activities.

Self-Evaluation

At this stage, the initial prototype of the "Galton Sriwijaya Board" was developed, including the pinboard structure, marble materials, containers, usage instructions, and LKPD. The design was internally reviewed to ensure alignment between the media structure and the learning objectives of normal distribution.

Expert Review

The "Galton Sriwijaya Board" and LKPD were validated by two lecturers from the Mathematics Education Study Program at Universitas Sriwijaya who teach Mathematical Statistics. The validation aimed to evaluate the quality of the developed teaching aid and LKPD based on three aspects: content accuracy, construct alignment with conceptual understanding indicators, and language clarity. The validation results are presented in Table 3.

Table 3. Expert Validation Results of the "Galton Sriwijaya Board" and LKPD

Validation Aspect	Validator 1	Validator 2	Average Percentage	Category
Content accuracy	87%	88%	87.5 %	Very Valid
Construct alignment	88%	89%	88.5%	Very Valid
Language clarity	89%	90%	89.5%	Very Valid
Overall	88%	89%	88.5%	Very Valid

The expert validation results showed that the "Galton Sriwijaya Board" and LKPD achieved an average validity percentage of 88.5%, which was categorized as very valid. The content accuracy aspect obtained an average score of 87.5%, indicating that the materials and statistical concepts presented in the teaching aid were appropriate. The construct alignment aspect reached 88.5%, demonstrating that the learning activities were aligned with the indicators of conceptual understanding. Meanwhile, the language clarity aspect obtained the highest average score of 89.5%, showing that the instructions and explanations in the LKPD were clear and understandable. Based on the experts' suggestions, several revisions were conducted, including improving the pin arrangement, strengthening the container structure, and refining the wording of LKPD instructions before the implementation stage.

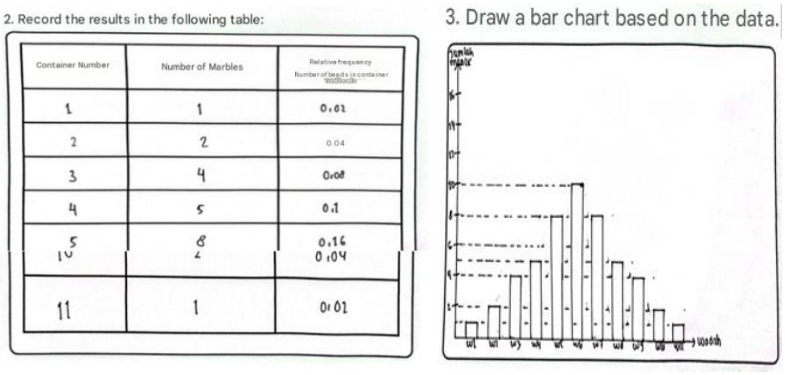
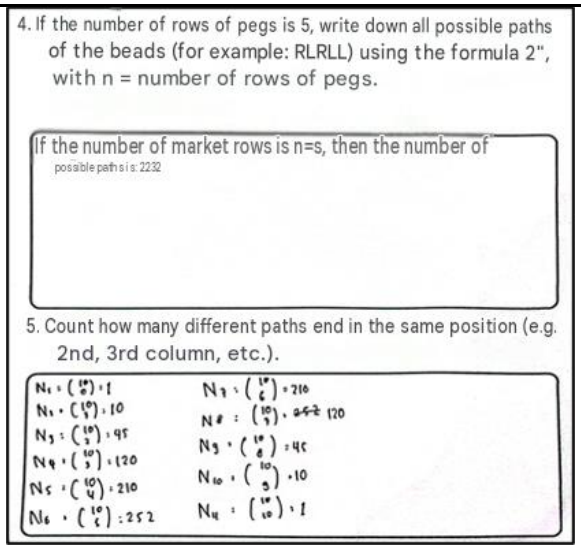
One-to-One

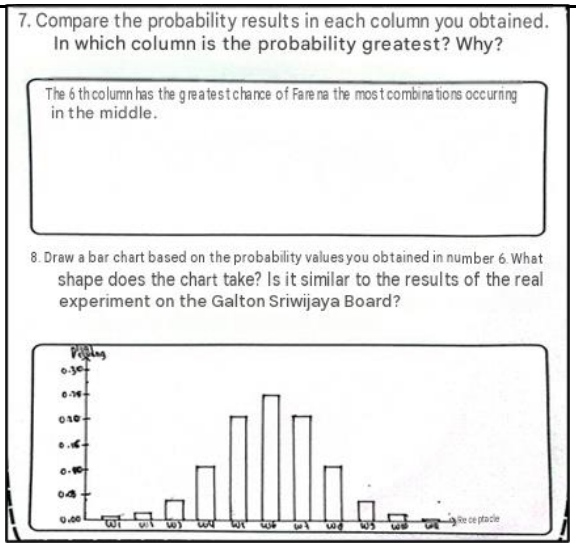
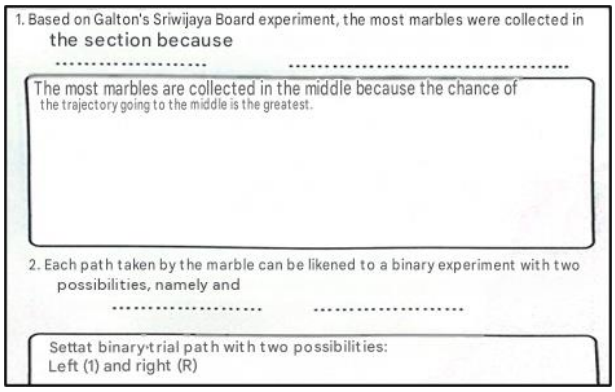
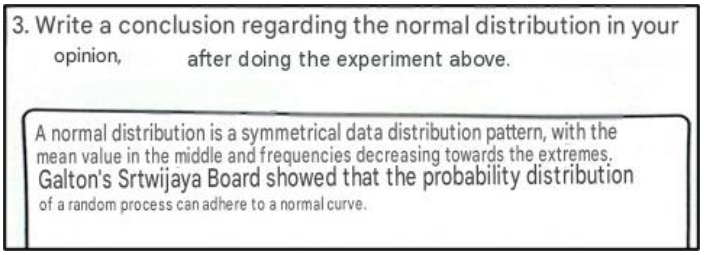
In the one-to-one stage, the prototype was tested on three students with different ability levels (high, medium, and low). The focus of this stage was to observe how students interacted

with the "Galton Sriwijaya Board" and how the media supported their understanding of the normal distribution concept.

Students conducted marble-drop experiments using the board and observed the resulting distribution pattern. The results of their observations were recorded in LKPD in the form of tables and bar charts. Students were able to connect the experimental process with the emergence of a bell-shaped distribution. Table 4 shows examples of students' responses in the LKPD during this stage.

Table 4. Results of the One-to-One Student Worksheet (LKPD) answers.

Example of LKPD Answers	Description
	Students were able to record the experimental results and represent the number of marbles in each container using bar charts correctly.
	The subjects were able to answer question 4 correctly, but they were a little confused about how to answer question 5. The researcher provided an explanation beforehand so that they would be able to answer correctly.

Example of LKPD Answers	Description
  	The subject can explain the reasons for their answers accurately. The subject can easily answer question 8 because they understand the concept of normal distribution with the help of the bar chart illustration. Overall, the subjects in the One-to-One stage have a good understanding of the concept of probability distribution using the "Galton Sriwijaya Board" teaching aid. They were able to explain the conclusions and answers in the closing activity very well and accurately.

Next, the researchers conducted interviews in the One-to-One stage to identify students' difficulties during the use of the teaching aid and in completing the LKPD. The interview results were used as qualitative data to support the evaluation of the "Galton Sriwijaya Board" in facilitating students' understanding of the normal distribution concept. The interview data were analyzed to identify students' interpretations of the experimental results and their understanding of the normal distribution pattern. The representative responses are presented in Table 5.

Table 5. Results of One-to-One Interviews.

Interview Findings	Interpretation of Students' Conceptual Understanding
Students explained that marbles moving randomly to the left and right repeatedly accumulated more in the middle containers and formed a bell-shaped distribution pattern.	Students understood that repeated random processes can produce a normal distribution pattern.
Students explained that the middle containers contained more marbles because there were more possible paths leading to those positions, while the outer containers had fewer possible paths.	Students understood the relationship between frequency distribution and the characteristics of normal distribution.

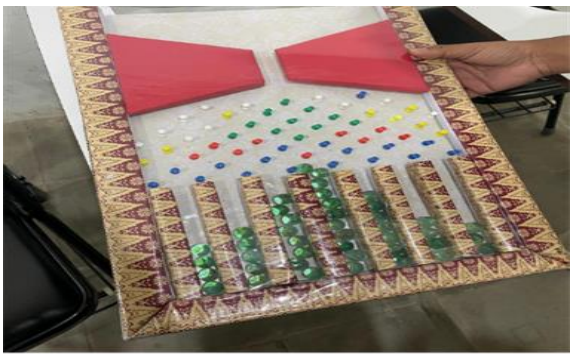
In addition to the general findings presented in Table 4, individual responses regarding learning difficulties and suggestions for improving the teaching aid are presented in Table 6.

Table 6. Results of Individual Subject Interviews, One-to-One Stage.

Subject	Subject Answer
Student 1	The student had difficulty drawing diagrams and suggested making the teaching aid sturdier.
Student 2	The student experienced difficulty in probability calculations with large denominators and suggested adjusting the marble size to better fit the containers.
Student 3	The student experienced difficulties in probability calculations and suggested strengthening the container dividers and adding more marbles.

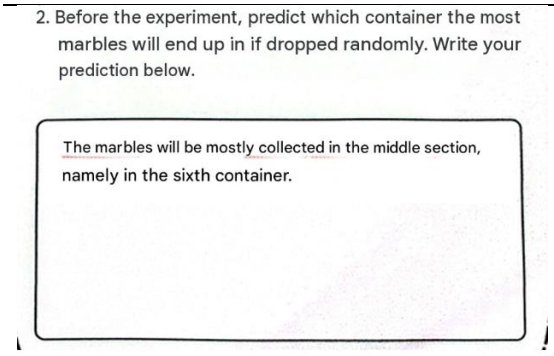
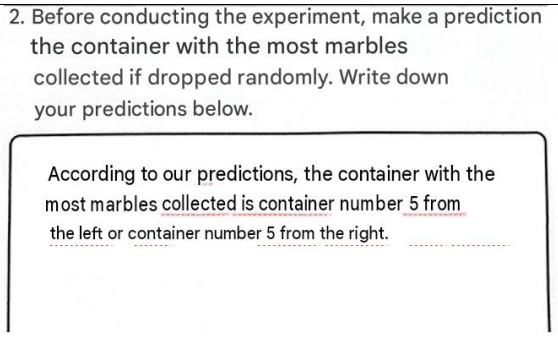
Based on the experts' suggestions during the expert review stage and the results obtained by the researchers during the one-to-one stage, the researchers revised the teaching aid prototype and the student worksheets. The revisions to the teaching aids can be seen in Table 7.

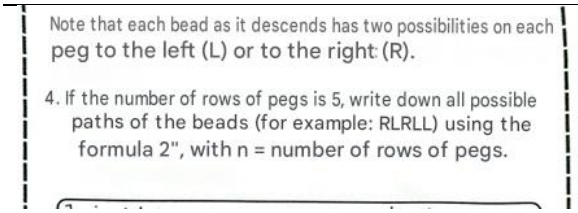
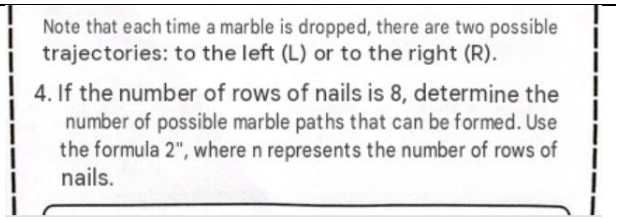
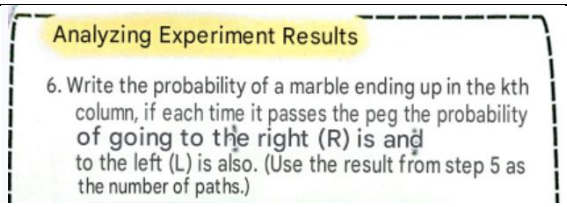
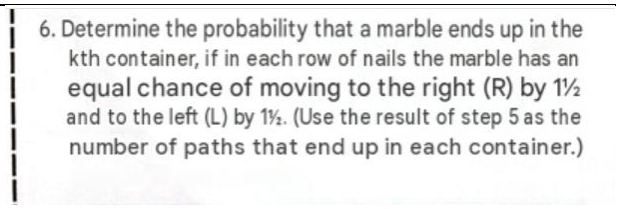
Table 7. Revision of the "Galton Sriwijaya Board" Teaching Aid.

Before Revision	After Revision
	
Description: The initial design showed an uneven pin arrangement and an insufficient number of receptacles in proportion to the number of lanes. This resulted in a ball distribution that did not match the expected pattern.	**Revision decisions:** 1. The researcher adjusted the spacing and rearranged the pinboard. 2. The researcher changed the number of containers at the bottom according to the pinboard layout. 3. The researcher replaced the marble containers with stronger materials. 4. The researcher also rearranged the visual elements to make them look more proportional.

There are also revisions to the LKPD as shown in Table 8 below.

Table 8. Revision of Student Worksheets (LKPD)

Before Revision	After Revision
	
	Revision decisions:

Before Revision	After Revision
	In question number 2 for the preliminary activity, the researcher changed the question to make it easier to understand than the previous sentence.
	
	Revision decisions: In the section prior to revision for number 4 in the core activity, the researcher still used the word "beads" and changed it to "marbles" because the object used was marbles. In addition, the number of peg rows was readjusted after the teaching aids were revised.
	
	Revision decisions: In question number 6, the researcher changed the word "column" to "container" and the word "peg" to "row of nails" to make it easier to understand, and the researcher added information that the chances of going to the right (R) and to the left (L) are equal.

Small Group

The small group evaluation involved six undergraduate students divided into two groups of three. Students used the Galton Sriwijaya Board to conduct ball-drop experiments, record the results, and complete the Student Worksheet (LKPD). All participants were able to follow the instructions and operate the media without significant difficulty.

The analysis of students' responses showed that both groups successfully answered the worksheet questions and demonstrated an understanding that the middle containers contained more marbles because they had a greater number of possible paths. Students also recognized that the resulting pattern formed a bell-shaped curve, indicating the characteristics of a normal distribution.

Figure 1 presents the LKPD responses from Group 1, illustrating students' ability to explain the relationship between the number of available paths and the frequency of balls in each column. The explanations provided were aligned with the predefined learning objectives.

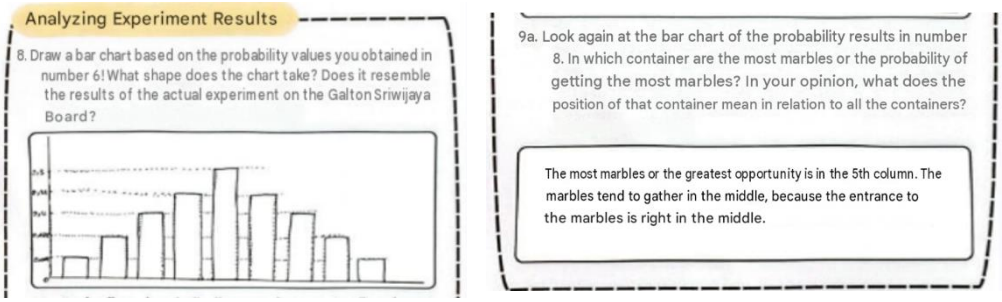


Figure 1. LKPD responses of Group 1 at the small group stage.

Figure 2 shows the responses from Group 2, which also reflect an adequate level of conceptual understanding. Students noted that increasing the number of trials would result in a more stable and structured distribution pattern. This observation corresponds to the fundamental concept of data convergence in repeated random experiments.

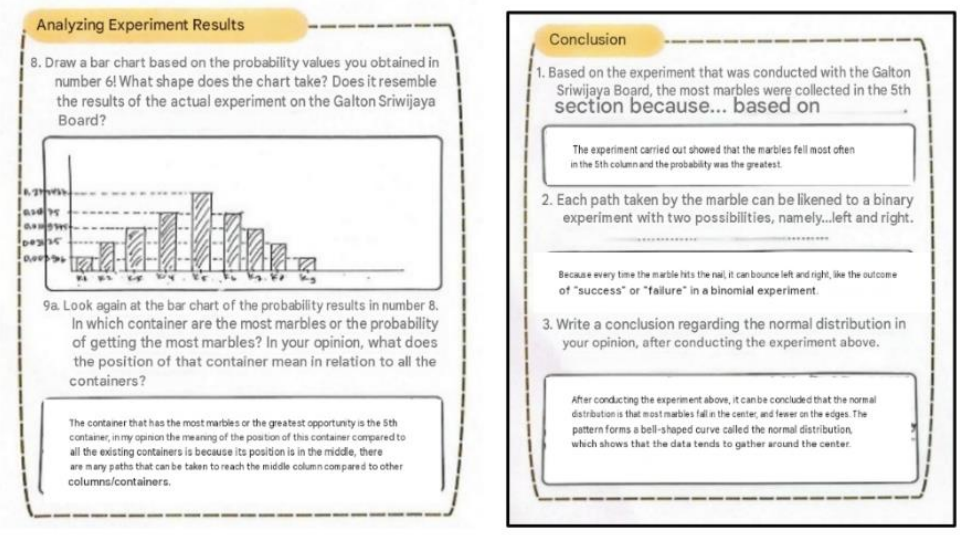


Figure 2. Examples of LKPD responses of Group 2 at the small group stage.

Brief interviews conducted after the activity indicated that students found the media easy to use and helpful in understanding the concept of normal distribution through direct observation. Overall, students were able to operate the media indenpently, complete the LKPD

independently, and draw conclusions based on experimental results. Therefore, the Galton Sriwijaya Board was considered valid and practical based on the formative evaluation results and was ready for further implementation in broader learning contexts. The results of the small group evaluation provided evidence regarding students' conceptual understanding after using the teaching aid.

A quantitative analysis was conducted to evaluate students' achievement based on two indicators: the ability to interpret random experiment results and the ability to generalize the characteristics of normal distribution based on experimental outcomes. To evaluate students' conceptual understanding at the small group stage, students' LKPD responses were analyzed based on two indicators. The achievement percentage was calculated from the total score obtained by students compared with the maximum possible score. The results of this analysis are presented in Table 9.

Table 9. Achievement of Students' Conceptual Understanding Indicators at the Small Group

Conceptual Understanding Indicator	Achievement Percentage	Category
Students' ability to interpret the results of random experiments using the Galton Sriwijaya Board	85%	Very Good
Students' ability to generalize the characteristics of normal distribution based on experimental results	80%	Good

The results of the small group evaluation showed that students demonstrated a good level of conceptual understanding after using the Galton Sriwijaya Board. The highest achievement was found in students' ability to interpret the results of random experiments, with an achievement percentage of 85%, categorized as very good. This indicates that students were able to observe and explain the distribution patterns produced by repeated marble-drop experiments. Meanwhile, the ability to generalize the characteristics of normal distribution obtained an achievement percentage of 80%, categorized as good. This finding shows that students were able to relate experimental results to the characteristics of normal distribution, although further implementation is needed to strengthen students' conceptual generalization skills.

A practicality evaluation was conducted at the small group stage to assess the ease of use, clarity, and perceived usefulness of the *Galton Sriwijaya Board*. Students completed a practicality questionnaire consisting of 18 items rated on a five-point Likert scale. The media was categorized as practical if the average score reached at least 60%. The results of the practicality evaluation are presented in Table 10.

Table 10. Practicality Evaluation Results

Participant	Total Score
M1	84
M2	84
M3	83
M4	83
M5	85
M6	84
Mean Score	**83,83**
Mean Percentage	**93,1%**
Practicality Category	**Very Practical**

Discussion

The findings indicate that the "Galton Sriwijaya Board" facilitated students' understanding of normal distribution through direct experimentation and visualization activities. Based on students' LKPD responses and interview data, students were able to interpret the results of marble-drop experiments by observing the distribution of marbles in each container. These findings suggest that the teaching aid provided opportunities for students to explore the relationship between random processes and distribution patterns during the learning activity. This finding indicates that students demonstrated an ability to connect experimental outcomes with the characteristics of normal distribution.

Furthermore, students demonstrated the ability to generalize the characteristics of normal distribution based on experimental data. By analyzing the distribution patterns generated from the Galton Sriwijaya Board experiment, students were able to relate repeated random processes to the characteristics of normal distribution. This finding is consistent with previous studies showing that learning activities involving concrete experiences and visualization can facilitate students' construction of mathematical concepts (Cahyaningsih et al., 2024; Kuling et al., 2025; Verlage et al., 2025).

The use of the teaching aid also aligns with constructivist and experiential learning principles, in which students construct knowledge through observation, experimentation, and interpretation of data (Wulantina et al., 2024). Through the activities using the Galton Sriwijaya Board, students were provided with concrete learning experiences that facilitated the visualization of abstract statistical concepts. By observing the relationship between possible pathways and marble frequencies, students were able to explain why the middle containers

tended to have higher frequencies than the outer containers. This learning process encouraged students to examine not only the final distribution pattern but also the underlying random processes that generated the pattern. Such experiences support students in constructing statistical concepts based on experimental evidence rather than relying solely on procedural explanations, which is consistent with previous studies emphasizing the role of experiential and visualization-based learning in developing mathematical understanding (Nursucita et al., 2026; Putri et al., 2026).

In addition, the formative evaluation process contributed to refining the quality and usability of the teaching aid. Revisions to the pin arrangement, terminology, and worksheet instructions improved the clarity and practicality of the learning activities. The practicality results obtained during the small group stage indicate that the media was easy to use and suitable for supporting statistics learning activities. However, since this study was limited to the prototyping stage, the findings represent formative evaluation outcomes rather than evidence of effectiveness in improving students' learning achievement. Therefore, further research is needed to investigate the implementation of the teaching aid in broader and more diverse learning contexts.

CONCLUSION

The study aimed to develop the "Galton Sriwijaya Board" as a teaching aid to facilitate students' understanding of normal distribution through hands-on learning activities and to evaluate its validity and practicality. The results indicate that the "Galton Sriwijaya Board" provides opportunities for students to interpret experimental results and explore the characteristics of normal distribution. The integration of the teaching aid with the LKPD supports students in completing learning tasks and drawing conclusions based on experimental observations. Expert validation by two lecturers in the Mathematics Education Study Program who teach Mathematical Statistics indicated that the developed teaching aid was valid in terms of content, construct, and language. In addition, the small group evaluation showed that the media is practical, with a practicality score of 93.1%, categorized as very practical. These findings demonstrate that the "Galton Sriwijaya Board" meets the validity and practicality criteria for use in learning activities. This study is limited to the prototyping stage of design research. Therefore, future studies are recommended to evaluate the effectiveness of the teaching aid in broader educational settings, including schools with different characteristics.

Further development may also include digital-based versions of the media to support more flexible and scalable learning experiences.

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