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Digital Didactical Design: Scratch Assisted Learning of Probability Materials in Junior High School

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Abstract

The purpose of this research is to explore students' learning obstacles in learning junior high school probability materials as well as to describe the role of Scratch programming application in the Learning Trajectory of learning junior high school probability materials. The research method used is Didactical Design Research which consists of several main research stages, namely, (1) Didactical situation analysis (exploring learning obstacles and developing HLT); (2) Metapedactical analysis (HLT implementation); and (3) Retrospective analysis, to analyze the learning trajectory process owned by students. The research was conducted on grade VIII students in one of the private junior high schools in Yogyakarta. The research subjects for the learning obstacle exploration were students who had learned the material of probability, namely 27 students of grade IX. While the research subjects for the implementation of didactical design were 63 students of grade VIII. All research subjects came from one of the private junior high schools in Yogyakarta. The results of the study found the existence of student learning obstacles in the material of probability which are divided into 3 types namely ontogenic obstacles, epistemological obstacles, and didactical obstacles. The researcher developed HLT and mathematical task with Scratch for the learning of probability material. The results showed that the use of Scratch programming application can help students understand the concept of probability. Leaning trajectory generated in accordance with the results of restrospective analysis showed several stages of learning, namely, (1) Situational; (2) Referential; (3) General; and (4) Formal.

Keywords: *Digital Didactic; Probability; Learning Obstacle; Learning Trajectory; Scratch*

Introduction

Probability is a mathematical concept related to uncertainty (Paul & Hlanganipai, 2014) (Smith, 1998). This concept is not only important in math subjects, but also in everyday life (Owusu et al., 2022) The concept of probability is often used to make the right choice, predict something, or minimize failure (Armiati et al., 2022). Understanding the concept of probability itself provides various benefits for students. Knowledge of uncertainty or probability can empower students to make wise decisions when facing various situations (Kennedy et al., 2008). A good understanding of probability also helps one to understand the risks and possible benefits of an action and also ensures fairness in everyday life (Bryant, 2012). Given the importance of probability, many countries place probability as part of the mathematics school curriculum including in Indonesia (Koparan & Rodríguez-Alveal, 2022; Wijaya et al., 2021).

In Indonesia, probability material begins to be taught at the junior high school level. The expected learning outcomes related to the concept of probability at the junior high school level are that students can understand probability material and the relative frequency of one event applied to a simple experiment. However, in reality, teaching probability material is not easy(Leonard et al., 2022; Rahmi et al., 2020). This is supported by several studies which found that learning mathematics, especially probability, still has many problems(Birgin et al., 2012; Koparan & Rodríguez-Alveal, 2022; Sezgin Memnun et al., 2019; Yusuf et al., 2021). These problems arise due to several reasons. One of the causes is the limited activities with real contexts in mathematics learning that can help construct students' knowledge related to probability materials (Maharani et al., 2022; A. D. Sari et al., 2024; Suryadi, 2010). This is not in accordance with the characteristics of probability material where probability material is material that is often encountered in everyday life (Kennedy et al., 2008) and should be taught using experiments in learning (Van de Walle et al., 2020; Wijaya et al., 2021).

To help students understand the concept of probability and minimize student learning barriers, there are several studies related to learning probability materials that have been conducted. (Rahayu et al., 2021) has developed a learning trajectory using the context of a picture clapping game to help reduce students' learning barriers in probability material. In addition, (N. Sari, 2022) has also designed HLT using a snakes and ladders game video which is expected to help students understand probability material.

Some studies suggest that in learning probability students should conduct experiments to develop their knowledge of the concept of probability. However, student experiments will be limited if done manually, for example, the limited number of dice throws. Therefore, the experiments that students will do in learning opportunities in this study will use the help of a simple programming application, Scratch, to help students understand the concept of opportunities. Scratch is a simple programming application that is easy for students to use to create stories, games, and even math calculators. The Scratch programming application was chosen because integrating programming in athematics learning can improve students' motivation, learning outcomes, and problem-solving skills(Forsström & Kaufmann, 2018). (Brandsæter, 2021) also suggests that programming can be a bridge between formal mathematics and the real world, for example in learning probability students can conduct unlimited repeated experiments using programming applications. In addition, the use of Scratch in learning mathematics has been proven to help students improve their understanding of the mathematical concepts learned(Fang et al., 2023; Iskrenovic-Momcilovic, 2020; Paparistodemou et al., 2017).

Based on the explanation above, the main objective in this study is to produce a digital didactical design based on students' learning obstacles on the material of grade VIII opportunities with Scratch, by looking at how the role of Scratch programming application in learning junior high school opportunities.

Method

Research Design

This research is a qualitative research, using Didactical Design Research (DDR) research design, where this research aims to obtain a didactical design that can overcome learning obstacles in learning probability material in class VIII. Didactical design research has a foundation in two paradigms, namely the interpretive paradigm and the critical paradigm(Suryadi, 2019). The interpretative paradigm contains a study of reality phenomena related to the impact of didactic design on a person's way of thinking. The critical paradigm has the main objective of implementing changes to the existing didactical design(Suryadi, 2019). The new didactical design will be developed as a step in improving the learning stages so that it can minimize the learning obstacles faced by students, especially in the material of probability in class VIII.

Research Procedure

The research procedure consists of three stages, namely didactical situation analysis, metapedactic analysis, and retrospective analysis. The didactical situation analysis stage begins with the process of extracting information on learning obstacles (prospective analysis). This data mining was conducted to find the students' learning obstacles on opportunity material from the perceptions of students and teachers, which later became a reference for developing a hypothetical learning trajectory (HLT). After that, the researcher developed HLT based on the learning obstacles found and learning tools in the form of mathematical tasks containing mathematical activities on chance materials with the help of Scratch programming application.

After the HLT had been prepared, the researcher conducted the implementation process of the HLT and the learning tools that had been prepared. After the learning process was completed, the researcher used restrospective analysis with a phenomenological approach to describe the learning trajectory that occurred during the implementation process. This research applied two cycles, the first cycle was applied to the pilot experiment and the second cycle was applied to the teaching experiment. Each cycle in this study will go through all three stages. For more details, the research scheme can be seen in Figure 1.

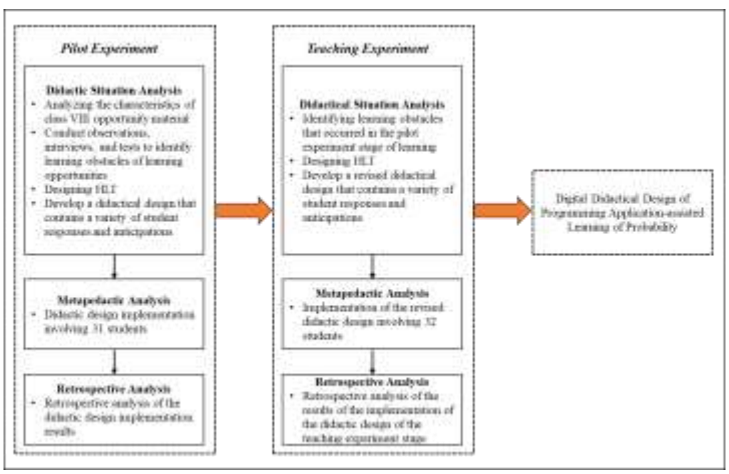


Figure 1. Research Procedure

Research Subject

The research subjects in this study were divided into two groups, namely the exploration of learning obstacles and the implementation of didactical designs that have been designed. The research subjects in the exploration of learning obstacles are students who have learned the material of opportunities, namely 27 students of class IX. Meanwhile, the research subjects for the implementation of didactical design were VIII grade students, namely 31 students in the pilot experiment cycle and 32 students in the teaching experiment cycle. The research subjects came from two private junior high schools in Yogyakarta

Data Collection Instrument

a. Didactic Situation Analysis

The didactic situation analysis stage begins with the process of extracting information about learning obstacles (prospective analysis). To explore data related to learning obstacles, researchers used 3 instruments, namely: (1) in-depth interview guidelines to teachers and students, (2) learning observation sheets, and (3) counting skill test questions. The data collection process was conducted sequentially. First of all, the researcher conducted an interview with the teacher. The interview process was conducted face-to-face to obtain more accurate information from the research subject. The main focus in this interview is information about what learning barriers students have, especially in the material of probability. After the interview process was completed, the researcher conducted classroom observations to confirm the results of the interviews that had been conducted previously. Researchers used 2 observers in the classroom where each focused on teacher and student activities during the learning process. Finally, the researcher gave test questions to students followed by in-depth interviews with students to see the learning obstacles experienced by students on the material of probability. After the researcher obtained information related to student learning barriers, then the researcher compiled a hypothetical learning trajectory (HLT) and mathematical activities (mathematical tasks). The preparation of HLT and mathematical activities refers to the learning barriers that have been found.

b. Metapedidactic Analysis

In this stage, the researcher implemented the mathematical didactical design along with the HLT that had been made in learning probability in class VIII. The instruments used in this stage were HLT and mathematical tasks that had been prepared based on the learning obstacles found.

c. Retrospective Analysis

For restrospective analysis, researchers used video recording instruments and observation sheets to record the learning process that occurred in the classroom. The observation process was carried out during the learning of probability material. This analysis was conducted to develop a revised didactical design after implementation.

Data

To maintain data validity, researchers used data triangulation methods, namely collecting video recordings of research activities and student worksheets(Cohen et al., 2017). The data collected in the form of photos and video recordings of activities, student worksheets, and important notes from researchers and teachers. The combination of all these data collection results was used to check the validity of the researcher's interpretation. The mathematical didactical design and HLT that had been designed also supported the validity of the research, because the didactical design and HLT that were prepared became guidelines in conducting research and references in answering research questions.

Results and Discussion

Students' Learning Obstacle in Junior High Opportunity Learning

The first stage in designing a didactical design for learning junior high school opportunities with Scratch is to analyze learning obstacles. The obstacles are the result of analysis through teacher interviews, learning observations, and tests of opportunity material given to students followed by interviews with students. Learning barriers experienced by students can be identified in 3 types of barriers presented in Table 1.

Table 1. Identification of Learning Obstacle Findings for Junior High Probability Materials

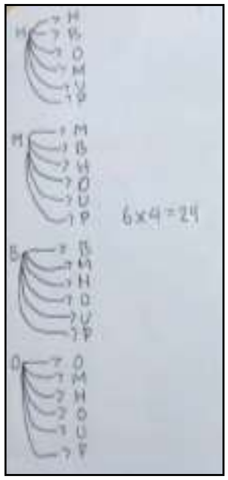
No	Types of Obstacle	Findings
1	*Ontogenic Obstacle*	Probability material is material that is considered difficult by students
		Lack of student interest in mathematics
		Limited understanding of the concept of sample space causes obstacles to the concept of theoretical odds
		Prior knowledge related to theoretical probability is strongly embedded, causing obstacles to the concept of expected frequency
2	*Epistemological Obstacle*	Students' limited understanding and mastery of probability material
		The context used in probability material is less varied
3	*Didactical Obstacle*	Lack of appropriate learning strategies used by teachers in teaching probability material
		Limited teaching materials and media used by teachers in teaching probability material

The results of the learning obstacle analysis were used as the basis for developing a hypothetical learning trajectory and its mathematical task. The hypothetical learning trajectory (HLT) consisted of 5 meetings with 7 activities. The HLT was implemented on 31 junior high school students in the pilot experiment cycle. Based on the results of the implementation in the pilot experiment cycle, there were several improvements made to the HLT. The improvements included adding changes to the location of the number line, as well as information to make it easier for students to generalize the formula. The improved HLT was then reapplied to 31 junior high school students with different schools. The results of the HLT implementation are explained as follows

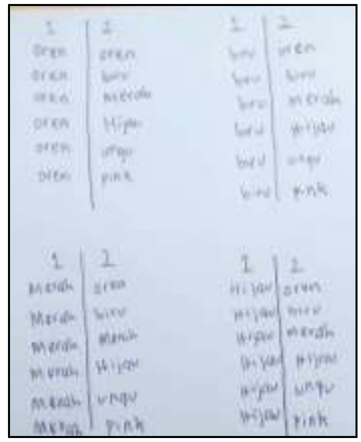
Meeting 1: Sample Point and Sample Space

In the first meeting, the context used was spinners, where students were asked to write down the possibilities that occur if there are two spinners that are rotated simultaneously. The purpose of this activity is for students to understand the concepts of sample point and sample space. Figure 2 shows an example of a student's answer in determining the probability of spinning two spinners.

Group work result 3



Group work result 5



Group work result 1

Figure 2. Student work in determining the sample point of 2 spinners

Figure 2 shows the results of students' answers when asked to write down all the possibilities that occur when there are two spinners rotated together. From the figure, it can be seen that there are 2 ways used by students to write down the possibilities of spinner rotation, namely by listing and table method. The list method is the informal method used by most students. Students will write down one by one the color pairs that might appear. The method used by students is in the referential level.

From Figure 2, it can also be seen that there are students who use the table method to write down the possibility of spinning the spinner. The table method is a more effective and efficient way because it reduces the risk of losing writing members of the sample space. The table method is at the general level, which is a potential tool to guide students towards formal mathematics.

However, both list and table methods are inefficient if the sample space is large. Therefore, there is a need for a vertical mathematization process to determine the number of members of the sample space, for example by counting techniques. In this spinner context, students are given a picture of 3 spinners and asked to determine the number of possibilities if the three spinners are rotated. The rotation of the three spinners makes students have to leave the way of listing and tables in determining the number of members of the sample space. The results of student work can be seen in Figure 3.

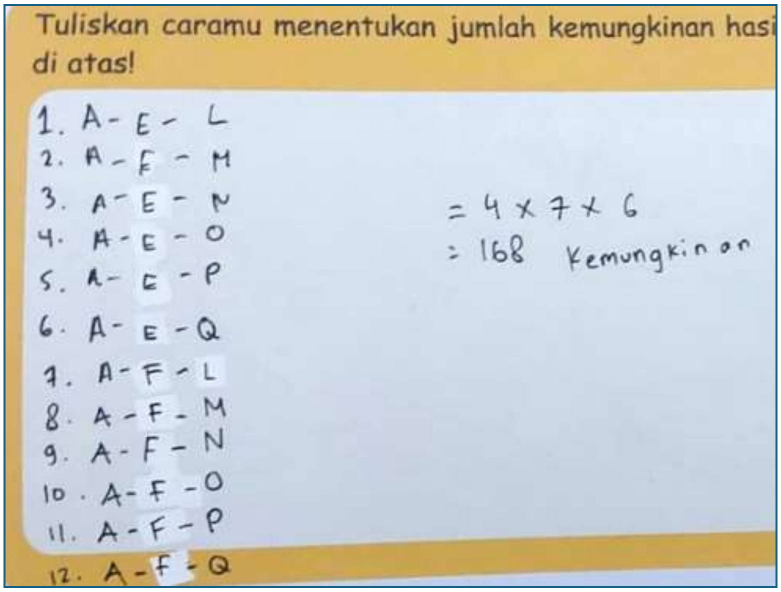


Figure 3. Student work in determining the sample point of 3 spinners

From Figure 3 on the left, it can be seen that at first the student tried to use the method of registering as in the previous problem. However, students find it difficult because there are too many possibilities that occur. Furthermore, by connecting the number of colors in each spinner with the number of possibilities that occurred in the previous problem, students found a way to determine the number of members of the sample space from spinning 3 spinners without having to register or make a table. Spinner 1 has 4 colors, spinner 2 has 6 colors, and spinner 3 has 7 colors which are then written in the formula as follows

Many members of the sample space = 4x6x7=128

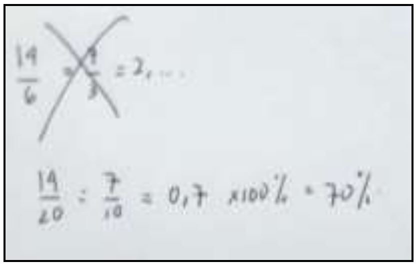
From this activity, it can be seen that although at first students used an informal way to determine the number of members of the sample space, this method can help students find a formal mathematical way to calculate the number of members of the sample space.

Meeting 2: Theoretical Probability

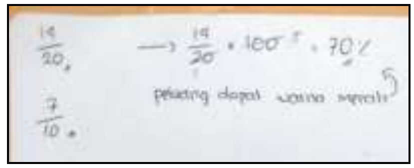
In the second meeting, students were given a problem using the context of marbles. The purpose of the activity at this second meeting is that students can calculate theoretical odds. In addition to providing visualization on the mathematical task, the teacher also provides props in the form of marbles that match the problem presented, which is also a situational stage given to students.

In this activity, at first students were asked to guess the marbles that were taken. Most students guessed the red marbles that would be taken because the red marbles had a larger number. In guessing these marbles, students still used non-formal ways according to the results of their respective thoughts. To further direct students to formal mathematics, students are asked to determine the chances of taking marbles of each color. The results of student work can be seen in Figure 4.

Group work result 6



Group work result 3



Group work result 5

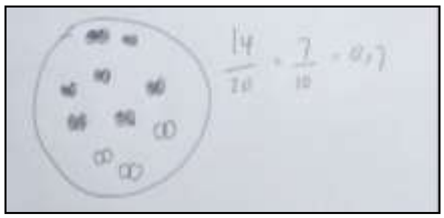


Figure 4. Students' work in determining the probability of taking the red marble

Based on the results of students' answers, there is a variety of formality in the way students determine the chances of taking the marbles. Most groups used the formal way by comparing the number of marbles to be calculated with the total number of marbles. However, one group used the informal method by representing the marbles with a small circle and dividing it to get a probability value of 0.7. The diversity of the level of formality can be a matter of discussion in class learning. To support this, students were asked to communicate the results of their work in front of the class, represented by group 3 and group 5.

The presentation and discussion activities went well. Students look enthusiastic both in presenting their work and in responding to their friends' work. In this activity, students and the teacher also concluded the theoretical chance formula which was also written on the student worksheet, namely $P(A) = \frac{n(A)}{n(S)}$.

Meeting 3: Simple Calculator

In meeting 3, students are asked to compile programming blocks in the Scratch programming application using the concept of chance that they have learned. Before students arrange the programming blocks themselves, students are asked to complete the blocks that have been arranged so that the programming can be run. In this activity, all students were able to assemble the programming blocks without significant obstacles. However, the time used by students is quite long. This is because students are not too familiar with programming applications so it takes a long time to complete it.

After completing the programming block, students are asked to compile their own programming block with a different context. In this activity, students will learn to apply the concepts of random events and theoretical probability in programming applications. Although not all students finished composing on their own, the number of students who succeeded in composing increased from the pilot experiment cycle. In the teaching experiment cycle, there were 10 students who managed to arrange their own programming blocks using the concept of theoretical probability. The following are the results of students' arrangement in programming.

Figure 5. Student programming block preparation results

Meeting 4: Empirical Chance

In the fourth meeting, there are 2 activities that students do. The first activity is to determine the choice with the dice, where students will roll the dice using the Scratch application and determine the choice based on the results of rolling the dice. The second activity is to determine the winner with a spinner, where students will spin the spinner using the Scratch application and determine the winner based on the results of spinning the spinner. The purpose of these two activities is to provide experience to students to find the concept of empirical opportunities. The following is an example of the results of spinning the spinner on Scratch and the results of student answers.

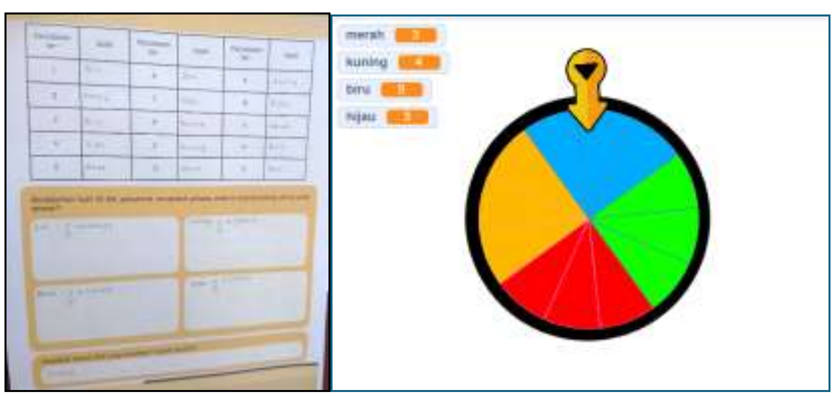


Figure 8. Spinner results and student answers

From Figure 8, it can be seen that after students conduct an experiment with Scratch, students determine the empirical probability by comparing the number of times the color appears with the number of trials conducted. Conceptually, these students have understood that to calculate the empirical odds is to compare the number of events with the number of trials.

To further strengthen the concept that empirical odds are odds based on experimental results, after getting their respective answers, students were asked to compare their answers with their friends' answers. From the results of the comparison, students found that the answers obtained by each student would vary depending on the results of the experiment. This emphasizes to students that empirical probability will depend on the results of the experiment.

Meeting 5: Expected Frequency

The activity at this meeting begins with students being asked to guess how many times prime numbers appear on several throws of the dice. Furthermore, students are asked to prove the results of their guess by rolling the dice using the Scratch application 5, 20, 50, and 100 times and writing down the results.

Based on the results of the roll, students are asked to compare the theoretical probability of the appearance of prime dice numbers with the empirical probability based on the results of their experiment. The purpose of this activity is to introduce students to the concept of expected frequency, where there is a relationship between the theoretical probability and the number of trials conducted. The following are the results of students' answers to the meeting 5 activity.

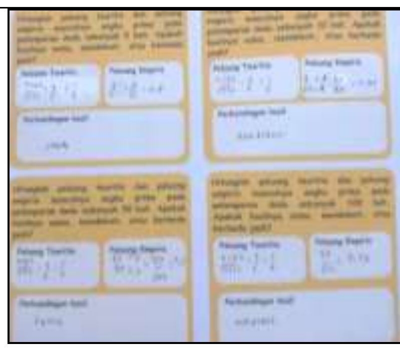
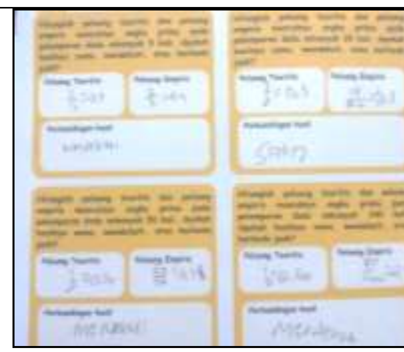
Group work result 1	Group work result 4
	

Figure 9. Student work in comparing the empirical and theoretical probability of rolling a dice repeatedly

Furthermore, to direct students to the expected frequency formula, one of the groups was asked to present their work. From the presentation of the results, the researcher directed students to the concept of expected frequency.

Peneliti: “bagaimana hasil dari perbandingan antara peluang teoritis dengan peluang empirisnya?” *Siswa: “ada yang mendekati ada yang sama kak”* *Peneliti: “nah, iyaa.. ternyata setelah dilakukan percobaan, nilai peluang empirisnya mendekati peluang teoritisnya yaa, bahkan ada yang sama. Nah, kalau kita melakukan 500 kali pelemparan, kira-kira nilai empirisnya akan mendekati peluang*	*Researcher: "What are the results of the comparison between theoretical probability and empirical probability?"* *Student: "Some are close, and some are the same, Miss/Sir."* *Researcher: "That's right. It turns out that after conducting the experiment, the empirical probability values are close to the theoretical probability values, and some are even the same.*

teoritisnya tidak?" *Siswa: "iya kak, mendekati"* *Peneliti: "brati peluang munculnya angka prima berapa yaa?"* *Siswa: "setengah yaa kak?"* *Peneliti: "iya betul setengah. Nah kalau kita melempar 500 kali, kira kira berapa kali munculnya angka prima?"* *Siswa: "berati ½ dikali 500 kan kak.. hasilnya 250 kak"* *Peneliti: "iya betul, ada 250 kali yaa kira-kira.. nah ini yang dinamakan frekuensi harapan. Bagaimana tadi cara menghitungnya?"* *Siswa: "peluang dikali banyak pelemparan kak"* *Peneliti: "okee sekarang tuliskan rumus formalnya sesuai petunjuk di LKPD yaa.."*	*Now, if we perform 500 trials, do you think the empirical probability will be close to the theoretical probability?"* *Student: "Yes, it will be close."* *Researcher: "So, what's the probability of getting a prime number?"* *Student: "It's half, right?"* *Researcher: "Yes, that's correct, half. Now, if we roll the dice 500 times, how many times will a prime number likely appear?"* *Student: "It would be ½ multiplied by 500, which is 250."* *Researcher: "Exactly, it's approximately 250 times. This is what we call the expected frequency. How did we calculate it earlier?"* *Student: "Probability multiplied by the number of trials, Miss/Sir."* *Researcher: "Okay, now write down the formal formula based on the instructions in your worksheet."*

Based on the dialog above, from the results of repeated experiments, students understand that the more experiments conducted, the empirical probability value will tend to approach the theoretical probability value. From this, students can estimate how many times prime numbers appear when the dice are thrown 500 times. Then with a little direction from the teacher, students find the concept of expected frequency where the way to calculate it is by multiplying the theoretical probability value by the number of trials or can be written as $Fh(A) = p(A) \times N$.

Learning Trajectory of Programming Application-assisted Probability Learning

One of the effective solutions to overcome the learning obstacles identified at the didactic situation analysis stage is to develop a didactic design. (Romdhani & Suryadi, 2016, Rosita et al 2019). In this study, the researcher developed a didactical design that contained pedagogical didactical actions given by the teacher, predictions of student responses, and anticipation of the predicted student responses. The hypothetical learning trajectory and student activity sheet provided are part of the didactical design for learning opportunities in class VIII. The learning trajectory that has been prepared is then implemented at the metapedactic analysis stage in the pilot experiment and teaching experiment cycles. From the implementation, the local learning trajectory (LLT) was produced.

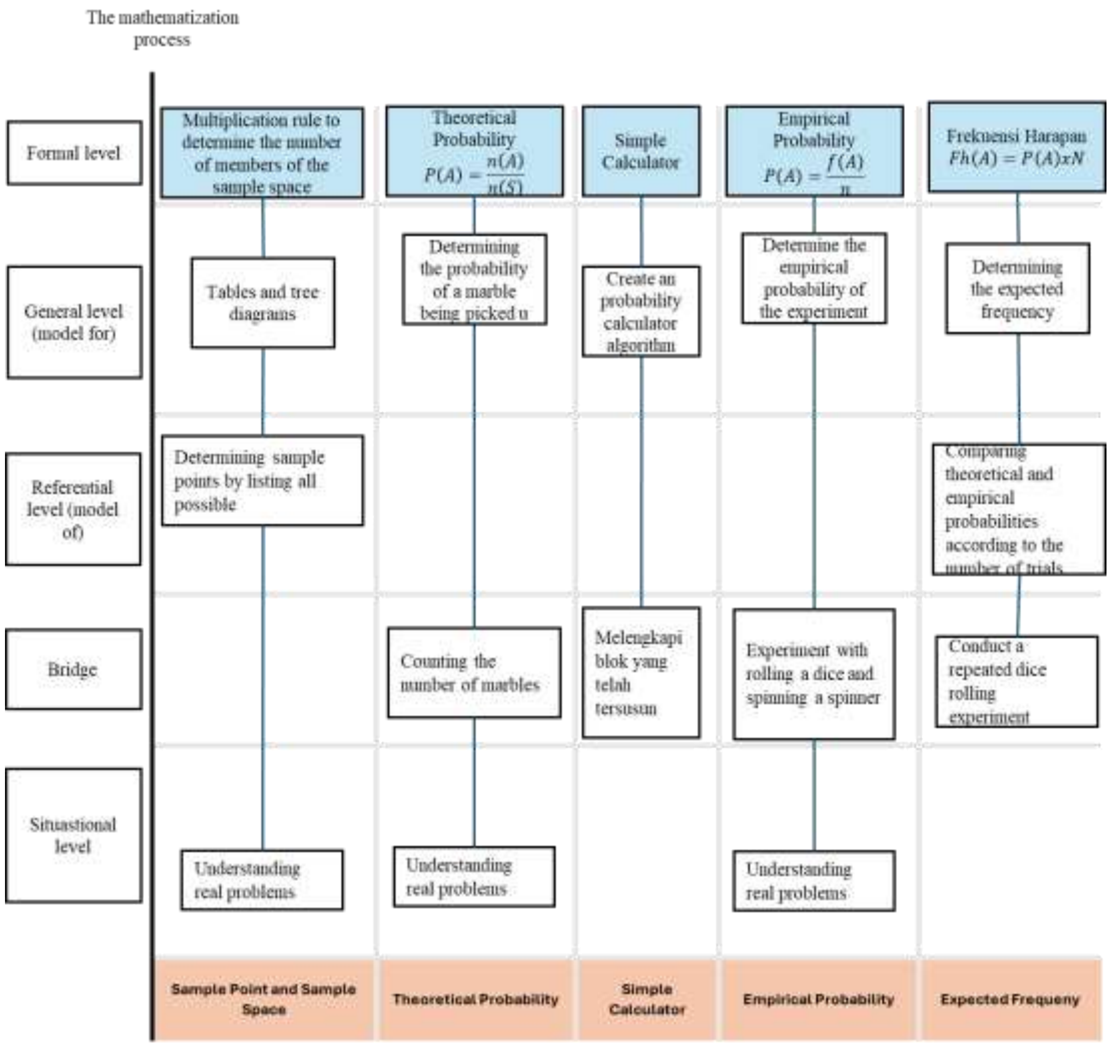


Figure 10. Learning Trajectory of Programming Application-assisted Probability Learning

The local learning trajectory was obtained based on the HLT that had been implemented in the pilot experiment and teaching experiment cycles. In addition, the overcoming of learning obstacles with the didactic design also supports other research which states that didactic design is effective in reducing learning obstacles and supporting the achievement of learning objectives. (Romdhani & Suryadi, 2016; Rosita et al 2019; Lestari, 2021; Nur'aeni & Muharram, 2018).

In this learning trajectory, students conduct experiments to discover the concept of chance. (Wijaya et al., 2021; Van de Walle et al., 2020 p. 642). In the designed didactical design, the Scratch programming application is useful to help students perform repeated experiments, such as the spinner and dice rotations performed in activities five, six, and seven. This is in accordance with the opinion of Brandsaeter (2021) which states that the use of programming applications can be a bridge between formal mathematics and the real world, one of which is the concept of chance, where by using programming applications the number of experiments conducted by students can be unlimited. In addition, in this study students were also asked to develop a simple calculator using the Scratch programming application, where by compiling the calculator students can apply the theoretical probability concept that has been learned in programming blocks. The findings in this study corroborate other research which states that the use of Scratch programming applications provides opportunities for students to develop intuition and conceptual understanding of probabilistic ideas. (Batanero & Diaz, 2012; Paparistodemou et al., 2017).

Conclusion

Based on the results of the research that has been conducted, it is found that there are learning obstacles experienced by students in the probability materials. The results also found that learning using Scratch application can help students understand the concept of probability to reduce the learning barriers that occur in students. Scratch application is used as a tool in conducting experiments to find the concept of . Scratch application is also used by students to develop programming to implement the concept of probability that they have learned.

Based on the conclusions obtained, some suggestions that researchers give, namely: (1) Scratch-assisted learning trajectory research helps students to understand the concept of probability in junior high school so that similar research can be done to help students understand other mathematical concepts; and (2) lesson planning that considers the expected student responses is highly recommended to be done by teachers so that the expected learning objectives can be achieved more optimally.

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