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The influence of research-based learning implementation in improving students' combinatorial thinking skills in solving local irregularity vertex r-dynamic coloring

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The influence of research-based learning implementation in improving students' combinatorial thinking skills in solving local irregularity vertex *r*-dynamic coloring

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Abstract. This research is one of the studies aimed at applying research-based learning and aims to determine its effect on the combinatorial thinking skills of students in solving local irregularity vertex *r*-dynamic coloring problem. The research method used in this research is mix-method. Mix-method research is a combination of qualitative research and quantitative research. The qualitative method is used to obtain data related to the results of testing on each indicator and the results of the portrait phase while the quantitative method is used for statistical analysis. The experimental class consisted of 41 respondents and the control class consisted of 30 respondents. The treatment given is different, namely between the treatment in the experimental class and the treatment in the control class. In the experimental class applied learning tools that have been developed and applied research-based learning methods. While the control class used research-based learning methods without the learning tools that have been developed. Based on the treatment that has been given, the results of students' combinatorial thinking skills show for the control class 53% are categorized as low-level, 37% are categorized as a medium level, and 10% are categorized as a high level of combinatorial thinking skills and then experimental class that 34% are categorized as low level, 44% are categorized as a medium level, and 22% are categorized as combinatorial high-level thinking skills. The results of this study of homogeneity of two classes by using a pre-test score of 0,701 result show sig> 0.05 Thus Spake the differences of the mean of two classes is not significant. The inferential statistical result of the independent sample t-test on the posttest results Showed that the sig 2-tailed value was 0.000 (p <0.05) so that was significant. The conclusion is there is a significant impact of the application of research-based learning in improving the students' combinatorial thinking skills in solving local irregularity vertex *r*-dynamic coloring.

1. Introduction

Graph theory is given to education in higher education. One of the topics presented in the course is the study of staining vertex, in particular, the study of local irregularity *r*-dynamic vertex coloring which requires combinatorial thinking skills (combinatorial thinking). To grow this combinatorial thinking skills must have needed an appropriate lesson plan.

Combinatorial thinking skills will make a person have the ability to think of all the possibilities that can occur in a certain condition. These skills can also train students in math, make an estimate, make generalizations, and think systematically [1]. This combinatorial thinking a particular aspect of mathematical thinking [2].

There are several indicators of combinatorial skills, the following is a breakdown of the indicators and sub-indicators which are shown in Table 1.

Table 1. indicators and sub-indicators combinatorial thinking skills

Indicator	Sub Indicators
Identifying some cases	a. Identify the property/characteristic of problems b. Apply some cases
Recognizing the pattern of all cases	a. Identifying patterns of settlement case b. Extending the pattern of settlement of cases obtained
Generalize all cases	a. Applying mathematical symbolism b. Counting cardinality c. developing algorithms
Proved mathematically	a. Calculating an argument b. Test algorithms c. Developing a bijeksi d. Test bijeksi e. Applying evidence inductive, deductive, and qualitative
Consider with other combinatorial problems	a. Interpretation b. Propose open issues c. Knowing the new combinatorial problems d. Finding potential applications

One of the alternative learning models that can be used to develop the skills of the combinatorial student is student-centered learning that is research-based learning. RBL is a learning method that uses contextual learning, authentic learning, problem-solving, cooperative learning, hands-on and minds-on learning and inquiry discovery approach [3]. This learning model provides an opportunity for students to build research steps. Lockwood stated that research-based learning is a research-based learning model in order to build knowledge in a way to formulate hypotheses, collect data, analyze, make inferences and draw up a report [4]. The purpose of research-based learning in higher education is to help students develop the intellectual abilities and a strong practical connection between each of the boundaries of research and student learning. Research-based learning plays an important role in improving the thinking skills of students. Allowing myself to think combinatorial is one way to improve the thinking skills of students. The habit of thinking combinatorial alone is not enough to improve the thinking skills students need for the development of devices that support the success of learning.

Learning device needs to be developed in the success of research-based learning activities based learning in higher education is the student worksheet, achievement test, and monographs. The availability of materials appropriate to the curriculum, characteristics, objectives, and problem-solving demands are several reasons that encourage the development of learning tools [5][6]. Student Worksheet is an activity sheet that contains information and instructions from teachers or lecturers to the students to be able to do an activity independent learning by practice or application of learning outcomes to achieve the learning objectives [7]. In addition to the worksheet student and monographs in designing learning, the device should consider the cognitive load of students.

Implementation of learning by using research-based instructional media bias based learning is used to look at student combinatorial skills presented in the form of phase portrait based on indicators and sub-indicators combinatorial skills mentioned in table 1. Based on these problems, it will be the development of learning tools to use research-based learning models aimed at upgrading the skills of students in combinatorial combinatorics problems. Problems are focused on the problems of discrete mathematics to the study of local irregularity *r*-dynamic vertex coloring. Therefore, in this study, the author chose the topic "The influence of research-based learning implementation in improving students' combinatorial thinking skills in solving local irregularity vertex *r*-dynamic coloring".

2. Research methods

This research is mixed-method research with a multi-method approach. Multi-method is a combination of qualitative and quantitative research methods. The method used is explanatory sequential design, which is a combination of research with quantitative data collection and analysis in the first phase while the second phase is followed by data collection and analysis of qualitative data to make a conclusion of the study in the first stage. If the quantitative and qualitative methods are not used together and the results are not accurate enough to understand the issues in the study using the mixing method can getting the best understanding.

This research aims to develop research-based instructional tools based on learning and produce learning tools such as worksheets students, achievement tests and monographs as well as find a significant difference between the control and the experimental class. This study has been developed as a mathematical learning device. Research devises development refers to the development model used in the study of research and development (R & D). Development of the device in this study based on the theory of research-based learning. Educational products developed in this study are the Student Worksheet, monographs, and tests of learning outcomes which include combinatorial skills tests.

Researchers gather quantitative data as the main data so that qualitative data is used as a data supplement. The collection of quantitative data as the primary data in the form of test questions related to local issues irregularity *r*-dynamic vertex coloring which is also related to the skills of the student combinatorial contain essay questions in a worksheet. After that, the results worksheet students will be assessed on an assessment rubric combinatorial thinking skills. Furthermore, in order to collect qualitative data obtained from interviews and observations conducted on the application of instructional media that have been developed in the experimental class that implements research-based learning, including in the control class who did not wear the development of learning tools.

One experimental class and the control class is given pre-test and post-test. Things to do at first is a quantitative analysis using independent samples t-test, but before the data analysis performed, homogeneity test and test for normality. Descriptive and inferential statistics were used to analyze the qualitative data. Information obtained by the frequency, average and standard deviation is used to describe statistical data on the application of the results of learning tools that have been developed. Independent samples t-test was used to compare the average of the two classes, with a significant difference at the 0.05 level. Qualitative analysis related to the activities of students, especially in identifying some cases, identify patterns of all cases, generalize all cases, proved mathematically, and consider other combinatorial problems. Each indicator will be judged by four criteria: (1) unfavorable; (2) sufficient; (3) good; (4) very good. The total sub-indicator is fifteen items. Thus, the maximum score is 60. Finally, the combinatorial thinking skills category will be grouped into three categories, namely the low-range category score 15-29, the medium category with a score range 30-44 and a higher category with a range of scores 45-60.

3. Main results

The development of a research-based learning device aims to determine the impact on the combinatorial thinking skills of students in the study of local irregularity *r*-dynamic vertex coloring. The development of the device is based on Thiagarajan development model that consists of four stages, ie define, design, develop, and disseminate. The first stage of development is the validation done by experts, followed by testing the effectiveness of learning tools that have been developed.

Learning device generated in this study of RPS, worksheets students, and final tests research using model-based learning research to the study of local irregularity *r*-dynamic vertex coloring. Discussion on the effectiveness and practicality of the learning device will present the achievement of the quality criteria of the learning device that has been developed using a research-based learning model for analyzing the combinatorial thinking skills of students.

Field trials using research-based learning models for measuring and analyzing the combinatorial thinking skills of students. At the first meeting of lecturers discuss the cardinality as prior knowledge to students. It was preceded by the student given the same graph to look cardinality, and at the end of the first meeting, students were asked to find a new graph to count cardinality. At the time of the work that professors around to find out the difficulties experienced by the students in calculating the cardinality.

This study found the results related to the analysis of the combinatorial thinking skills of students in solving local problems irregularity r-dynamic vertex coloring on the application of research-based learning tools based learning. The pretest is given to both classes, both experimental class and control class. By using a t-test, researchers analyzed data obtained on homogeneity and normality. Based on the pre-test results, it can be seen that the two classes had the same variant. Therefore, the class is said to be homogeneous. The results of the pretest of 71 students indicate that the combinatorial skills of 30 students in the control class are 10% or 3 students with high combinatorial skills, 27% or 8 students with moderate combinatorial skills, and 63% or 19 students with lower combinatorial skills. While the 41 students in the experimental class are 12% or 5 students with high combinatorial skills, 24% or 10 students with the skills combinatorial moderate, and 64% or 26 students with lower combinatorial skills. The results of these two classes can be presented in a diagram like in Figure 1.

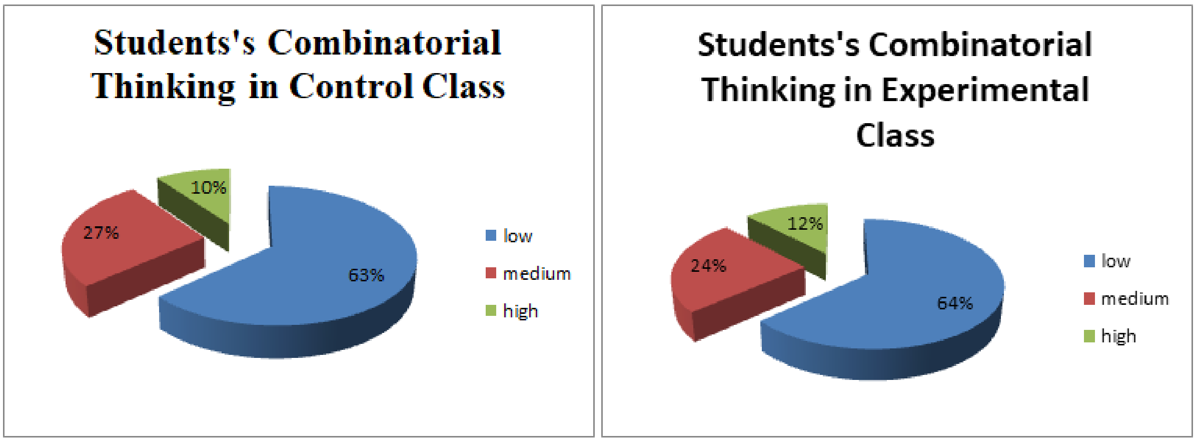

Figure 1. Distribution of combinatorial skills of students during the pretest

Before applying the learning tools that have been developed, homogeneity tests conducted prior to the 71 students of grade control and experimental group using a t-test. In Table 2 and Table 3 it can be seen that the homogeneity of the pretest results obtained value (Sig.) Of homogeneity of variance was 0.701. It can be concluded that the assumption of homogeneity of variance is met because the significant value gained more than 0.05. This proves that the average student combinatorial skills of these two classes are homogeneous.

Table 2. Homogeneity test pretest

Levene Statistic	df1	df2	Sig.
.149	1	69	.701

Table 3. The average value of pretest results from a control class and experimental class

class	Mean	N	Std. Deviation	Variance	Std. Error of Mean
control	30.3333	30	11.18291	125.057	2.04171
experimental	30.2439	41	11.77663	138.689	1.83920
Total	30.2817	71	11.44825	131.062	1.35866

The average score on the pretest results is the control class 30.3333 (SD = 11.18291), while the average value pretest result in the experimental class is 30.2439 (SD = 11.77663). The difference between the average pretest score is 0.701 ($p > 0{,}05$), it means that the average difference between the two classes is not significant.

Table 4. The Levene's test for equality of variances independent sample t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
pretest	Equal variances assumed	.149	.701	.032	69	.974	.08943	2.77036	-5.43729	5.61616
	Equal variances not assumed			.033	64.411	.974	.08943	2.74795	-5.39956	5.57842

Table 4 also shows that the t-test results obtained sig. (2-tailed) was 0,974 ($p > 0{,}05$), so there are no significant differences between pretest results in a control class and experimental class. This also indicates that both are homogeneous.

Furthermore, the researchers showed the research after learning device usage. Before it is done, it will be shown the results of data normality test post-test results of students as Table 5.

Table 5. Test for normality in post-test results of the control and the experimental class

	class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
post-test	control	.116	30	.200[*]	.937	30	.073
	experimental	.123	41	.125	.965	41	.241

From table 5 can be known that significant value to a control class is 0.730 and for class experiments is 0.241. This suggests that significant value is more than 0.05, which means the result of the post-test of both classes of normal distribution.

Table 6. The standard deviation for the results of post-test grade control and experiment

class	Mean	N	Std. Deviation	Std. Error of Mean
control	31.9667	30	5.31415	.97023
experimental	39.7805	41	5.21782	.81489
Total	36.4789	71	6.50902	.77248

While in table 6 can be known to the average post-test results from a control class is 31.9667 (SD = 5.31415) and the average post-test result for an experimental class is 39.7805 (SD = 5.21782). Thus, it can be concluded that the average post-test results of the experimental class higher than the class of control after the implementation of research-based instructional tools based learning. Furthermore, in Table 7 indicated that sig. (2-tailed) from the independent t-test was 0.000 ($p < 0{,}05$). It means that there are significant differences between the post-test results of these two classes. The conclusion is there is a significant impact of the application of research-based learning in improving the student's combinatorial thinking skills in solving local irregularity vertex *r*-dynamic coloring.

Table 7. Independent sample t-test on grade control and experiment

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
post-test	Equal variances assumed	.085	.771	-6.185	69	.000	-7.81382	1.26340	-10.33423	-5.29341
	Equal variances not assumed			-6.167	61.983	.000	-7.81382	1.26704	-10.34660	-5.28104

Results postest of 71 students showed that skill combinatorial of 30 students in the control class to change the number, ie which initially contained 63% or 19 students with the skills combinatorial lower to 53% or 16 students, of 27% or 8 students with the skills combinatorial is becoming 37% or 11 students, while students with lower combinatorial skills do not change the amount, which remains at 10% or 3 students. For the 41 students in the experimental class were originally there is a 64% or 26 students with the skills combinatorial low turn out to be 34% or 14 students, originally there were 24% or 10 students with the skills combinatorial moderate to 44% or 18 students, and 12% or 5 students with the skills of combinatorial higher to 22% or 9 students. The results of the second class post-test are presented in the diagram like Figure 2.

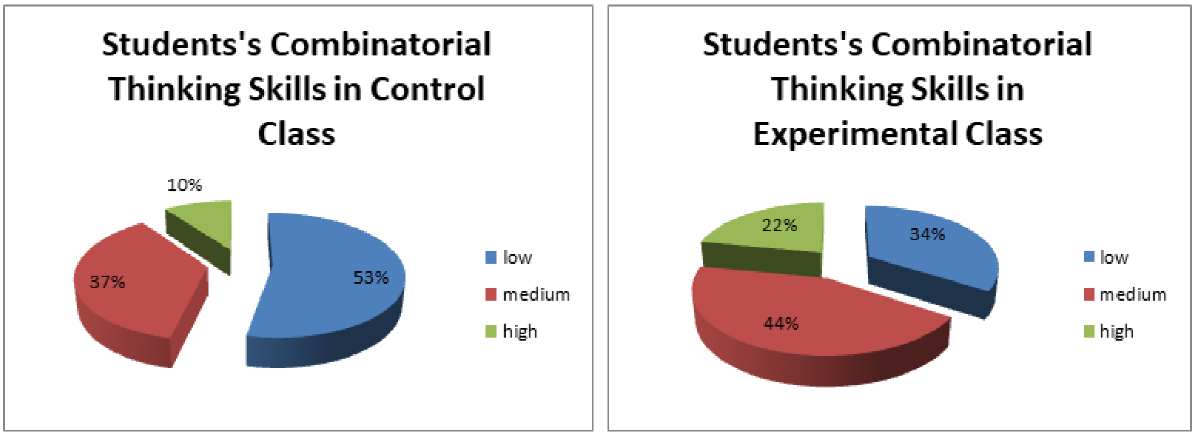

Figure 2. Distribution of combinatorial skills of students during the pretest

To know in detail the process of combinatorial skills of students, researchers using the phase portrait. Images obtained with the phase interviewing the student so that researchers can figure out the logic of these students, from the first step to the last step. Each indicator is represented by a particular code, after which the code is assumed to be a vertex, and each groove thinks students represented as a directed line in accordance with the groove in accordance with the logic of the student. One portrait phase combinatorial skills of students can be seen in Figure 3.

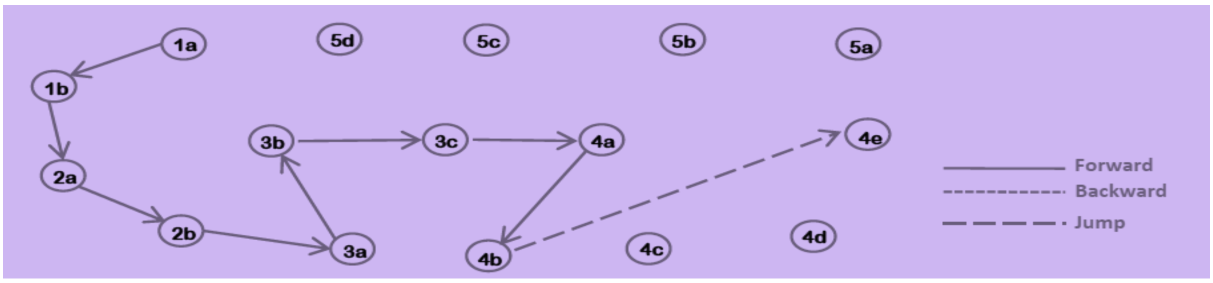

Figure 3. Images phase combinatorial students with the skills being

Images are taken to interesting phase process, combinatorial thinking skills of students in resolving problems in the study of local irregularity r-dynamic vertex coloring. Subject selection is based on the work of post-test, it was determined six subjects, three of grade control (subjects 1, 2, and subject 3) and 3 of the experimental class (subject 4, 5, and subject 6), an interview conducted on the subject that has been determined to know the thinking process in solving local irregularity r-dynamic vertex coloring.

Subject 1 has reached level 3 of the ability to think combinatorial, based on the results of the analysis of the work subject 1 was able to understand the coloring is simple in a graph then subject 1 was able to apply the symbolism of mathematics is shown by being able to calculate the cardinality and the subject of an also been able to develop a way of giving coloring ie precedence by giving staining on the vertex having the greatest degree. Based on a job analysis and interviews on the subject 1 then the flow of combinatorial thinking skills can be seen in the following phase of this portrait:

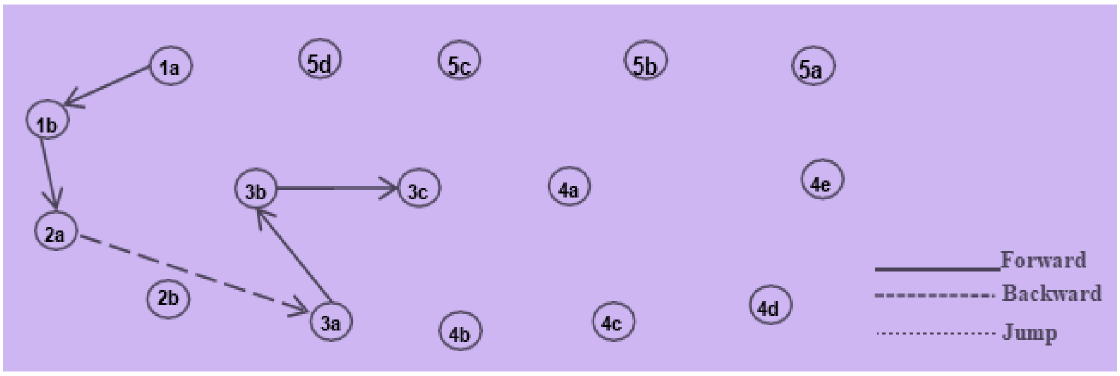

Figure 4. Images phase of the subject 1

Subject 1 in step 1 to step 2a think straight according to the stages and then in step 2a jump to the stage later to stage 3a 3b and 3c. Thus the subject 1 is at level 3 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

Subject 2 has reached level 3 of combinatorial thinking skills, based on the analysis of work subject 2 was able to understand the simple staining in a graph then subject 2 has been able to apply mathematical symbolism. Based on a job analysis and interviews on the subject of the groove 2 combinatorial thinking skills can be seen in the following phase of this portrait:

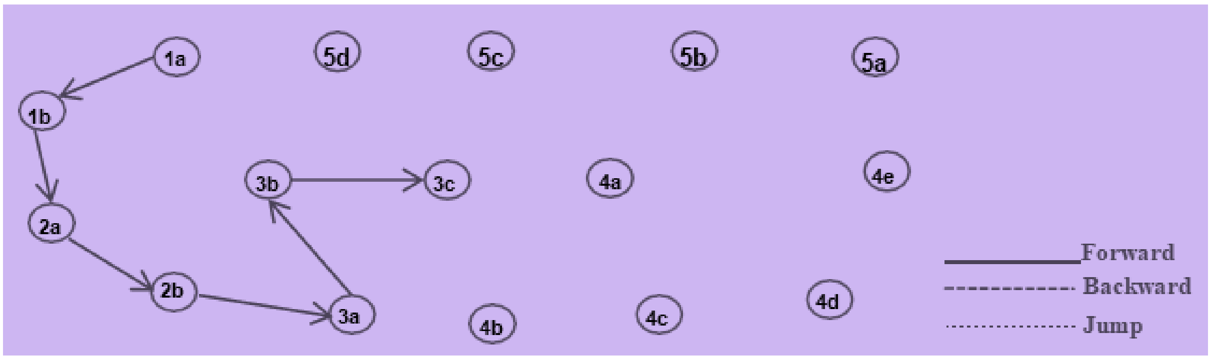

Figure 5. Images subject phase 2

Subject 2 In step 1a through step 3c to think straight in accordance with the stages. Thus the subject 2 is at level 3 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

Subject 3 has reached level 4 of combinatorial thinking skills, based on the analysis of work subject

3 was able to understand the simple staining in a graph then subject 3 has been able to apply mathematical symbolization shown by being able to calculate the cardinality and test algorithms that have been made. Based on a job analysis and interviews on the subject of the groove 3 combinatorial thinking skills can be seen in the following phase of this portrait:

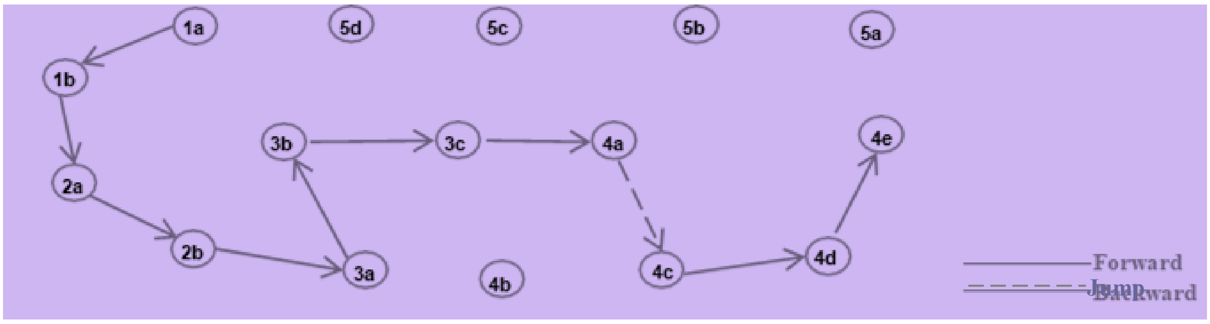

Figure 6. Images of the subject phase 3

Subject 3 in step 1 to step 4a think straight according to the stages and then in step 4a then jump to step 4c to 4d and 4e stage. Thus the subject 3 is at level 4 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

Subject 4 has reached level 4 of combinatorial thinking skills, based on the analysis of the subject work 4 succeeded in developing an algorithm, calculate and test algorithms, the subject 4 can also apply inductive deductive proof and qualitatively. Based on a job analysis and interviews on the subject of the groove 5 combinatorial thinking skills can be seen in the following phase of this portrait:

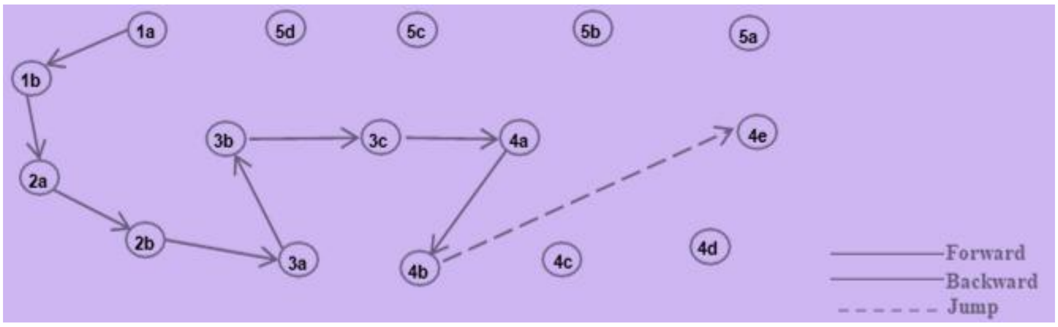

Figure 7. Images of the subject phase 4

Subject 4 In step 1 to step 4b think straight according to the stages and then in step 4a jumps to step 4e. Thus the subject 5 is at level 4 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

Subject 5 has reached level 5 of combinatorial thinking skills, based on the analysis of the subject work 5 successfully develop algorithms, calculate and test algorithms, the subject 5 can also apply inductive deductive proof and qualitatively. Based on a job analysis and interviews on the subject of the level 5 combinatorial thinking skills can be seen in the following phase of this portrait:

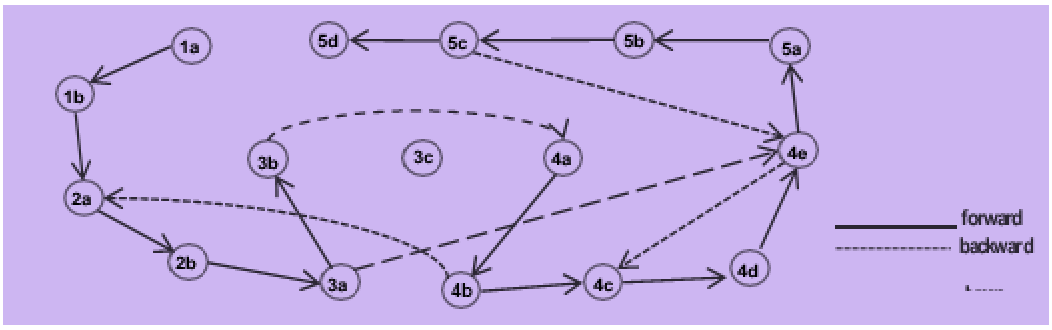

Figure 8. Portrait subjects phase 5

In step 1 to step 3b think straight according to the stage in step 3b then jump to stage 4a and then to stage 4b 4b but on the subject first step back to 2a. In step 3a jump to 4e and then returned to the stage 4a, continue to 4d, 4e, 5a, 5b, 5c, this line of thought back to 4a then continues to step 5d. Thus the subject 5 is at level 5 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

Subject 6 has reached level 5 of combinatorial thinking skills, based on the analysis of the subject work 6 managed to develop a simple algorithm, calculate and test algorithms and apply deductive and inductive proving qualitative graph is then able to apply on the other. These capabilities result in clear about the interview below.

The results of the interview subjects 6:

Researcher	:	Are you able to understand the vertex of the graph coloring?
College student	:	Yes, I think I can do it on a pattern with different graphs and then implement in some cases
Researcher	:	Thus were you able to identify the pattern of the conclusion of the given case?
College student	:	I still can not give the symbols in this matter, if I could do without the use of symbols
Researcher	:	Are you able to calculate the cardinality and develop algorithms?
College student	:	Yes, I can calculate the cardinality of the graph is given, but the algorithm I created a simple
Researcher	:	Are you sure that you create a simple algorithm?
College student	:	Yes, I have done the calculations of the algorithm that I created and tested in a graph
Researcher	:	Are you able to develop a bijection?
College student	:	No, I can not develop a bijection
Researcher	:	Are you able to apply the proof?
College student	:	No, I can not do
Researcher	:	Are you able to do the interpretation of your work?
College student	:	Yes, I can do it but not to make a bijection
Researcher	:	Are you able to propose an open issue based on the problems that you solve?
College student	:	Yes, I think that get though a simple algorithm can be performed on the other graph.

Based on a job analysis and interviews on the subject of the groove 6 combinatorial thinking skills can be seen in the following phase of this portrait:

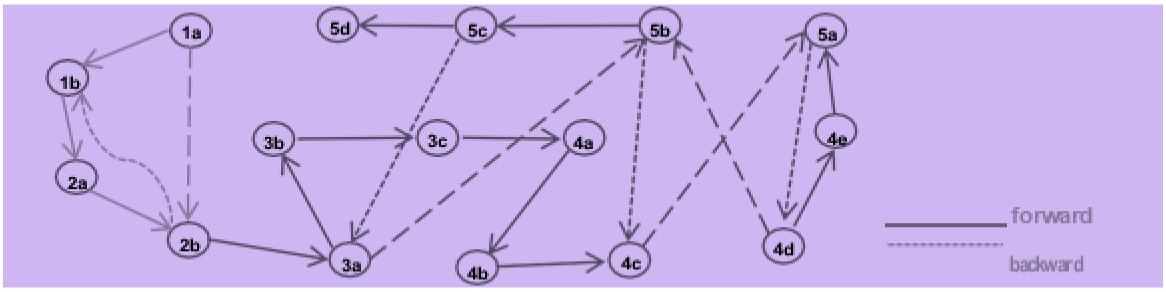

Figure 9. Images subject phase 6

Subject 6 goes into a loop in a phase 1b, 5a, 5b, and 5c and jump gradually 1a, 3a and 4c. Thus the subject 8 is at level 5 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered. Subject 6 in step 1 to step 4b think straight according to the stages and then in step 4a jumps to step 4e. Thus the subject 6 is at level 4 in view of characteristics portrait that shows the phases and sub-indicators that have been mastered.

4. Discussion

This research was conducted to analyze the influence of research-based learning implementation in improving students' combinatorial thinking skills in solving local irregularity vertex *r*-dynamic coloring. The results of this study indicate that the implementation of research-based learning has a significant influence on improving the combinatorial thinking skill of students. Results postest of 71 students showed that skill combinatorial of 30 students in the control class to change the number, ie which initially contained 63% or 19 students with the skills combinatorial lower to 53% or 16 students, of 27% or 8 students with the skills combinatorial is becoming 37% or 11 students, while students with lower combinatorial skills do not change the amount, which remains at 10% or 3 students. For the 41 students in the experimental class were originally there is a 64% or 26 students with the skills combinatorial low turn out to be 34% or 14 students, originally there were 24% or 10 students with the skills combinatorial moderate to 44% or 18 students, and 12% or 5 students with the skills of combinatorial higher to 22% or 9 students. It can be concluded that the average post-test results of the experimental class higher than the class of control after the implementation of research-based instructional tools based learning.

This result is closed to the result of Suntusia [3] research. Since the steps of this learning model stress to the student-centered learning and under the lecturer supervision, students are encouraged to identify problems and develop problem-solving strategies based on experimental experience and literature studies, it implies that the student's mind is always consistently active in solving a given problem. Furthermore, this study was closed to the study conducted by Septory [16] showing that the awareness of combinatorial thinking impacts on academic achievement. This indicates that when we can improve student combinatorial thinking skills, it will imply the improvement of students' academic achievement.

The research-based learning also provides a different learning experience which can develop student combinatorial thinking skills. It also contributes to the existence of positive student activities under research-based learning implementation [20]. The data obtained through the observation process revealed that students gave a positive response. The highest score of observation criteria reached 48%. It indicates that, during RBL implementation, students are strongly active to engage with solving the problem, and 29% of students reach the active level, and the rest of 23% are hesitate inactive levels. It can be concluded that RBL can contribute a positive learning process on solving the local irregularity vertex *r*-dynamic coloring problem. Finally, its implementation can improve the students' combinatorial thinking skills.

5. Conclusions

In this paper, we have discussed the influence of research-based learning implementation in improving student skills in solving combinatorial thinking local irregularity *r*-dynamic vertex coloring. Results show that after the implementation of learning tools based on research-based learning, the results of post-test of 71 students showed that skill combinatorial of 30 students in the control class to change the number, in which initially contained 63% or 19 students with the skills combinatorial lower to 53% or 16 students, of 27% or 8 students with combinatorial skills is becoming a 37% or 11 students, while students with lower combinatorial skills do not change the amount, which remains at 10% or 3 students. While the average post-test result from a control class is 31.9667 (SD = 5.31415) and the average post-test result for an experimental class is 39.7805 (SD = 5.21782). Thus, it can be concluded that the average post-test result of the experimental class higher than the class of control after the implementation of research-based instructional tools based learning. Furthermore, sig. (2-tailed) from the independent t-test was 0.000 ($p < 0,05$). This means that there are significant differences between the post-test results of these two classes. Thus, it can be concluded that there is a significant effect of the application of research-based learning tools based learning to improve student skills in problem-solving combinatorial local irregularity *r*-dynamic vertex coloring.

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