Cypriot Journal of Educational Sciences

Volume 18, Issue 2, (2023) 533-543

www.cjes.eu

Metacognitive and critical thinking skills of genetics of biology students with project-based learning

Mariana Rengkuan[*], Manado State University, Faculty of Mathematics, Sciences, and Earth, Tondano 95618, Indonesia, https://orcid.org/0000-0002-0632-8045

Marleny Leasa, Pattimura University, Faculty of Teachers Training and Education, Ambon 97233, Indonesia, https://orcid.org/0000-0003-0718-3477

Herry Maurits Sumampouw, Faculty of Mathematics, Sciences, and Earth, Manado State University, Tondano 95618, Indonesia, https://orcid.org/0009-0003-8030-8557

Suggested Citation:

Rengkuan, M., Leasa, M. & Sumampouw, H. M. (2023). Metacognitive and critical thinking skills of genetics of biology students with project-based learning. *Cypriot Journal of Educational Sciences*. *18*(2), 522-532. https://doi.org/10.18844/cjes.v18i2.7299

Received from November 12, 2022; revised from January 19, 2023; accepted from March 20, 2023.

Abstract

This study aimed to determine the effects of project-based learning in the Covid-19 pandemic era on biology students' metacognitive and critical thinking skills in the genetics concept. The research model used was a quasi-experimental design. The population in this study were fifth semester students who offered genetics courses consisting of 4 classes A to D. Samples were taken randomly, that is classes A and B. The data were analyzed using the Anacova. The results show that students with the PjBL model have better metacognitive skills and thinking skills than those with conventional learning models. The PjBL model could be used as a reference to improve the metacognitive and critical thinking skills. Therefore, further research can be used to examine PjBL learning models on other higher thinking skills such as collaboration skills, problem-solving skills, and creative thinking skills.

Keywords: project-based learning, metacognitive skills, critical thinking skills, genetic study

[*] ADDRESS OF CORRESPONDENCE: Mariana Rengkuan, Faculty of Mathematics, Sciences, and Earth, Manado State University, Tondano 95618, Indonesia.
Email address: marianabio05@unima.ac.id

1. Introduction

A genetic study in the university's biology department has a purpose defined in Graduated-Student Study Achievement (Capaian Pembelajaran Lulusan or CPL). Department of Biology of Faculty Mathematics and Sciences, Manado State University, has graduated-student profiles of biology teachers and researchers. Consequently, genetic study becomes an important and must-study of cognitive, psychomotor, and attitude aspects. From a cognitive aspect, the genetic study aims to achieve CPL by knowing theory, principles, and procedure of scientific proposition and the basic of biology research and biology study. From general skills, the genetic study is pointed to stimulate logic, critical, systematic, innovative thinking in case of development and implementation of knowledge due to their expertise. From the attitude aspect, genetic study promotes devotion to God Almighty, religious attitudes, humanity values, loving nation, nationalism, also responsibility. A genetic study in this recent era is different from the past, that inheritance-oriented. Nowadays, genetic content taught includes genetic theory, reproductive theory, how to work on genetic material, and the change and the manipulation of genetic material (Sumampow, 2013). These concepts refer to genetic concepts learned and developed by a genetic lecturer at Malang State University who is a professor in the genetic field (Corebima, 2009).

The Covid-19 pandemic era has had a significant influence on the learning process in school, as well as the process in the university. This outbreak will inevitably significantly impact designing the learning process that can empower learners (Dhawan, 2020). It is a challenge for educators to adapt to this pandemic. The learning outcomes must remain the goals in the learning process. The intended learning objective is that the students can understand all the concepts taught in the school, or in other words, have a good understanding of the concepts in the material being taught (Alsoufi et al., 2020).

Many factors can influence the achievement of these learning outcomes. These factors can originate from the students or their surroundings (Konold et al., 2018). The students' thinking skills are a factor influencing the achievement of learning objectives is (Sung et al., 2016). Many studies have found a relationship (even influence) between formal reasoning skills and learning achievement in biology subjects. Thinking activities are critical in students' concept comprehension (Vlachopoulos & Makri, 2017). A deep understanding of the subject matter is only possible with emphasizing thinking. These statements show the importance of thinking skills in learning activities. For this reason, various efforts must be made to improve thinking ability (Cascio, 2020).

A good thinking skill cannot be automatically possessed. This skill can be developed through activities or experiences that improve thinking skills. Various methods or techniques in school learning activities can improve critical thinking skills (H. Z. Wu & Wu, 2020). Three primary efforts can be made to improve students' critical thinking skills: questioning techniques, writing techniques, and general information processing models. These three types of efforts can be done separately to improve students' critical thinking skills. In general, studies that have been conducted are closely related to the development of questioning techniques and the use of a learning model (Carroll & Harris, 2020). However, other factors that need to be considered, such as the students' metacognitive skills (Bae & Kwon, 2019). Metacognitive skills are the students' ability to know and monitor their thought processes (De Carvalho Filho, 2010).

Metacognition is recognizing and monitoring the thinking or the cognitive process itself (Pennequin et al., 2010). Therefore, students with good metacognitive skills can easily control the learning process and achieve the goal more precisely. Achieving this state requires the knowledge of the best method to improve the students' metacognitive skills. Knowing the proper method can apply directly to the learning process to improve the students' metacognitive skills, considering the importance of appropriate metacognitive skills in students (Ashman et al., 1994).

Metacognitive skills are essential in the learning (Peral & Dubé, 2014). Developing metacognitive skills in students is a valuable educational goal, as these skills can help them to become self-regulated learners (Ali & Yasmeen, 2019). Self-regulated learners are responsible for their learning progress and adapts their learning model to the task's requirements. Consequently, the students can achieve all of the goals and monitor their shortcomings to improve themselves. In addition, Slavin (2000) stated that since the thinking ability and learning skills are examples of metacognitive skills, students can learn how to think about their thinking processes and apply special specific learning models to solve challenging tasks. For this reason, metacognition has significant advantages in learning activities. In this way, the teacher should consider its existence in teaching and learning activities. Students with good metacognitive skills can plan, monitor, and evaluate their own learning activities. It creates independence in the learning process (Knox, 2017).

The reality of teaching and learning process especially on campus, shows different things, where the lectures have a conventional sense and have yet to consider the heterogeneity of students. Most lectures apply the lecture method and do not promote the students' thinking skills. Lectures have not facilitated metacognitive skills and do not consider students' various abilities (Rapanta et al., 2020). It can be seen that most students' engagement in learning activities is still not optimal. Students need to get more chances to develop independent learning. The learning process is one-way lecturers deliver the learning material and the students receive it. As a result, students have poor critical thinking skills and do not become independent learners (Bilik et al., 2020).

The facts about genetic study in the level of university in Indonesia are not fully oriented to the development of metacognitive skills and critical thinking skills yet, as well the student of Manado State University. The genetic study in Manado State University is totally different compared to Malang State University, as Sumampow (2011) stated. The genetic study in Biology Departement of Malang State University has been applied genetic study patterns based on the constructivism study model. The model of project-based learning, RQA (Reading, Questioning, and Answering), empowerment of thinking through question (Pemberdayaan Berpikir Melalui Pertanyaan/PBMP) (Hariyadi et al, 2018).

These condition can be predicted since biology learning for high school students tends to informational transfer through discourse only. The student is not trained to participate actively, thinking critically and creatively. Their comprehension is more limited to the book's or text's content only. They are not given the right stimulus to overcome the problem by utilizing a higher level of thinking, so their thinking level is generally very ordinary. As a result, learning achievement still needs to be below the maximum completeness criteria as intended by a teacher (Bororing et al, 202; Rengkuan, 2018). This fact occurs in one school and many senior high schools in Indonesia, especially in biology. It is admitted honestly that in the past, the study of biology was more oriented toward pursuing exams than preparing students for their future life. Consequently, it can be concluded that biology study, in general, is still lacking in empowering high-level thinking skills, including metacognitive skills and critical thinking skills (Corebima, 2016).

Such conditions can be improved by using a learning model that offers students the opportunity to become independent learners through metacognitive skills and think critically through learning models. Learning models that can be used include the project-based learning model (Hernáiz-Pérez et al., 2021).

This model is identical to the activities of scientists, so it is very suitable for students. This can be seen in the learning phases, which consist of presenting problems, analyzing existing conditions using SWOT analysis, planning projects, carrying out projects and reporting projects (Hanney, 2018). Some researchers report that this project-based learning model gives students complete freedom to explore their skills during the phases of this model (Kim et al., 2011). You (2020) reported that the project-based

learning model could encourage creative thinking in students. The same report from Zhou (2012) claimed that this model could effectively increase the creative learning effect of the students, achieving the goal of increasing national competitiveness as a whole. Craig & Marshall (2019) wrote that project-based learning helps improve STEM learning compared to traditional teaching approaches. A similar result was reported by Costa-Silva et al., (2018), in which the research shows that the students in project-based learning have superior results.

Hence, project-based learning can help students to become independent, creative, collaborative, and critical learners according to 21st century learning goals. It can be achieved because the project-based learning model is autonomous. Bell (2010) explains that the project-based learning model is challenging because, through autonomous learning, the responsibility of the learners can be better and generate creative ideas from the students, as they are different from conventional projects or conventional learning. It makes the project a task with meaningful and challenging values. Several studies have successfully applied the project-based learning model to lectures, including lectures in engineering and dentistry. This model can meet the requirements of the 21st century (T. T. Wu & Wu, 2020). The research is also supported by the results of the research of Battelle for Kids (2019) which reported the project-based learning model can develop 4Cs (critical and creative thinking, collaboration, and communication skills).

Learning in genetics subject offers the opportunity to apply the project-based learning model (Habók & Nagy, 2016). It is supported by the abstract concept of genetics and requires evidence through simple research. In addition, project-based learning is expected to help students become self- regulated learners. Self-regulated learners are responsible for their learning progress and adapts their learning model to the task requirements (Hasni et al., 2016). Likewise, in other dependent variables, namely the thinking ability, the students are assisted by this model to understand genetics. It is a high abstraction that matches the thinking ability characterized by abstraction. An interesting thing was also revealed by Corebima (2006) that higher thinking skills and critical thinking ability have a mutually supportive relationship. This relationship appears to be in the form of metacognitive skills that support higher-level thinking and critical thinking skills. Higher thinking skills and critical thinking involve a combination of deep understanding of specific topics, the ability to use basic cognitive processes effectively, understanding and control of fundamental cognitive processes (metacognitive), attitudes, and characteristics (Mohseni et al., 2020). In order to be able to think high and think critically, a student needs several elements that can support this. These elements take the form of a thorough understanding of a learning topic, basic thought processes, metacognitive skills, attitudes, and dispositions. The skills mentioned earlier will affect mastery of the concept, in line with the opinion of Jin & Ji (2020).

A genetic study in university is taught by numerous and full of theoretical and conceptual studies. Many studies explicitly show that genetic study must be designed as attractive as possible, so the students can easily understand abstract concepts. For examples chromosome, the students can be led to find chromosome in various living things, so the concept about chromosome in not only recitation or exist in shadows.

Through project-based learning, chromosome can be studied and found by the project which the student designs. Then the data's shape and structure are seen. The role of this chromosome can be easily explained if students have found, recognized, and analyzed them. Based on various previous research, it was revealed that only a couple of universities use project-based learning for genetic study. The rest uses RQA and PBL (Sumampouw, 2013; Hariyadi et al, 2018). Among these models, project-based learning is considered more relevant to provide chances to develop metacognitive skills and critical thinking skills. Thus, this research aimed to analyze the impact of project-based learning in genetic study associated with students' metacognitive and critical thinking skills.

2. Method and materials

2.1 Research design

The research used a quasi-experimental plan applying a non-equivalent pre-test and post-test control-group design. This study used a control group and experimental group, in which both were formed naturally from the beginning.

The experimental category accepted the treatmeant as designed, while the control category did not accept the treatmeant as experimental category (Ibnu et al, 2013)**.** The form of this research design is as in Table 1.

Table 1.
Table 1. Research design

Group	Pre-test	treatment	Posttest
Experiment	O1	X.	O2
Control	O3	- -	O4

2.2 Population and Sample

The population in this study was all students in the fifth semester of the 2019/2020 academic year. The sample in this study was in A and B classes. The students in A class were used as the control class, while those in B class used as the experimental class. Determination of the class used in this research was done randomly in classes with students' heterogeneous academic abilities. Regarding numbers, A class has 32 students and B class has 35 students. This study used research tools as a test to measure metacognitive skills and critical thinking skills.

2.3 Data Collection

Data collected in this research are metacognitive skills and critical thinking. Metacognitive skills associated with prediction, planning, monitoring, and evaluation skills. The metacognitive skills test was integrated into the critical thinking skills test. Critical thinking skill was based on the theory developed by Facione (1990), which consist of 4 indicators: analysis, evaluation, inference, and explanation.

This research needs two types of data, which are about the metacognitive skills and critical thinking skills. The data were obtained using the prepared instruments. The following describes how data was collected and grouped. 1) In the experiment and control classes, both received a pre-test at the beginning of the lesson. Before lesson was taught, a pre-test of metacognitive skills and critical thinking was given 2) At the phase of giving treatment, the experimental class was then treated with project-based learning, but the control class was not. 3) At the end of the lesson, both classes received a post- test of metacognitive and critical thinking skills. The results from these two tests are used to identify the students' metacognitive and critical thinking skills.

Metacognitive skill was evaluated by the student's answers using a rubric developed by Corebima (2012). According to that rubric, the range score of metacognitive skill was between 0 - 7. A score of 0 was given if there was no answer. In contrast, the highest score was given if students fulfilled the assesment criteria in their sentences and the order of explanation of answers was coherent, systematic, and logic in Grammar. Also, it was completed with reasons (analysis, evaluation, creation), and the answer was correct. A test was conducted to measure the metacognitive skills of students based on the test results by checking if there was any change in the students' grades from the pre-test and the post-test. It was measured how significant the changes were, and those were converted with the total number of questions.

2.3 Data analysis

Any data obtained, either from metacognitive skills or critical thinking skills, which covered the evaluation in the beginning and the end, must undergo a prerequisite test before it can be used in the analysis. This test was performed in order to see the distribution of the data obtained, whether it is usually distributed and homogeneous or not. After the data homogeneity test was performed, the data was then analyzed by Anacova techniques. Anacova analysis technique was performed on the other data in which the results from the pre-tests were used as a covariate. Therefore, in the data analysis phase the pre-test results were valid as covariates contained in X column in the data table analysis and the post-test results in the Y column. If the analysis result was significant (independent variables affect the dependent variable), the process could have proceeded to the advanced test. The significance of the analyzed data was based on the following points.

1) If the probability value was > 0.05, the null hypothesis was accepted, and the research hypothesis was rejected.
2) If the probability value was < 0.05, the null hypothesis was rejected, and the research hypothesis was accepted.

3. Results

3.1 Influence of project-based learning on metacognitive skills

Based on the results displayed in Tables 2 shows that the project-based learning model affects the students' metacognitive skills. It is indicated by the model's probability value of 0.014 < 0.05. Hence there is a significant difference between students taught by the project-based learning model and those taught by the conventional learning model. The results demonstrate that the learning model influences students' metacognitive skills. The students who used the project-based learning model have higher metacognitive skills and differ significantly from those who received the conventional learning model. In the project-based learning model, the students have to identify the problems, plan the projects, create schedules, and monitor the progress of the implemented project. These require metacognitive skills as these skills allow students to perform these stages or syntax. It can be concluded that the project-based learning model trains students in metacognitive skills. Table 2 below shows a summary of the data analysis results.

Table 2

Table 2. Summary of the Anacova results of the data calculation for metacognitive skills

Source	Type III Sum of Squares	df	Mean Square	F.	Sig.
PjBL corrected	3671.593	4	971.898	7.502	0.000
Intercept	1536.804	1	1536.804	12.561	0.001
XMKI	1593.401	1	1593.401	13.023	0.001
Model	805.943	1	805.943	6.587	0.014
Academic	2.040	1	2.040	0.017	0.898
Model*Academic	261.124	1	261.124	2.1234	0.152
Error	4526.978	37	122.351		
Total	162086.411	42			
Corrected total	8198.571	41			

R-square =0.448 (adjusted R-square = 0.388)

3.2 The influence of pjbl on the critical thinking skills

Based on Table 3, the project-based learning model affect the students' critical thinking skills. Advanced test results also show that the students taught by the project-based learning have a higher thinking ability than those taught by a conventional learning model.

Table 3. Summary of Anacova results of critical thinking skills

Source	Type III Sum of Squares	df	Mean Square	F.	Sig.
PjBL corrected	2277.214 [a]	4	569.304	11.467	0.000
Intercept	5254.502	1	5254.502	105.839	0.000
0XMKI	1128.868	1	1128.868	22.738	0.000
Model	599.672	1	599.672	12.079	0.001
Academic	159.612	1	159.612	3.215	0.081
Model*Academic	3.881	1	3.881	0.78	0.781
Error	1836.905	37	49.646		
Total	69329.000	42			
Corrected total	4114.119	41			

R-square =0.554 (adjusted R-square = 0.505)

4. Discussions

The project-based learning model can improve the student's ability to think because, in this model, students analyze current conditions using SWOT analysis, in which the students are asked to address the problems of strengths, weaknesses, opportunities, and threats, when the students assess the problem that would be the theme of the project. During this phase, students are allowed to develop their critical thinking skills. According to Willard & Duffrin (2006), the project-based learning model can help develop students' critical thinking skills. Other researchers also state that this project-based learning model can improve children's creative thinking skills (Chen et al., 2019).

The project-based learning model can improve students' conceptual understanding since this model aims to improve the academic mastery of the students. According to Lin et al., (2021), project-based learning is a learning model that can help improve students' thinking skills. The project-based learning model allows students to do a project and present it to friends. Students build the concept through the laboratory experiment, which will be a long-term memory. A similar study was carried out by Vogler et al., (2018) found that project-based learning can influence creative thinking and learning outcomes. Project-based learning can improve learning outcomes (Yilmaz et al., 2020). Project-based learning provides the proper support and the right time, which can help students master the concept of learning (Lee et al., 2015).

Understanding the concept is closely related to the students' ability to think. Students with higher thinking skills have a better conceptual understanding than students with lower thinking skills. Students with better thinking skills will more easily digest the material taught to gain a deeper understanding of the concepts. In addition, metacognitive skills play a role in understanding the concepts. Students with good metacognitive skills can draw attention to the essential aspects that can be used to optimize the understanding of the key concepts. According to Anonymous (without years), metacognitive skills help draw attention to the important information and store it in memory, which can sometimes be achieved through modeling. Therefore, metacognitive skills make students aware of essential parts that need to be understood from within a subject.

The student tends to have experience using their metacognitive for they manage themself and monitor themself through the learning process they undergo through genetic projects. However, many students need to realize the process of cognitive that occurs. They may lack knowledge, and detailed awareness of deep cognitive processing and effective strategy to complete particular tasks in genetic projects.

Metacognitive helps to motivate students as they realize the power of thinking to solve the problem and set goals. Metacognitive skills seem familiar to students with the same academic ability but can be transferred in different context. The quality and frequency of metacognitive activities increase when the student can transfer the acquired skill from one context to another different context (Smith et al, 2017).

5. Conclusion

The following conclusions can be obtained based on data analysis and discussion results. Applying the project-based learning model in the Covid-19 pandemic impacted Manado State University biology students' metacognitive and critical thinking skills. Based on the results of this study, the authors propose the following, 1) The concept of genetics learning is expected to use the project-based learning model because it has been proven to improve student metacognitive and critical thinking skills successfully. 2) This study only discusses the project-based learning model. Therefore, it must be tested in other learning model to determine the effect to the metacognitive skills, thinking ability, and understanding of student' concepts. Further research can be used to examine project-based learning models on other higher thinking skills such as collaboration, problem-solving, and creative thinking skills.

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