JURNAL BIOEDUKATIKA
http://journal.uad.ac.id/index.php/BIOEDUKATIKA
2338-6630 (Print) | 2541-5646 (Online)

Critical thinking and representation skills of biology students: Are they related?

Any Fatmawati [a, c, 1], **Siti Zubaidah** [a, 2 *], **Sutopo Sutopo** [b, 3], **Susriyati Mahanal** [a, 4]

[a] Biology Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, Indonesia
[b] Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, Indonesia
[c] Biology Education, Faculty of Engineering and Applied Science, Universitas Pendidikan Mandalika, Mataram, Indonesia
[1] anyfatmawati@undikma.ac.id *; [2] siti.zubaidah.fmipa@um.ac.id; [3] sutopo.fisika@um.ac.id;
[4] susriyati.mahanal.fmipa@um.ac.id
* Corresponding author

ARTICLE INFO

Article history
Received August 27, 2021
Revised October 19, 2021
Accepted February 27, 2022

Keyword:
Critical thinking skills
Representation skills
Plant Physiology

ABSTRACT

Critical thinking skills are relevant skills in the contemporary industrial 4.0 era. The current study aimed to investigate the correlation between critical thinking and representation skills and the extent to which the two variables are related. This study was conducted at UNDIKMA and UNW Mataram, West Nusa Tenggara, Indonesia between March and August 2020. It involved 62 students from the Department of Biology Education. The research data were gathered using essay questions on Plant Physiology. Data analysis was performed using the Pearson correlation test, followed by a simple linear regression analysis. The statistical analysis showed a correlation between critical thinking and representation skills among biology students (r = 0.948, p < 0.001, N = 62). The correlation was positive with regression equation Y = 12.122 + 0.835x. Therefore, educators are advised to promote critical thinking in the classroom to support student representation skills.

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Introduction

Critical thinking is the most valuable quality that schools can teach their graduates, and it is a learning goal at all levels of education in the world (Thompson, 2011). Other experts agree that critical thinking is a complex process requiring high-level reasoning to accomplish the intended results (Wechsler et al., 2018), which are used to solve problems effectively, have emerged as important skills needed to compete in the face of developments and changes in today's new information age (Ismail et al., 2018).

Critical thinking is required for proving something, interpreting something, solving difficulties, collaborating, and competing (Facione, 2011). Critical thinking needs to be integrated into the biology classroom in order to produce quality people (Heaviside et al., 2018). Critical thinking is also one of the Biology learning objectives because it positively affects creative thinking skills and student learning outcomes (Fatmawati et al., 2019).

Students' critical thinking skills have not been fully developed, as evidenced by the findings of earlier scholars. According to a study conducted at the Department of Biology Education, STKIP Bima, pupils' critical thinking skills were poor (Nurfathurrahmah, 2018). A study of 139 students from UIN Alauddin Makassar, STKIP PI Makassar, UPRI Makassar, and STKIP Yapim Maros showed that students performed poorly in critical thinking (Amin et al., 2017). In addition, Wulandari et al. (2016) discovered that undergraduate students from the Department of Biology Education at PGRI Ronggolawe, Universitas Tuban continued to struggle with critical thinking. Furthermore, the findings of other studies revealed that Biology students' critical thinking skills remained inadequate (Mahanal et al., 2017; Temel, 2014).

The phenomena mentioned above also occurred at the Department of Biology Education of UNDIKMA in West Nusa Tenggara. A preliminary study conducted during the even semester of 2018/2019 found that students who took the Plant Physiology course indicating that their critical thinking had not progressed well. The issues around students' critical thinking development have gotten a lot of attention in the educational community. As a result, efforts must be made by applying various learning strategies that can aid in the development of students' critical thinking in the classroom (Arikunto, 2013).

Other skills, such as representation skills, can be aided by critical thinking. Representation skills are essential in the current Industrial Revolution 4.0 age since representing helps individuals effectively capture information. Representation skills assist individuals in responding to information acquired through the sensory system. Internal representations referred to information processed in the brain and interpreted as actions (Carolan et al., 2008). Internal representations expressed, illustrated, and symbolized into an item in graphic forms like graphs, drawings, diagrams, formulas, and so on are referred to as external representations (Ainsworth, 2018; Treagust & Tsui, 2013). Representations help students understand the scientific knowledge they receive from many sources. Therefore, representation skills should be developed in students.

Students require representation skills to grasp the scientific material they read from diverse learning sources, including textbooks, scientific journals, and other internet-based sources (Ainsworth, 2018; Hwang et al., 2007), so that they may create complicated visualizations (Kozma, 2003). A person with strong representation skills is distinguished by offering concrete and efficient information so that it is easily understood by others (Ainsworth, 2018; Schnotz, 2002). Information provided through representations can help to strengthen particular talents so that they can be transferred to new contexts (Ploetzner et al., 2009).

According to research, students' representation skills are not fully developed. Students continue to be passive when compiling representations of complex biological content studied in the classroom (Hwang et al., 2007). Students tend to fail to translate scientific knowledge into understandable forms (Farida et al., 2010; Utami et al., 2019). Furthermore, students are limited in their ability to compile verbal representations, images, or graphs concerning their assignments to impact their learning results (Sumarno et al., 2016).

Students' poor representation skills result from their failure to understand and represent scientific concepts (Tang et al., 2014). In fact, representation skills can be trained by involving students in preparing representations (Treagust & Tsui, 2013). Students' representation skills develop through a process of elaboration and discussion of ideas around representation. Therefore, students should be provided with the opportunity to expand their knowledge and skills in representation (Prain et al., 2009). Students also need to know the relationship between Biology concepts and other science domains (Rau & Matthews, 2017).

Biology covers a vast variety of topics, one of which is plant physiology. Plant physiology is a subfield of botany that explores how plants function in their daily lives (Hopkins & Huner, 2008). Plant physiology is the study of the physiological functions performed by plants throughout their lives (Taiz & Zeiger, 2010). Plant physiology is distinguished by its complexity and wealth of material, which includes illustrations, drawings, symbols, and verbal instructions. Thus, an in-depth examination of how to teach plant physiology to university students is necessary to help these students acquire

critical thinking and representational skills.

Many studies have been carried out on critical thinking skills (Fuad et al., 2017; Mahanal et al., 2017; Zubaidah et al., 2017) and representation skills (Gilbert, 2010; Rahmatina et al., 2017; Schönborn & Bögeholz, 2009). However, to our understanding, no research has been conducted on the relationship between critical thinking skills and representation skills. Therefore, this study aimed to discover the correlation between critical thinking skills and representation skills and the significance and direction of the correlation between the two variables.

Method

A correlational research design was employed to reveal the correlation between students' critical thinking skills (independent variable) and representation skills (dependent variable). The current study was carried out from March to August 2020. The study participants were recruited from the sixth-semester students from the Department of Biology Education at Universitas Pendidikan Mandalika and Universitas Nahdlatul Wathan Mataram, Indonesia.

The participants in this study were 62 sixth semester Biology Education students from Universitas Pendidikan Mandalika and Universitas Nahdlatul Wathan Mataram, both located in West Nusa Tenggara, Indonesia. The study was conducted during the even semester of the 2019/2020 academic year. The students were randomly assigned to one of two groups: the experimental group or the control group. The determination of the control group and the experimental group was carried out randomly, so that the students from Universitas Pendidikan Mandalika acted as the experimental class using LCMR (Learning Cycle Multiple Representation), while the students from Universitas Nahdlatul Wathan Mataram acted as the control class using LC (Learning Cycle).

Two types of instruments were used in this study: an instrument to measure students' critical thinking skills and an instrument to measure students' representation skills. The instrument used to assess students' representation skills was developed based on nine indicators suggested by Anderson et al. (2013). The instrument consists of 11 essay questions on Plant Physiology that have been validated and rated for their reliability and validity. There was a substantial link between each item on the total score, with a coefficient of correlation ranging from 0.364 to 0.653 (quite valid). Additionally, the Cohen's Kappa reliability test yielded coefficient values ranging from 0.429 to 0.683 (good). The findings of the student representation skills evaluation were compared to a rubric adapted from Lengkana et al. (2020). The rubric rates representation skills on a scale of 1-5, with the following categories: very good (5), good (4), fair (3), poor (2), and very poor (1).

The critical thinking skill instrument adopted indicators from Finken and Ennis (1993), namely Focus, Reason, Inference, Situation, Clarity, and Overview, which is abbreviated as FRISCO. The instrument is in the form of an essay test consisting of 11 questions on Plant Physiology, which had high validity. There was a fairly substantial correlation between the items and the total score, ranging from 0.344 to 0.771. The Cohen's Kappa reliability test revealed a coefficient value of 0.520-0.723 (good category). The critical thinking scoring rubric employed a 0-to-5 point scale. Critical thinking abilities were classified as underdeveloped (0-2), developed (3-4), and highly developed (5) (Zubaidah et al., 2018).

Data analysis was performed using Pearson correlation analysis, followed by simple linear regression. The Pearson correlation test was conducted to investigate the correlation between students' critical thinking skills and representation skills. Meanwhile, the simple linear regression analysis was carried out to examine the significance and direction of the correlation. All of the statistical analyses were run at a significance level of 5%.

Results and Discussion

The analysis results of students' representation skills and critical thinking skills are presented in Table 1. The lowest score of representation skills reported by students was 47.27, while the highest score was 90.91, with a mean score of 70.63, a standard deviation of 13.02 and a variance of 169.57. Furthermore, the lowest and highest critical thinking skills scores were 45.00 and 95.00, respectively, with a mean

score of 70.05, a standard deviation of 14.79, and a variance of 218.66.

Table 1. Students' representation and critical thinking skills scores

	N	The lowest	The highest	Mean	Std. Deviation	Variance
Representation skills	62	47.27	90.91	70.63	13.02	169.57
Critical thinking skills	62	50.0045.00	95.00	70.05	14.79	218.66

The results of the Pearson correlation analysis are presented in Table 2. Critical thinking skills had a significant correlation with representation skills with r = 0.948, p < 0.001, N = 62. The contribution of critical thinking skills to representation skills is depicted in Table 3.

Critical thinking and representation skills correlate with R of 0.948 and R-square of 0.899. These figures indicate that 89.9% of students' representation skills are influenced by critical thinking skills, while other variables affect the remaining 10.10%.

The result of the regression analysis presented in Table 3 shows an F-calculated of 535.916 with a significance level of 0.000 < 0.05. Therefore, it can be concluded that students' critical thinking skills significantly contribute to their representation skills.

Table 4 contains the regression coefficient of the correlation between the two variables. The equation Y = 12.122 + 0.835x can be used to predict students' representation skills. The regression coefficient (b = 0.835) implies that increasing students' representation skills scores by one increase their critical thinking skills scores by 0.835. Since the regression coefficient is positive, it can be concluded that the association between variable X (critical thinking skills) and Y (representation skills) is positive. The 0.000< 0.05 significant value indicates that critical thinking skills positively affect students' representation skills (Table 5).

Critical thinking is a multifaceted construct that includes cognitive, dispositional, motivational, attitudinal, and metacognitive processes (Sanchez et al., 2015). Because it encompasses multidimensionality, critical thinking seeks to attain goals in the most efficient manner possible (Halpern, 2014). Despite its academic importance, critical thinking assists human resources in planning, managing, monitoring, and assessing academic tasks that extend beyond the classroom and into personal and social life. Furthermore, the capacity to evaluate the same material from many perspectives can help develop critical thinking skills (Hong & Choi, 2015). Someone with critical thinking will be motivated to keep doing their best, as evidenced by their conduct during the thought process (Miele & Wigfield, 2014).

Critical thinking skill leads to quick, cognitive processes free of assumptions related to the previous student's academic competence (Caroselli, 2009). The capacity to think critically should be cultivated at a young age through learning, particularly science learning (Zubaidah, 2010) because it is helpful in training children to be problem solvers and responsible citizens. This skills should continually be developed as part of the learning process (Mackey, 2016). Those skills can demonstrate an understanding of complex relationships in biology. Students can relate these complex phenomena from various levels of the organization to their mastery of concepts (Facione, 2011).

Table 2. The results of the Pearson correlation analysis

		Representation skills	Critical thinking skills
Representation Skills	Pearson Correlation	1	.948**
	Sig. (2-tailed)		.000
	N	62	62
Critical thinking skills	Pearson Correlation	.948**	1
	Sig. (2-tailed)	.000	
	N	62	62

Table 3. The result of the regression analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.948[a]	.899	.898	4.16631

Table 4. The result of the regression analysis

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9302.517	1	9302.517	535.916	.000[a]
	Residual	1041.490	60	17.358		
	Total	10344.007	61			

Finken and Ennis (1993) propose six indicators of critical thinking skills, which are explained in detail below. To begin, *Focus* is defined as the capacity to concentrate on existing questions or issues in order to form judgments about what to think. Second, *Reason* relates to understanding the justifications for or against judgments made in light of pertinent conditions and facts. Additionally, *Inference* is the process of arriving at reasonable or convincing conclusions. A critical aspect of inference is identifying assumptions and developing solutions, while taking into account alternative interpretations of situations and information. *Situation* includes understanding the situation and always keeping the situation in mind to help clarify questions and know the meaning of key terms, relevant parts as support. The following indicator is *Clarity*, which refers to the capacity to define the terms used in thinking. Finally, *Overview* refers to the process of reviewing and extensively researching the decisions made.

Based on examining the participants' responses to critical thinking questions, it is clear that they can only conduct one or two critical thinking indicator inclinations, such as focus or inference, or reason or overview. Only a few students were able to craft faultless responses. Therefore, critical thinking skills in students must be nurtured from an early age (Fatmawati et al., 2019), so that they can develop knowledge and abilities to solve issues, make judgments, assess all assumptions, and perform investigations or research based on data and information gathered to create the necessary information or findings (Wechsler et al., 2018). Critical thinking skills are a subset of higher-order thinking skills, which help support other skills (Sari et al., 2021).

An example of the question used to measure the participants' representation skills is as follows: "*Explain how H_2O is changed into O_2 during photosynthesis. Describe the physiological processes that occur in plants at the macroscopic, microscopic, and symbolic levels*". An example of the student (LA) answer to the question is presented in Figure 1.

Figure 1 depicts how "LA" (one of the research participants) explains the process of a plant receiving water (H_2O) from the soil until it eventually creates oxygen (O_2), which is then released through its leaves. When explaining the process of photosynthesis, the student is able to describe macroscopic components (such as the roots, stems, and leaves of plants), microscopic components (explanation of stomata and chlorophyll), and symbolic components (writing symbols for oxygen, water and carbohydrates) in a variety of ways, as shown in the illustration above.

According to constructivist principles, a person's knowledge is composed of previous information, which is then utilized to build additional abilities, such as representation skills (Ainsworth, 2006). External representations are representations of the results of one's thoughts (Beck & Nerdel, 2019). Students in this study developed external representations such as the ability to characterize multiple concepts in different languages, draw various physiological processes of plants using drawings, and make tables presenting the diverse processes in plants horizontally. This is consistent with the expert opinion that pupils can visualize physical ideas and processes and problem-solve (Opfermann et al., 2017). The success of a student's learning is intimately tied to their ability to interpret external representations (Anderson et al., 2013; Mackey, 2016) . As a result, representation can be regarded to be part of pupils' thinking skills (Prain & Tytler, 2012).

Table 5. The regression coefficient of the contribution of critical thinking skills to representation skills

Model		Non-standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.122	2.582		4.695	.000
	Critical thinking skill	.835	.036	.948	23.150	.000

When learning concepts on challenging material, representations might bring unique advantages (Ainsworth, 2008). Plant Physiology is made up of various complicated materials, including microscopy, macroscopy, and symbolism of plants. Students' representation skills can assist them in identifying the consequences of a process, predicting results, sorting information, clarifying concepts, demonstrating how a system works, organizing discoveries, explaining how elements of a topic are connected, and determining the causes of various effects (Carolan et al., 2008). Higher-order thinking skills (HOTS) are related to representation ability (Tajudin & Chinnappan, 2016). This phenomenon is because the organized representation has the potential to be a learning tool that can boost students' thinking skills and motivation, attention, and attractiveness (Al-Samarraie et al., 2013). Another expert states that representation skills can be developed through novel learning methodologies such as multi-representation (Sutopo, 2013).

An example of the question used to measure the participants' critical thinking skills is as follows: "*Normally, plants receive their nutrients by photosynthesis; however, the Venus flytrap (Dionaea muscipula) is an exception, as it obtains its nutrition through capturing insects. What is the cause of this occurrence? Explain!*". An example of the student (LA) answer to the question is presented in Figure 2.

Figure 2 indicates that the student has been successful in providing an explanation for a natural phenomenon. The explanation of the student with the initials "LA" has been able to meet the indicators of critical thinking skills, namely focus, reason, inference, clarity, and overview. The critical thinking skills of this student have assisted him in his representational skills. These characteristics can be observed in the way he offers his responses with supporting arguments and then depict his answers in the form of images, either macroscopically, microscopically or symbolically.

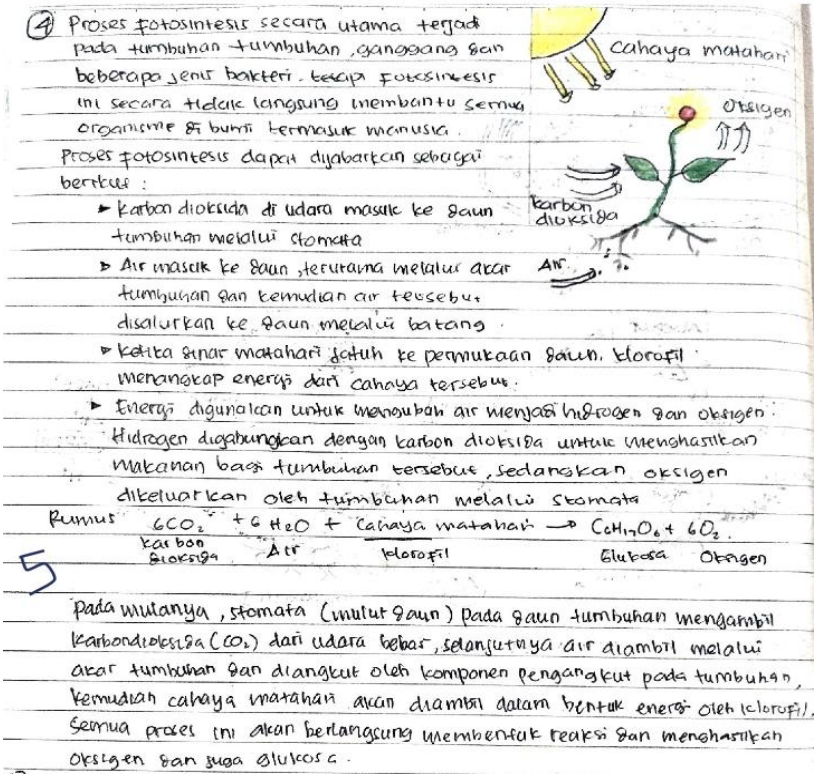

Figure 1. An example of student answer to a representation skills test item

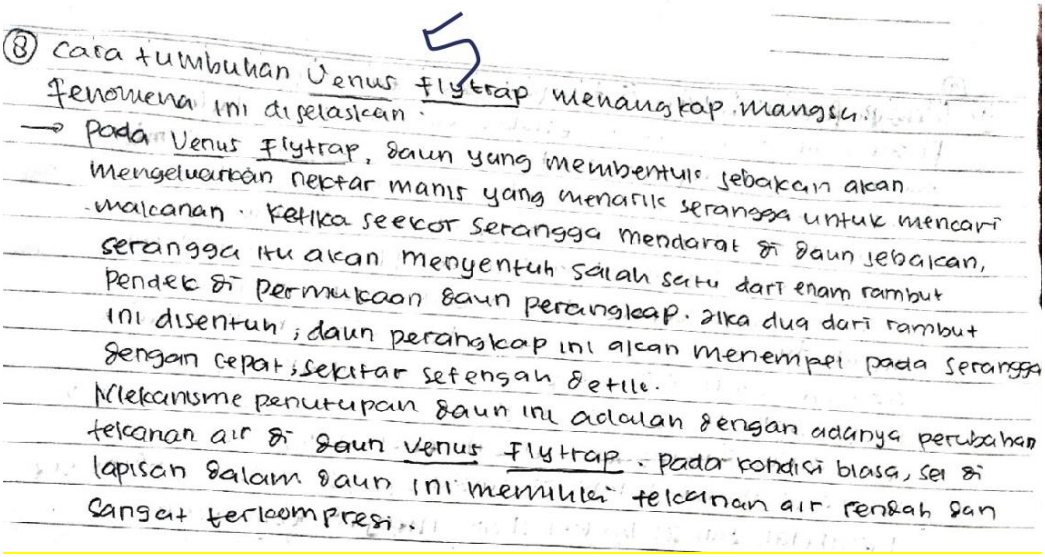

Figure 2.An example of student answer to a critical thinking skills test item

Conclusion

Based on the findings and discussion above, it is possible to conclude a significant correlation between biology students' critical thinking skills and representation skills (r = 0.948, p 0.001, N = 62). The regression equation Y = 12.122 + 0.835x demonstrates that the two variables have a positive connection orientation, with 1 point added to critical thinking skills equaling 0.835 points added to representation skills. According to the findings of this study, empowering critical thinking skills in learning automatically improves students' representation skills. Therefore, it is suggested that further researchers investigate the association between critical thinking skills and other variables such as creativity and scientific literacy.

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