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Development of a STEM-based digital learning space platform to enhance students' mathematical creativity in future learning classrooms

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Abstract
This study focuses on developing a web-based digital learning space (DLS) designed to support a STEM learning model that fosters students' mathematical creativity. The DLS builds upon traditional learning management systems by introducing customizable elements tailored to individual teaching and learning environments (PTEs and PLEs). These features allow for the formation of diverse learning networks within the DLS. This enhanced version integrates frameworks for STEM learning, engaging activities, instructional videos, quizzes, evaluations, feedback tools, and a chat feature for direct communication with instructors. The research and development process employed a 4D model–define, design, develop, and disseminate–and involved validation from content and media experts, confirming the DLS's reliability for broader testing. Results indicate that the STEM-based DLS is highly suitable for mathematics education, as shown by validation from experts, practicality tests from users, and effectiveness tests that measured students' mathematical creativity. This study also found moderate improvement in students' creative mathematical thinking (Ng = 0.554) within classrooms using the STEM-based DLS, highlighting its effectiveness for enhancing these skills. Thus, this STEM-focused DLS offers a mobile-friendly digital environment that effectively promotes students' mathematical creativity.

Keywords: digital learning spaces, STEM, mathematical creativity, learning autonomy, 4D developmental model

INTRODUCTION

The concept of Industry 4.0, introduced by German economist Klaus Schwab, emphasizes widespread automation and integrated data networks that are rapidly transforming how people work and interact (Effoduh, 2016). The swift technological shifts call for adaptive skills, often referred to as 21st century skills, which include critical thinking, communication, collaboration, social skills, creativity, and information literacy (Radziwill, 2018; Zubaidah, 2017). Education systems must evolve to equip learners with these foundational abilities (Kennedy & Odell, 2014).

One such critical 21st century skill is creative thinking, essential for problem-solving and innovation. Reflective and decision-based, creative thinking empowers students to approach problems imaginatively and courageously (Sirajudin et al., 2021). Mathematics, known for cultivating logical and inventive thought, plays an instrumental role in building these skills, though studies reveal that many Indonesian students still struggle with creative mathematical thinking (Priyanto & Dharin, 2021; Waluya et al., 2021). In response, there is a pressing need for innovative learning strategies that can foster creativity.

In the modern workforce, STEM education has become increasingly valuable due to rising demands in fields like economics, science, and engineering (Xu & Ouyang, 2022). To address these demands, students must acquire problem-solving skills during their education. Autonomous learning, which emphasizes self-guided and proactive study, has gained popularity worldwide, leading to the creation of self-access learning centers in many universities (Khabiri & Lavasani, 2012). Autonomous learning enables students to take responsibility for their learning paths, thereby fostering

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Contribution to the literature

- This research contributes to the literature by developing an innovative learning model based on STEM-based Digital Learning Spaces (DLS) to improve students' mathematical creative thinking abilities.
- This research expands insight into how digital technology can be integrated with STEM approaches to create learning environments that are interactive, contextual, and support the development of student creativity in mathematics.
- In addition, this research fills a gap in the literature regarding the effectiveness of STEM-based DLS, especially in the context of mathematics learning at the secondary school level, which is still rarely studied in depth.

independence and resilience (Feri & Erlinda, 2012). This concept has been shown to strengthen learning autonomy, particularly when combined with active learning and collaboration (Yasmin & Naseem, 2019).

A STEM-integrated approach offers a dynamic, interdisciplinary learning experience, promoting critical thinking, collaboration, and problem-solving through interactive challenges (McDonald, 2016; Septiadevana & Abdullah, 2024; Tramonti et al., 2024). With the advancement of information technology, STEM-based e-learning is now feasible through platforms like learning management systems (LMS). However, while LMS platforms proved effective during the COVID-19 pandemic (Quansah & Essiam, 2021), they still have limitations, such as limited time-bound access, course restrictions, and teacher-centered structures (Athaya et al., 2021; Clark et al., 2021; Grainger et al., 2021). These limitations can hinder students' ability to study autonomously, explore course materials across disciplines, and network beyond the classroom.

The digital learning space (DLS) was created in line with networked learning (NL) theory, advocating for technology-enhanced global learning connections (Boholano, 2017). DLS offers an open-access, virtual learning space that facilitates synchronous and asynchronous teaching and learning, enabling students to access materials anytime. This flexibility fosters student autonomy and enhances interactivity with features such as evaluations, community learning spaces, and real-time content-sharing options for teachers and students alike. By supporting personal teaching environment (PTE) setups, the DLS encourages student-centered learning with accessible and cost-effective technology.

This research aims to develop a STEM-based DLS that supports mathematical creativity, offering a mobile, flexible platform accessible to students across Indonesia. By integrating STEM materials, assessments, discussion forums, and TIMSS- and PISA-type questions infused with Indonesian culture, the DLS provides a culturally relevant and engaging learning experience. While studies on STEM and DLS exist, this research offers a novel approach by integrating a STEM model with a web-based DLS, allowing interaction and resource-sharing in a virtual space specifically aimed at boosting creative mathematical thinking. This DLS-based STEM approach intends to offer a comprehensive, scalable learning innovation for future educational needs in Indonesia, fostering student creativity and autonomy.

The present study aims to develop a STEM-based DLS platform that is valid, practical, and effective in enhancing students' mathematical creativity. The research questions guiding this study are:

1. What developmental process ensures that a STEM-based DLS platform is both valid and practical for digital mathematics learning?
2. To what extent does a STEM-based DLS platform enhance students' mathematical creative thinking within an autonomous learning framework?

THEORETICAL FRAMEWORK

Mathematical Creative Thinking

To navigate the rapidly evolving demands of the 21st century, individuals need flexible and creative mathematical thinking skills to adapt to changing environments (Steinberg, 2013). Thinking is generally understood as the use of reasoning to make decisions or reach conclusions, aligning with Sirajudin et al. (2021), who describe thinking as the mental application of human reasoning. Santrock (2016) views creativity as the capacity to approach ideas in novel and unconventional ways to find unique solutions. Torsi categorizes creativity into several components: fluency, flexibility, originality, and elaboration (Blayone et al., 2017; Hadar & Tirosh, 2019). Based on these views, creative thinking can be defined as the mental process of recognizing and solving problems by considering fresh information and ideas with an open perspective, enabling connections to be drawn for problem-solving.

Widodo et al. (2021) identified four key indicators for evaluating creative thinking: fluency, flexibility, originality, and elaboration. This is consistent with Schoevers et al. (2020), who describes five types of creative behaviors that contribute to one's creative capacity: fluency, flexibility, elaboration, sensitivity, and authenticity (Jia et al., 2019). In addition, Steinberg (2013) adds elaboration, sensitivity, and construction as factors in creative problem-solving. This study adopts four indicators to assess students' mathematical creative thinking abilities:

(a) students' ability to provide accurate answers and procedural solutions to problems involving experimental probabilities (fluency),

(b) students' capability to devise multiple approaches to solving probability problems (flexibility),

(c) students' originality in proposing their own ideas for solving probability tasks (originality), and

(d) students' detailed responses, enriched or further developed in solving probability problems (elaboration).

STEM Approach

STEM education, encompassing science, technology, engineering, and mathematics, has gained significant attention globally as various nations have incorporated it into their educational curricula, reporting numerous advantages. STEM is not a new concept; its application has long contributed to advancements in the industrial and technological sectors (English, 2016; Orakci & Durnali, 2023). Countries such as Taiwan have embedded STEM in their educational systems, emphasizing student-centered learning (Lou et al., 2011). Other countries, including the United States, Malaysia, Finland, China, and the Philippines, have also integrated STEM. According to Hmelo-Silver (as cited in Tseng et al., 2013), combining STEM with project-based learning can deepen students' understanding of the connections between learning goals and problem-solving while enhancing their interest in learning. STEM learning typically includes interactive components like communication, collaboration, problem-solving, leadership, and creativity. Implementing STEM can encourage students to design, develop, and apply technological solutions, reinforcing cognitive and affective skills and practical knowledge (Akaygun & Aslan-Tutak, 2016; Alatas & Yakin, 2021).

Through a systematic blend of concepts, knowledge, and skills, STEM learning can provide students with meaningful educational experiences (Shahali et al., 2017). Critical aspects of STEM-based learning include

(a) asking questions and identifying engineering problems,

(b) creating and using models,

(c) planning and conducting investigations,

(d) data analysis and interpretation (mathematics),

(e) using mathematics, ICT, and computational thinking,

(f) building explanations (science) and designing solutions (engineering),

(g) supporting claims with evidence, and

(h) acquiring, evaluating, and communicating information (NCTM, 2014).

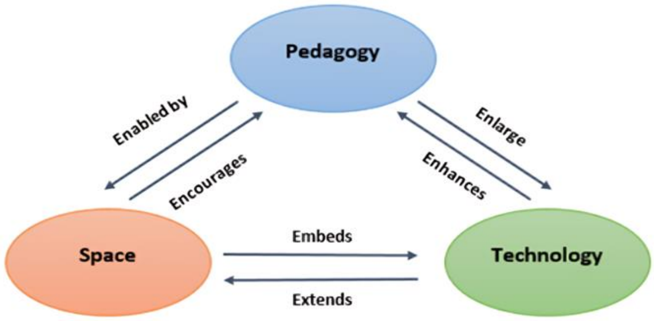

Figure 1. Diagram of PST (Radcliffe et al., 2008)

Key advantages of STEM learning noted by experts include practical knowledge application, increased motivation, and the ability to transfer knowledge to new contexts. Additionally, STEM allows students to play an active, meaningful role in their learning (Tseng et al., 2013).

Digital Learning Spaces

Research on DLS gained momentum in 2003, driven by ideas to reform educational environments for the "digital generation." Studies on DLS now cover a range of educational aspects, including planning, design, implementation, and evaluation. Countries such as the United States, the United Kingdom, and Australia have made notable progress in investigating this concept. Brown, an American expert, has discussed design principles, technology configurations, and student learning styles for digital environments, emphasizing the distinct needs of digital generation learners. EDUCAUSE, an American higher education research institute, published *Learning Space*, the first monograph to systematically explore DLS design in 2006 (Wu, 2018). This work addresses trends in learning space design, focusing on changes in students, technological advances, and an evolving understanding of learning. Australian professor David proposed the "pedagogies-learning-space-technology" framework to assess learning space design, noting that these elements interact dynamically (Wu, 2018) (**Figure 1**).

The concept of learning spaces has evolved from traditional, physical settings to digital, informal, and now online DLS. NL theory, rooted in social-constructivism, has significantly influenced digital learning models, emphasizing the importance of connected, collaborative learning environments (Harrison, 2018). DLS are virtual, open-access learning environments that continue to develop alongside advancements in information technology, enabling broader, ongoing access to educational resources. DLS promotes interactivity and collaboration, supporting both synchronous and asynchronous participation among educators and students (Moore-Russo et al., 2015). DLS can facilitate multimedia interactions and open discussions, supporting student-centered learning through low-cost, manageable PTEs and personal learning environments (PLEs) (Harrison, 2018; Wu, 2018). Although promising, studies on integrating STEM with DLS technology remain limited. This research aims to investigate how mathematical reasoning can be effectively nurtured in young learners by integrating STEM-based DLS environments into early education, particularly through engaging three-year-olds in tasks incorporating both mathematics and science.

Learning Autonomy

Learning autonomy has gained importance in recent educational discourse, especially concerning lifelong learning skills. This focus on autonomy has transformed traditional classroom approaches, leading to self-access learning centers worldwide, such as SALC at Kanda University, ASLLC at The Education University of Hong Kong, SAC at Hong Kong University of Science and Technology, and ELSAC at the University of Auckland. Autonomy involves students taking responsibility for their learning, whether through developing strategies, techniques, or materials for independent study (de Vink et al., 2023; Khabiri & Lavasani, 2012; Martín-Páez et al., 2019; Najeeb, 2013). It also encompasses the capacity for self-reflection, decision-making, and independent action. Yasmin and Naseem (2019) list seven key characteristics of autonomous learners: understanding one's learning style and strategies; active engagement; risk-taking in communication; hypothesis formation; attention to detail and precision; willingness to revise ineffective approaches; and an open, tolerant attitude toward targets.

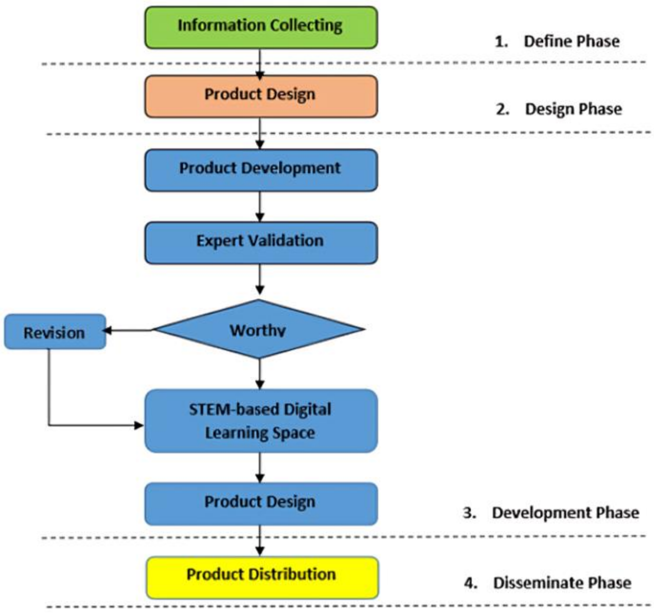

Figure 2. R&D flow (Source: Authors' own elaboration)

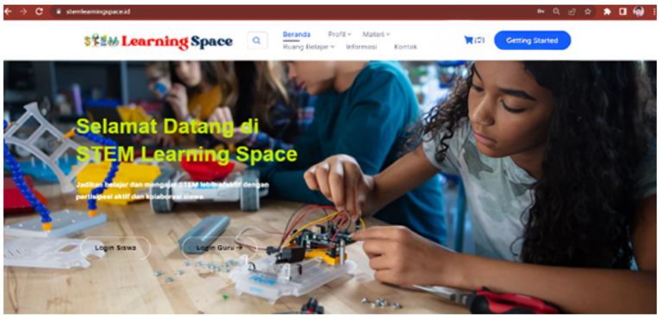

Figure 3. Home view from STEM learning spaces (https://stemlearningspace.id/)

METHOD

Design Research

This research uses the R&D method (*research and development*) proposed by Thiagarajan (1976) with a 4D model consisting of 4 stages, namely; define, design, develop, and disseminate. This method is used with the aim of producing a product in the form of a STEM-based DLS learning system, as well as modules and products in the form of a DLS web that can be accessed online, integrated synchronously and asynchronously, aimed at developing scientific literacy and mathematical abilities. The first objective is referred to as the development function in which it is contained PTEs and PLEs while the second objective is referred to as validation to measure the level of effectiveness of using the DLS based on STEM learning models. The steps are explained in more detail below: The R&D steps in an integrated and systematic manner can be seen in **Figure 2**.

At the phase of *define* consisting of

(a) *Front-end analysis* (initial and final analysis) which contains activities for creating background problems from basic learning plans in STEM-based subjects.

(b) *Learner analysis* (student analysis) which contains activities to prepare and disseminate needs analysis to students, including anticipating learning obstacles students in online learning and what learning environment the teacher must prepare.

Second phase: Level of instructional planning of learning strategies STEM based DLS. This stage aims to design a learning strategy instructional design program STEM with the help of DLS. The design stage consists of four steps, namely preparing tests/instruments, selecting media, preparing teaching materials, and initial planning of instructional design learning strategies. The following displays the main menu of the stem learning spaces web which can be accessed on the web https://stemlearningspace.id/ shown in **Figure 3**.

Third phase: Learning strategy development stage *STEM* based DLS. At the prototype stage of learning strategy development *STEM* based-DLS will be validated first by experts/experts. The experts involved consist of 2 fields of expertise, namely:

(a) ICT media experts and

(b) material content experts, where each field consists of 3 experts who assess.

The input from experts will be applied for improvements at the next stage. Fourth phase: Dissemination phase, after receiving the product/results from implementing the learning strategy *STEM learning strategy based on DLS* then dissemination will be carried out such as writing journal articles, workshops for seminar teachers and so on.

Participants

In the initial stage of development, 10 junior high school students were selected at a school in Kuningan Regency, West Java, Indonesia. The second stage carried out wider trials on 60 students from 2 different schools in Kuningan Regency and field trials/field tests on 120 students from 3 different schools in Kuningan Regency, West Java, Indonesia. This research process was also assisted by 3 mathematics teachers in each school and also 3 students as observers and collaboration partners in the classroom learning process.

Instrument and Validity

To assess students' learning outcomes, pre-test and post-test questions were used, focusing on indicators of mathematical creative thinking skills. These questions aim to evaluate students' creative thinking in mathematics throughout the learning process. For gauging student autonomy in learning, a questionnaire with a rating scale was utilized. The questionnaire applied a 5-point Likert scale (Abdullah et al., 2019), from 1 (strongly disagree) to 5 (strongly agree), allowing evaluation of each component related to attitudes, opinions, and perceptions on social phenomena. The DLS website underwent rigorous validity testing, including evaluations by experts in material content, IT media, and STEM learning. Instruments included mathematical creativity tests, learning autonomy surveys, validity assessment sheets, and practicality questionnaires for the DLS learning platform. Following expert review, the DLS platform demonstrated good practicality and effectiveness.

Data Collection and Analysis

To examine types of mathematical argumentation children express during STEAM activities, several data sources were utilized: photos, videos, and audio recordings of the students engaging in activities, which were transcribed for further analysis. Critical thinking was assessed using a rubric developed by Steinberg (2013), focusing on five key indicators:

(a) fluency,

(b) flexibility,

(c) making connections,

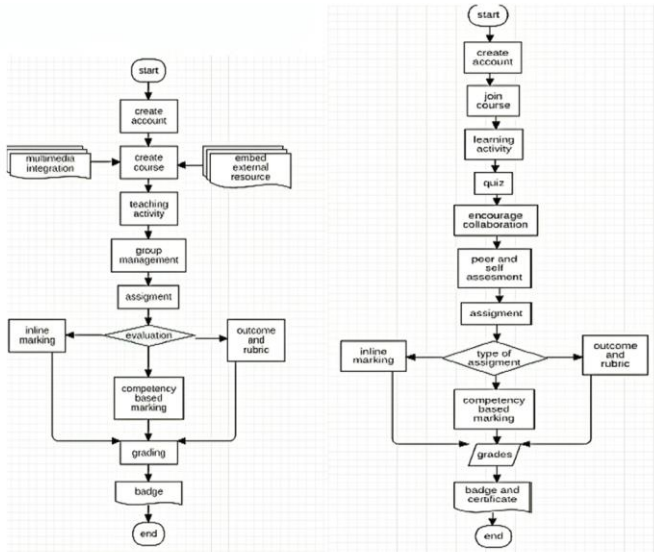

Figure 4. PTEs and PLEs flowchart (Source: Authors' own elaboration)

(d) construction, and

(e) originality.

This rubric helped classify children's arguments reflecting creative thinking during various activity stages, specifically at three points:

1. At the beginning of the assembly,
2. During manipulation and experimentation, and
3. At the end, with final arguments presented at activity closure.

For the questionnaire, the Likert scale (Abdullah et al., 2019) was used again, scoring responses from 1 (strongly disagree) to 5 (strongly agree) to capture attitudes, opinions, and perceptions. Quantitative methods with descriptive analysis were employed to evaluate the development of this STEM-based DLS design. Descriptive analysis organized data systematically as numbers and percentages to derive general conclusions. The research analyzed respondents' views on the feasibility of STEM-based DLS teaching materials, using a descriptive analysis technique to illustrate validity, practicality, and effectiveness outcomes.

Development of STEM-based DLS Learning Features

In designing the DLS, which is a website, we designed it with web developers, STEM practitioners and the educator/teacher community and students as users of the DLS. Flowcharts or flow diagrams were used to describe each activity of each user in detail. The flowchart is shown in **Figure 4**. In this stem learning spaces design there is an Introduction menu, Material Deepening, STEM Project Activities, Evaluation and there are also creative thinking questions as targets for improving students' skills in this research. After students log in, in the initial course material menu, progress achievements that have been followed, material

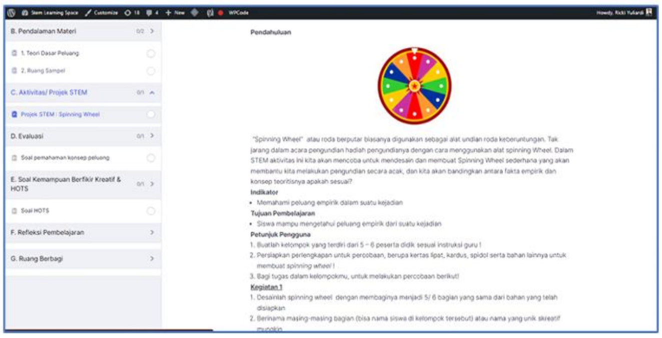

Figure 5. STEM activity features in DLS (https://stemlearningspace.id/)

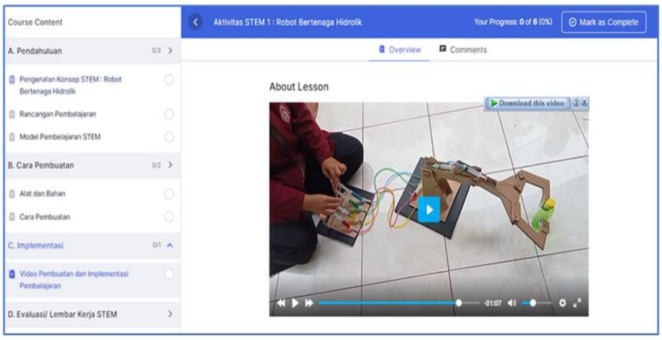

Figure 7. Features results of learning experiences in DLS (https://stemlearningspace.id/)

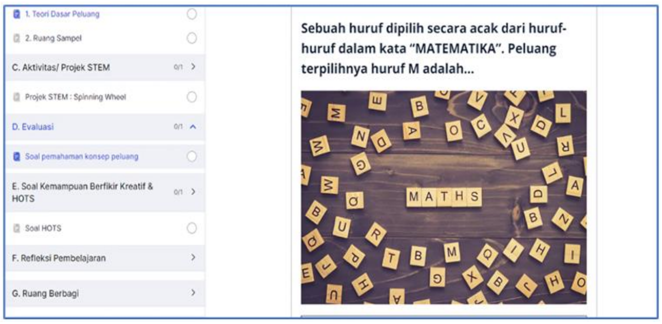

Figure 6. Quiz feature in DLS (https://stemlearningspace.id/)

to be studied, learning guidelines, tags to make searching and target participants are displayed. In the initial menu students can explore concepts with the materials provided in the DLS feature, which can be accessed synchronously or asynchronously.

The DLS being developed will be equipped with STEM learning materials and videos, uploading assignments, online assessments and discussion forums, the Indonesian STEM community learning share feature, and the questions presented will be questions that develop 4C skills (creativity, critical thinking, communication, and collaboration) and refers to TIMSS and PISA type science and mathematics. **Figure 5** presents an initial view of the STEM based learning project in DLS.

In the activities/STEM project menu, STEM integrated learning activities are presented that can be done together with group colleagues in class. Through the project based learning model, students make STEM teaching aids guided by the teacher. Students also make direct observations and write down the results of their discussions on the LKPD (students worksheet) that has been prepared. The results of group discussions and videos for each group will be uploaded via DLS. Apart from that, the learning feature is also equipped with an interactive quiz which will measure the level of student understanding with an interactive quiz where the system will provide feedback according to the student’s answers and provide instructions for correct completion. The interactive quiz feature is shown in **Figure 6**. In the interactive question practice menu, students can work on questions online and there will be feedback on student answers which will be recorded and can be checked by the teacher so that the teacher can assess the level of student understanding of the learning material.

Then STEM learning spaces is also equipped with video examples of making teaching aids and implementing STEM-based learning. With this feature, teachers, students and STEM activists from various parts of the world can adapt the STEM learning that has been carried out. The following is an example of a web display that contains a video of making props and implementing STEM learning, which is exemplified by making robotic arm props, shown in **Figure 7**.

Furthermore, there is a space room feature, this feature can be accessed and used by teachers/students and STEM activists to share experiences, implement learning and impressions from participating in STEM learning. In this feature there is also sharing of good practices that have been carried out in the school, so this is in accordance with the NL theory which can connect classes without any border.

Description of the STEM Tasks

This project introduces a STEAM framework focused on theoretically and empirically analyzing opportunity characteristics, specifically by examining repeated trials of a spinning wheel experiment. The aim is to deepen understanding of the concept of probability and compare theoretical outcomes with empirical results. Over two months, five activities were conducted as experiments to bridge science and mathematics. In each activity, children were encouraged to answer questions or formulate hypotheses, gathering data through hands-on experimentation and manipulation. This allowed them to validate their ideas, explain outcomes, perform verifications, and build transferable knowledge and skills. The STEM learning stages were structured around the engineering design process (EDP), an iterative approach engineers use to create solutions, with stages including asking, imagining, planning, creating, and refining (Hill-Cunningham et al., 2018). Notably, the EDP’s cyclical nature allows students to enter at any stage and iterate until an optimal solution is reached.

Table 1. Implementation of STEM with digital space

Task	STEM stages	Explanation	Instructions	Duration
1	Start with the essential question	The teacher asks essential questions: Students are asked several questions related to problems found in everyday life.	Teacher: Ask the essential questions ask about the use of a spinning wheel Students: Try to design and create spinning wheel simple method that will help us carry out random drawing	2 lessons, 50 min each, & synchronous
2	Design a plan for the project (spinning wheel)	Designing project planning: In planning to design a project, students are invited to discuss it in groups: How to make it, materials and tools, etc.	Look for literature/references about the manufacture/design of tools *spinning wheel* ! Design it *spinning wheel* by dividing it into n equal parts from the prepared ingredients! Give each part a name (can be the name of a student in the group) or a unique name that is as creative as possible.	2 lessons, 50 min each, & synchronous & asynchronous
3	Create a schedule	Preparing a schedule: Students prepare a start and finish schedule.	Project work is given 1 week until next week's meeting, students make a project work schedule and record progress results via the stem learning spaces web	8 lessons, 50 min each, & asynchronous
4	Monitor the students and the progress of the project	Monitor the progress of project development by students.	Include your group work plan in the progress menu on the STEM learning spaces	8 lessons, 50 min each, & asynchronous
5	Assess the outcome	Testing results, measuring the extent of learning achieved through projects produced by students.	After making the spinning wheel, do an experiment by spinning the spinning wheel 20, 40 and however many times you want Observe the experimental results obtained on the spinning wheel ! Write down the experimental results obtained on the spinning wheel in the table provided!	4 lessons, 50 min each, & synchronous
6	Reflection	Evaluating experience: Reflecting on students' experiences in the process of completing a project and finding new innovations.	After you have carried out the activities above, write down the conclusions from the results of your discussion and present them in front of the class!	2 lessons, 50 min each, & synchronous

Table 1 provides a detailed overview of the activity characteristics and teaching objectives.

As for this learning objective, we will help students understand what the empirical probability of an event is through a series of STEM activities starting from designing, drafting, creating media, testing hypotheses and reflecting on the results of observations. Below are presented the stages of the STEM learning process:

Stage 1. Start with the essential question

The aim of this experiment is to show children what the empirical probability of an event is, using Spinning wheel media, children will be asked to divide the spinning wheel circle into n equal parts, then children will test whether the probability of each part appearing in the spinning circle is the wheel is the same as the theoretical probability, in fact the more experiments carried out, the empirical probability will equal the theoretical probability of an event:

In the assembly, the question that triggers the first experiment is presented: How do we design a spinning wheel that can prove the empirical probability of winning a lottery?

At this point, the aim is for the children to make a first in this initial phase, the goal is for students to take a first approach to the idea and generate their first hypothesis. A spinning wheel is a tool used to draw lots. Usually in drawing events the winner is determined using the Spinning Wheel tool. In this STEM activity we will try to design and create a simple Spinning Wheel method that will help us in conducting random draws, and we will combine empirical facts and theoretical concepts, as appropriate. The answers given by children are then taken by the teacher as possible hypotheses for experimental purposes in class groups. First, he asked questions in an attempt to raise doubts among the students, and then invited them to corroborate, to think about how to know who was right or whether they were all right. The teacher then asked them the question: how to design a spinning wheel that can spin well and give fair results to each part of the spinning wheel.

Stage 2. Design a plan for the project (spinning wheel)

In planning to design a project, students are invited to discuss it in groups: how to make it, materials and tools, etc. In groups, children are instructed to look for

Figure 8. Students search for literature regarding spinning wheel media design through DLS (Source: Field study)

Figure 9. Students discuss the design of a spinning wheel (Source: Field study)

literature/references regarding the manufacture/design of spinning wheel tools, they can look for literature sources from YouTube, websites and the www.spacelearning.id platform which also provides video tutorials on making spinning wheels (**Figure 8**).

Then students are asked to divide the circle into n equal parts, the process of dividing a circle into n equal angles can be manually using a ruler and protractor or assisted by mathematical software such as GeoGebra, Wingeom, and other applications (**Figure 9**). Then students are instructed to give each part a name (can be the name of a student in the group) or a unique name that is as creative as possible.

After designing the spinning wheel design that will be made, they use the materials and tools that have been provided in making their STEM project. The aim of this phase of the process is that, based on their sense of touch and sight, they reflect and show their critical thinking and creativity.

Figure 10. The teacher and students check the spinning wheel props (Source: Field study)

Stage 3. Create a schedule

Due to limited learning time in class, the STEM project will be completed at home, we give approximately 1 week to complete the project. Each group member is responsible for their respective tasks and ensuring the project is completed according to the target. The progress of project creation is reported via the www.spacelearning.id platform and students can also ask questions via the sharing menu and discussions related to STEM projects.

Stage 4. Monitor the project

At the project monitoring stage, researchers checked the results of each student's project, including the feasibility of the spinning wheel in terms of design, whether the design was good, or whether there were deficiencies in the design so that the wheel did not spin properly (because it could result in an unfair chance of winning if the design was poor). If design deficiencies are found, students will be asked to redesign until a good design model is created (**Figure 10**).

Stage 5. Access the outcome

After the spinning wheel media was finished, students tried to carry out a simple experiment by spinning the spinning wheel 50 and 100 times, someone was tasked with recording the results of the events that occurred (**Figure 11**).

In view of the answers given, the teacher assumes them as possible hypotheses, in order to create the need for experimentation. To do this, she questions the validity of the answers given through different questions. In this phase, after students perform a predetermined number of spinning wheel rotations, students compare empirical facts and theoretical concepts about opportunity, whether they are appropriate, the question is asked again in the class group so that based on the experiments carried out, the solution can be specified, defined and concluded and

Figure 11. Students carry out experiments, by spinning the wheel and recording them (Source: Field study)

Figure 12. Students make presentations and explain the conclusions of the experiments (Source: Field study)

generalized. The teacher writes down the conclusions reached and invites children to compare them with their initial beliefs or ideas.

Stage 6. Reflection

This phase aims to evaluate experience, reflect on students' experiences in the process of completing a project and discovering new innovations (**Figure 12**).

In this reflection process the teacher asks about the results of the opportunity experiment and whether the empirical results that emerge are in accordance with the theoretical results, some of the answers given by the children to this question are, as follows:

> Group 1: Our group divided the spinning wheel into 5 parts (consisting of the names of Indonesian cities), the results that appeared on the spinning wheel were 18, 23, 21, 17, and 21, respectively.
>
> Group 2: In our group, we divided the circle into 8 parts which we named after the names of our group's students, after we had done 100 rounds we could find the average results were close to 12 and 13.
>
> Group 3: In our group, we have divided it into 4 equal parts, the averages we got are, 24, 26, 23, and 27 are all almost the same! approaching 25!
>
> Group 4: In our group, we divided it into 5 parts, but the results we got were 20, 21, 13, and 26.
>
> Teacher: Ok, good work for groups 1, 2, 3, and 4!, based on the results in the table, the comparison between the number of times appears and the number of trials, what can you conclude ?
>
> Group 1: We think it is called probability, every inner plane of the circle gets almost the same chance of appearing!
>
> Teacher: Does anyone want to comment on why group 4 has results that are far from the average?
>
> Group 4: Some were unbalanced, maybe because the wheel design was one-sided and unbalanced!
>
> Teacher: Ok, ok, let's check together if the rotating wheel design is not balanced, can you improve your work?
>
> Group 4: Ok Sir!
>
> Teacher: In your opinion, what is the definition of probability?
>
> Group 2: Yes, probability is the quotient between the occurrence of an event n *(A)* and the number of all events n *(P)*.
>
> Teacher: In your opinion, if the number of trials is increased, will the empirical opportunities and theoretical opportunities be the same?
>
> Group 3: We think so, the more experiments are carried out, the empirical chances will be closer to the theoretical chances!
>
> Teacher: It is great!, keep up your good work!

Below are examples of high-level thinking questions regarding the concept of probability.

Look at the picture in **Figure 13**! At an event, a guest spins the spinner arrow, the arrow can stop anywhere on any part of the spinner. The spinner is colored 1/8 blue, 1/24 purple, 1/2 orange, and 1/3 red. So, determine the color that is easiest to get and most difficult to get according to probability theory. Prove your argument!

Answer 1: First equate the denominators:

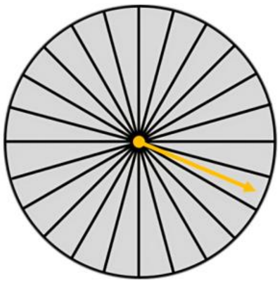

Figure 13. Spinner with 24 equal parts (Source: Authors' own elaboration)

Table 2. The result of material experts

Aspect	Limited trial	
	AV	Criteria
Quality of content and purpose	3.90	Valid
Instructional design	4.00	Valid
Learning design	4.05	Valid
Evaluation and feedback	3.86	Valid
Sharing and discussion features	3.95	Valid
Validity average	3.95	Practical

Note. AV: Average value

Least common multiple from 8, 24, 2, 3 = 24.

Blue part (B): $B = \frac{1}{8} = \frac{1\times3}{24} = \frac{3}{24}$.

Purple part (U): $U = \frac{1}{24}$.

Orange part (O): $O = \frac{1}{2} = \frac{1\times12}{24} = \frac{12}{24}$.

Red part (M): $M = \frac{1}{3} = \frac{1\times8}{24} = \frac{8}{24}$.

Now, we can see that the color with the highest probability is orange (12/24), making it the easiest to get. Conversely, the color with the lowest probability is purple (1/24), making it the most difficult to get. Thus, according to probability theory, orange is the easiest color to get, while purple is the most difficult.

Answer 2: There is a student who proposes a different answer where he will color the spinning wheel picture according to its parts, he multiplies his parts by a total of 24 parts, in concept he is actually using the smallest common multiple, but we will see how he thinks differently.

RESULTS

After the initial finalization process of the media is complete, a review is carried out by experts who will assess the validity of the teaching aids (namely material experts and media experts). Each expert fills out a validation questionnaire that has been prepared based on predetermined aspects. Data from media questionnaires by material experts are presented in **Table 2**.

From **Table 2**, it can be seen that the average value for each aspect of the material consists of

(a) Quality of content and objectives,

(b) learning design,

Table 3. The results of media experts

Aspect	Limited trial	
	AV	Criteria
DLS web display	4.20	Good
DLS menu feature design	3.80	Good
Audio-visuals clarity and interactive media	4.25	Good
Appropriateness aspect programming	4.20	Good
Validity average	4.11	Practical

Note. AV: Average value

Table 4. Data description (between-subjects factors)

		Value label	N
Learning model	1	Experiment	60
	2	Conventional	60
Autonomy level	3	High	40
	2	Medium	40
	1	Low	40

(c) learning design,

(d) evaluation and feedback, and

(e) sharing and discussion features.

So, from all these aspects the average–the average obtained is 4.35. The validity of the media can be determined by changing the score to a scale of 5. Based on the results *expert judgement*, in the first year (limited trial) an average score of 3.95 was obtained with good criteria, Furthermore, the data from the media questionnaire results by media experts are presented in **Table 3**.

Based on **Table 3**, the expert assessment results mean the average value of each media aspect consists of

(a) visual design aspects,

(b) aspects of the DLS menu,

(c) aspects of audio video explanation, and

(d) aspects of program suitability, in the first year (limited trial) an average score of 4.11 was obtained with good criteria, then after revisions were made based on input from media experts it was refined and tested again.

The limited trial was carried out in class VII of junior high school in Kuningan Regency with a total of 20 students. This class trial was carried out to see the effectiveness of the DLS based STEM learning strategy which was developed using student response questionnaires and student learning outcome tests.

Based on **Table 4**, it can be seen that the total sample used was 120 students, divided into 60 students in the experimental class and 60 students also in the control class. As for the division of levels of student learning autonomy, it is known using surveys and questionnaires, from these results students in 1 class are categorized into 3 levels, namely students who have high, medium and low learning autonomy, each evenly numbering 20 people in each group levels. The results of

Table 5. Group statistics

	Learning model	N	M	SD	SEM
Total	Experiment	60	.6140	.16138	.02083
	Control	60	.5213	.17786	.02296

Note. M: Mean; SD: Standard deviation; & SEM: Standard error mean

Table 6. Descriptive statistics

Level autonomy	Learning model	M	SD	N
Low	Experiment	.4875	.13314	20
	Control	.3455	.14522	20
	Total	.4165	.15518	40
Medium	Experiment	.6247	.10715	19
	Control	.5605	.10462	21
	Total	.5910	.10940	40
High	Experiment	.7248	.14376	21
	Control	.6632	.10909	19
	Total	.6955	.13062	40
Total	Experiment	.6140	.16138	60
	Control	.5213	.17786	60
	Total	.5677	.17539	120

Note. M: Mean & SD: Standard deviation

the student pre- and post-test differences are shown in **Table 5**.

The next data analysis method that the researchers used was the two-way analysis of variance (ANOVA). Two-way ANOVA is used to test a comparative hypothesis of more than two or more samples and samples consisting of two or more types simultaneously. In **Table 6** descriptive data is presented on the average increase in students' mathematical creative thinking abilities based on the learning model and level of student learning autonomy.

From **Table 6**, it can be seen that STEM-based learning at a high level of learning independence has an average value of increasing mathematical creativity of 0.7248, STEM-based learning at a medium level of learning autonomy has an average value of increasing mathematical creativity ability of 0.6274, learning STEM-based learning at a low level of learning autonomy has an average value of increasing mathematical creativity ability of 0.4875. Meanwhile, conventional learning at a high level of learning autonomy has an average value of increasing the mathematical creativity score of 54.45, conventional learning at a moderate level of learning autonomy has an average value of increasing a mathematical creativity score of 46.50, and conventional learning at the low learning autonomy has an average value of 40.11. Furthermore, to fulfill the assumption test that all data groups have a homogeneous distribution, they are tested using the Levene test in **Table 7**.

Based on the output of **Table 7**, the significance value is known. Levene's test for equality of variances on the result variable is 0.516, because it is > 0.05, it can be concluded that the data variance of experimental and control class students is homogeneous and the variance

Table 7. Levene's test of equality of error variances[a, b]

		LS	df1	df2	Sig.
LDM	Oon mean	.852	5	114	.516
	On median	.760	5	114	.580
	On median & with adjusted df	.760	5	100.16	.581
	On trimmed mean	.873	5	114	.502

Note. Tests the null hypothesis that the error variance of the dependent variable is equal across groups & LS: Levene statistic

Table 8. Independent sample t-test

		Total	
		Equal variances assumed	Equal variances not assumed
t-test for	t	2.989	2.989
equality	df	118	116.902
of means	Sig. (2-tailed)	.003	.003

between groups is not significantly different, so that the parametric independent sample t-test and two-way ANOVA test can then be used.

Based on the results of the independent sample t-test analysis (**Table 8**), it can be seen that the Sig. (2-tailed) value is 0.003, below 0.05, so it can be concluded that there is a significant difference in creative thinking ability between the control and experimental classes. The next data analysis method that the researchers used was the two-way ANOVA. Two-way ANOVA is used to test a comparative hypothesis of more than two or more samples and samples consisting of two or more types simultaneously. In this study, researchers wanted to find out whether there was a significant difference between the averages of the two groups between groups of students who used experimental learning models using STEM-based DLS and those who used conventional learning, in terms of learning autonomy (high, medium and low). The results of the two-way ANOVA analysis with the help of SPSS are presented in **Table 9**.

Corrected Model

The effect of all independent variables together on the dependent variable. The significance value shows Sig. 0.000 < 0.05 = significant, this means the model is valid.

Intercept

The value of the change in the dependent variable without being influenced by the existence of the independent variable, meaning that without the influence of the independent variable, the value of the dependent variable can change. Based on **Table 9**, 4.18 the significance value shows Sig. 0.000 < 0.05 this means a significant intercept.

Learning Model

In **Table 9**, the significance value shows Sig. = 0.000 < 0.05 this means the learning model has a significant

Table 9. Two-way ANOVA test results

Source	Sum of squares	df	Mean square	F	Significance
Corrected model	1.870[a]	5	.374	23.814	.000
Intercept	38.608	1	38.608	2,458.04	.000
Autonomy level	1.575	2	.788	50.146	.000
Learning model	.239	1	.239	15.202	.000
Autonomy level * learning model	.042	2	.021	1.327	.269
Error	1.791	114	.016		
Total	42.330	120			
Corrected total	3.661	119			

Note. [a]R squared = .511 (adjusted R squared = .489)

Table 10. Multiple comparisons Tukey HSD

(I) Level autonomy	(J) Level autonomy	Mean difference (I-J)	Standard error	Significance
Low	Medium	-.1745*	.02802	.000
	High	-.2790*	.02802	.000
Medium	Low	.1745*	.02802	.000
	High	-.1045*	.02802	.001
High	Low	.2790*	.02802	.000
	Medium	.1045*	.02802	.001

effect. Differences in learning models significantly influence students' mathematical creative thinking abilities

Autonomy Level

In **Table 9**, the significance value shows Sig. = 0.000 <0.05 this means that the level of learning autonomy has a significant effect. Differences in autonomy levels influence students' mathematical creative thinking abilities

Model * Autonomy Level

In **Table 9**, the significance value shows Sig. = 0.002 < 0.05, then model*math level has a significant effect.

Meanwhile, to see further the differences between levels of autonomy, you can see **Table 10**.

From **Table 10**, the differences in learning autonomy at high, medium and moderate levels show a Sig. = 0.000 < 0.05, then there is a significant difference. The difference in learning autonomy at high and low levels shows the value of Sig. = 0.000 < 0.05, then there is a significant difference. The conclusion is that there are differences in students' creative mathematical thinking based on their level of autonomy, where students who have a high level of learning autonomy tend to have better creative thinking abilities. Based on the results of the data analysis above, there is a difference in the increase (N-gain) in the ability to think creatively in mathematics between students who learn using STEM-based DLS and students who learn conventionally (Sig.2 tailed 0.03 < 0.05), where students who learn using STEM have a higher increase compared to students who study conventionally.

Based on the results of the questionnaire, student responses to STEM-based DLS learning, 82% of students are interested in taking part in mathematics learning using a STEM learning model based on DLS, because STEM learning based on DLS helps students to understand the material through a series of projects that are relevant to everyday life. 85% of students agree with the learning model. STEM based on DLS helps students learn actively and independently, because of the ease of DLS which can be accessed anytime and anywhere, the quiz feature helps students practice their abilities better, and 82% of students agree that STEM learning through the DLS feature is able to improve creative abilities. mathematics better with high order thinking skills type questions.

DISCUSSION

The findings in this research strengthen the position of the DLS as an improvement over conventional LMS, this is in line with research (Dowling, 2012) where teachers and students can adjust the desired learning environment, besides that the blended learning method combined with DLS can have a significant impact on learning (Bygstad et al., 2022; Wang, 2019), Apart from that, the existence of sharing and discussion forums can increase student involvement in learning (Lane, 2016). Based on the finding above, the DLS developed is adapted to the stages of STEM learning starting from essential questions, where in these essential questions students are invited to think about the concept of mathematical opportunities that exist in the real world by taking the working concept of the spinning wheel as an example. In this phase, students are trained to think fluently and flexibly as an indicator of their ability to think creatively in mathematics. In the design a plan for the Project phase, students in groups look for references and try to design spinning wheel props from everyday tools and materials, in this phase students are trained to work creatively and innovatively, in this phase students are trained to make relationship connections empirical results of opportunities on the spinning wheel with theoretical opportunity material. Then in the next stage is the stage of making a schedule and monitoring the creation of the project, students collaborate and are given the freedom to make the spinning wheel as creatively as possible within the specified time limit. Next, in the Assess the outcome phase, students practice with the Spinning wheel media that has been made, students play the lottery and record it on the worksheet that has been provided, the teacher assesses the level of quality and originality of the students in making the spinning wheel props. Next, students will make connections between empirical data in the field and the theoretical concept of opportunity, students will also test the results carefully, this is aimed at improving the constructing aspect of students' knowledge as part of an indicator of their ability to think creatively in mathematics.

Then STEM learning spaces is also equipped with video examples of making teaching aids and implementing STEM-based learning. With this feature, teachers, students and STEM activists from various parts of the world can adapt the STEM learning that has been carried out. The following is an example of a web display that contains a video of making props and implementing STEM learning, furthermore, there is a sharing room feature, this feature can be accessed and used by teachers/students and STEM activists to share experiences, implement learning and impressions from participating in STEM learning. In this feature there is also sharing of good practices that have been carried out in the school, so that this is in accordance with theory *NL* which can connect classes without any borders. Based on the validity, practicality and effectiveness criteria previously explained, this research produces a new tool product in the form of a STEM-based DLS web.

This STEM-based DLS has several advantages, namely:

(a) it is easy for students to access material anytime and anywhere because it is web-based,

(b) the DLS developed has a menu that makes it easier for students to learn and connect with teachers, other students and materials interactively,

(c) there are STEM-based learning features which are equipped with STEM problems, videos of STEM learning projects, and

(d) there are interactive quizzes which are equipped with feedback on student answers.

The results of this study are in line with research Lin et al., (2017) where the final results of the research show that there is a positive response from students when using DLS where there are benefits that are felt when compared to conventional learning, namely increasing learning time, improving learning performance, and creating interactive discussions with teachers. They can be used in DLS which can result in the creation of multiple learning connections. This DLS has the potential to replace traditional LMS. Besides that Chourishi (2015) said that DLS can improve learning effectiveness very well. However, implementing DLS into learning also has challenges, as per the results of the research Moore-Russo et al., (2015) namely teachers need to adapt to various online learning spaces (DLS), in the future there will need to be improvements in teacher and student interactions, the best way to identify which digital resources are most suitable, as well as best practices that can be used to utilize online learning spaces effectively and efficient.

The implications of this research are that the findings of this research are useful for enriching theoretical studies regarding the integration of technology-based STEM learning, especially the integrated use of DLS. The process of creating and developing DLS can be imitated and modified by STEM educators to be able to make STEM learning more innovative, through more complete features. Apart from that, this research is useful for teachers in enriching insight and means of collaborating on STEM implementation experiences in the classroom. For policy makers and policy makers, this research can be a reference in creating technology-based learning innovation programs that are in line with the demands of the 21st century.

Regarding the limitations of the study, we would like to comment that, due to the nature of the study, the sample size was only 120 children, so the results are still limited in their generalizability. In this regard, hopefully future research can expand the field study to a larger sample to analyze the results shown here from a quantitative point of view also with a diverse range of STEM projects. Then, the factors of facilities and infrastructure and internet networks are also a focus that cannot be ignored, there is a need for additional supporting technological facilities and infrastructure, which can reach various regions and improving the quality of facilities and infrastructure, including IT technology equipment in schools that can support online learning more optimally.

CONCLUSION

The DLS was developed based on a STEM learning approach and has met standards in the research and development process. The development process is carried out following 4D design (define, design, develop, and dissemination), so that the development process is carried out in a structured and systematic manner according to the stages in 4D design. The feasibility test results show that the STEM-based DLS is suitable for use in mathematics learning. At the evaluation stage, the digital learning room was proven to be effective in learning. The results show an increase in students' mathematical creativity abilities. The STEM-based DLS learning model developed can also have a significant impact on increasing students' autonomous learning abilities, by giving students freedom to study independently, being easily accessible anytime and anywhere and being able to develop good communication and collaboration skills, in addition to making STEM projects make students responsible. Apart from that, the interactive quiz feature can help students understand better because there is feedback and evaluation of the results of students' answers that are developed. Apart from that, there is a sharing space that can be used by teachers, students and STEM activists around the world to share good STEM learning practices that have been carried out. This shows that DLS STEM learning spaces can be an innovative learning alternative that can connect classrooms without boundaries in future.

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APPENDIX A: CREATIVE THINKING ABILITY TEST

1. Rina brings a plastic bag of candy which will be distributed to Ayi and Tara. In the plastic there are 13 orange-flavored candies, 11 melon-flavored candies and 10 grape-flavored candies. Determine:
   a. Ayi's opportunity to take 4 orange-flavored candies.
   b. There is a chance that Tara will take 2 grape-flavored candies if Ayi succeeds in taking 4 orange-flavored candies.
2. Of the 36 students in a class, students aged less than 18 will be randomly selected to work on math problems on the blackboard. If the probability of selecting a student under 18 years of age is 0.25 then determine how many students in the class are 18 years of age or older!
3. An ice cream shop wants to launch a new flavor for its customers. However, the shop conducted a survey first regarding what flavors people like most. The results of the survey are given in **Table A1**. If the store wants to launch two new flavors, specify which flavors have the greatest chance of being liked by consumers?

Table A1. The results of the survey

Ice cream flavor	Many people like it	Many people don't like it
Macchiato	45	15
Tiramisu		40
Hazelnut	35	45

4. Class VIII A consists of 16 male students and 20 female students. As many as 3/4 of the male students and 2/5 of the female students take motorbikes to go to school. If a student is randomly selected to be class president, then find the probability that the student selected is a boy or one who drives a motorbike to school!
5. A doctor is conducting an experiment using drug A to cure disease X with a chance of cure of 0.6. Determine the number of people who are expected to recover if drug A is used for disease X in 750 people!
6. At the company's 10^{th} anniversary celebration, Pandu was selected as an exemplary employee and had the opportunity to choose 1 prize from 4 boxes provided. Each box contains a blue ball representing a motorbike, a yellow ball representing a car, and a red ball representing a laptop with the composition given in **Table A2**. Pandu wants to get a car prize, determine which box has the greatest chance of getting a car!

Table A2. The composition

Box	Blue ball	Yellow ball	Red ball
1	12	10	8
2	9	15	11
3	14	18	12
4	10	15	17

7. Haris plans to log in to an account that requires a password. Unfortunately he only remembered that his password was one of the letters between the vowels. So because he forgot, Haris tried to enter the password randomly. Determine the probability that Haris enters the password incorrectly three times in a row!
8. The picture in **Figure A1** is a spinner with 24 equal parts. At an event, a guest spins the spinner arrow, the arrow can stop anywhere on any part of the Spinner. The spinner is colored 1/8 blue, 1/24 purple, 1/2 orange, and 1/3 red. So, the most difficult color to get (indicated by the arrow) is purple. Prove your argument.

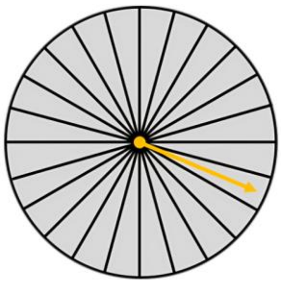

Figure A1. Spinner with 24 equal parts (Source: Authors' own elaboration)