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The Correlation of Critical Thinking and Concept Mastery to Problem-Solving Skills: The Role of Complexity Science-Problem Based Learning Model

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Annotation. Critical thinking skills and concept mastery are essential to solve a problem for every individual. This study describes that the contribution of critical thinking and concept mastery to problem-solving skills through CS-PBL is 65.3%. It could be concluded that CS-PBL is applicable to develop students‘ critical thinking skills, concept mastery, and problem-solving skills. Thus, the implementation of CS-PBL is strongly recommended.

Keywords: *critical thinking, concept mastery, problem-solving, complexity science, problem-based learning.*

Introduction

Numerous complex problems have to be faced daily in the era of globalization and technological advances. Problem-solving skill is a primary competency related to higher-order thinking and knowledge required to solve problems effectively (van Laar et al., 2018) (Graesser et al., 2018). Individuals use their knowledge to understand the problem and develop a suitable solution (Kozikoğlu, 2019). Higher-order thinking skills play an essential role in achieving the educational goal as they allow the students to generate ideas to solve complex problems (Bezanilla et al., 2021). Graduate students who do not develop higher-order thinking skills would face difficulty when competing in the working environment (Acharya, 2018). Therefore, most educators consider higher-order thinking skills as the most desired objective of the learning process.

Critical thinking is one aspect of higher-order thinking (Shukla & Dungsungnoen, 2016). Critical thinking can be defined as the skill to think logically from various perspectives to find a solution to a problem (Valenzuela et al., 2017). It is not just a set of skills required to be mastered but a thinking process of individuals to solve a problem (Kalelioğlu & Gülbahar, 2014). Studies by Uzunöz et al. (2018) and Snyder and Snyder (2008) concluded that critical thinking skills are significantly correlated with problem-solving skills. Critical thinking is essential as it helps students to address social, health, food, and environmental problems practically and effectively (Ma et al., 2016)

Implementing critical thinking will allow students to go through several thinking processes, such as analyzing information from observation, experience, and reasoning to make decisions and provide accurate and reasonable results or conclusions (Kongrugsa et al., 2016). Someone with critical thinking skills knows how to assess relevant evidence and reason for the problem, evaluate them, and then draw a conclusion to generate an argument (Wechsler et al., 2018). Critical thinking skills facilitate students' abilities to actively establish and construct knowledge and then understand their own cognitive skills and apply them to solve the problem (Az-Zahra et al., 2021).

The cognitive dimension of analyzing, evaluating, and synthesizing encourages students to master a complex concept. Amanda et al. (2021) stated a significant correlation between concept mastery and problem-solving. Mahmoud (Mahmoud, 2012) reported that numerous students experienced difficulty in the initial problem-solving process due to a lack of concept mastery. Simbolon et al. (Simbolon et al., 2020) identified several mistakes when students answer a question; two of those are the poor use of concepts and inaccurate data analysis. Canobi et al. (Canobi et al., 1998) explained the importance of concept mastery in problem-solving, particularly in recognizing the problem. Concept mastery can help students dig for information and analyze problems to generate solutions. It is assumed that students who master the concept will quickly solve everyday problems.

Therefore, problem-solving skills need to be investigated deeper by implementing the appropriate learning model. Complexity science-problem-based learning (CS-PBL) is an active learning model using contextual and authentic problems to train thinking skills, acquire knowledge and concept, and generate relevant solutions to solve a problem. CS-PBL applies the complexity science approach and Problem-Based Learning (PBL) principles.

The complexity science approach that replaces the reductionist concepts is an approach to train students in the way of thinking in problem-solving (Aldrich, 2008) to generate rational solutions. Complexity science is built on the current research and thinking in the biology of the 21st century, where the system is viewed as non-linear and capable of adapting to changing environments (Allen & Varga, 2006). Complexity science considers that nature's living system cannot be understood by studying the components separately since the system is very complex (Fogelberg & Frauwirth, 2010). Therefore, complexity science trains individuals in the way of thinking by focusing on the system's pattern and the relationship between the components constructing the system (Goldberger, 1996) as a complex system consists of interconnected and interactive components.

One of the complex systems is human physiology. Various disciplines are required to understand the mechanism of human physiology, such as biology, chemistry, physics, psychology, and environment (Eke et al., 2002) as its system is affected by the interaction of external and internal environment, and all organs work interdependently to maintain system balance (Hester et al., 2011). Human physiology is widely recognized as a difficult subject (Slominski et al., 2019). Rodríguez-Barbero (Rodríguez-Barbero & López-Novoa, 2008) reported that one of the problems in teaching human physiology in Spanish medical school was that the material of each system was studied separately. It hampered students in comprehending the complex interrelationships between systems. After completing the subject of Human Physiology, the students still lacked an understanding of the integration between organs and systems. The lecture was equipped with limited laboratory activity, where it only measured a few simple parameters. This finding is in line with the observation result in the Human and Animal Physiology subject in the Department of Biology. The students' score on problem-solving in the Human and Animal Physiology subject was 66.7 or medium category, and their answers to the problem-solving question were focused only on biology. It was not comprehensive and less rational to be applied in everyday life. The results indicated that Problem Based Learning (PBL) was implemented in the learning process.

The implementation of PBL still had several weaknesses, such as the given problems were structured and not in an open-ended or complex question, which did not follow the characteristics of PBL where the given problems should be open-ended and do not have a single answer (Mansor et al., 2015). The problems in PBL are focused to train students' reasoning using realistic and unstructured questions like medical diagnoses (Ju & Choi, 2017).

The implementation of PBL was complemented with laboratory activity and literature study as an inquiry process. The weakness of performing laboratory activities is the lack of engagement between the student's experience in the laboratory with the real-life problem-solving (Hofstein & Lunetta, 2004). The effect of applying inquiry using only laboratory activity is that students' ideas or solutions are less comprehensive and focused only on biology, making it unsuitable to be applied in everyday life. 21st-century biology is more dependent on other disciplines such as social, cultural, and humanities to solve more complex problems, particularly those related to health, energy, and the environment (Hiong & Osman, 2015). This study found that students' solutions or ideas did not follow the basic principles of PBL, which should be based on actual problems and interdisciplinary (Delisle, 1997). The given problem in PBL requires students to use various disciplines to find solutions or ideas to solve existing problems.

Based on the findings, CS-PBL was proposed to be the solution. Therefore, the study aimed to determine the correlation between critical thinking and concept mastery in problem-solving skills through the implementation of CS-PBL. This study's findings could be a reference for institutions that adopt and implement learning models to develop the required skills in the 21st century.

Methods

Study Design

This study applied a correlational descriptive design. Critical thinking and concept mastery were used as predictors, while problem-solving was used as a criterion. The study was conducted at the Department of Biology, State University of Malang, Indonesia. The sample consisted of 38 students taking the Human and Animal Physiology class. CS-PBL was undertaken in one semester with 16 meetings. Students had an essay test on the last day of the semester to evaluate their critical thinking skills, concept mastery, and problem-solving skills. The learning process was performed in 7 steps (Amanda et al., 2022). Details are presented in Table 1.

Table 1
The CS-PBL Syntax

No	CS-PBL learning model syntax	Students' activities
1	Problem Orientation	Students analyze the given phenomenon through their worksheets.
2	Organizing students to learn	Students gather information from various resources related to the existing problem.
3	Identifying required disciplines and concepts	Students identify disciplines and concepts required to solve the problem and create a mind map to connect or link the main problem with the required disciplines.
4	Conducting research and clarification to the team of experts	Students investigate to gather information and acquire explanations directly from the expert.
5	Analyzing and connecting information and data	Students analyze and connect obtained data by creating a mind map to find the source of the problem and generate ideas from the problem.
6	Presenting problem-solving ideas	Students perform presentations to report problem-solving ideas and carry out a discussion.
7	Evaluating	Students evaluate and reflect on ideas and the problem-solving process.

Instrument of the Study

The instrument to measure critical thinking skills was an essay test integrated with concept mastery and problem-solving test consisting of 17 items. It had been validated through a reliability test of Pearson's product-moment and Cronbach's Alpha. The validity and reliability test results indicated that all test items were valid and reliable. The critical thinking assessment consists of 6 critical thinking indicators: Focus, Reason, Inference, Situation, Clarity, dan Overview (FRISCO) (Ennis, 1993). The concept mastery assessment consists of six indicators: remembering, understanding, applying, analyzing, evaluating, and creating (Krathwohl, 2002). Problem-solving skills evaluation consisted of 4 indicators: understanding the problem, devising a plan, carrying out a plan, and looking back over to the result (Pólya, 2004).

Data Collection and Data Analysis

Data on critical thinking and concept mastery were collected by administering an essay test to students. The test answer was assessed based on defined indicators in the selected rubric. Data were analyzed using multiple regression analysis supported by SPSS for Windows and performed at a significance level of 5%. Normality and homogeneity tests were performed using Kormogolov-Smirnov and Levene's test before carrying out the multiple regression analysis.

Results

ANOVA analysis result to calculate the correlation significance of critical thinking skills and concept mastery is presented in Table 2. Table 2 shows the significant value of 0.000 < 0.050, which means that critical thinking skills and concept mastery have a significant relationship to problem-solving skills through the application of the CS-PBL learning model.

Table 2
ANOVA Analysis Result

	Sum of Squares	Df	Mean Squares	F	Sig
Regression	514.355	2	257.178	27.317	.000[b]
Residual	273.020	29	9.414		
Total	787.375	31			

Table 3
Multiple Linear Regression Summary of the Correlation of Critical Thinking Skills and Concept Mastery to Problem-Solving Skills

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.808[a]	.653	.629	3.0683

Furthermore, the regression test results in Table 3 indicate that the correlation coefficient (R) is 0.808 with a value of R square of 0.653. It means that critical thinking skills and concept mastery contribution were 65.3% to problem-solving skills, while the rest of 34.7% was affected by other factors. The relative and effective contribution of critical thinking skills and concept Mastery to problem-solving skills can be seen in Table 4. Table 4 displays that critical thinking skills have a relative contribution to students' problem-solving skills by 82.5%, while concept mastery has 17.5%. Critical thinking skills and concept mastery effectively contribute toward problem-solving skills by 53.9% and 11.4% consecutively, with a total effective contribution of 65.3%.

Table 4
The Relative and Effective Contribution Summary of Critical Thinking Skills and Concept Mastery to Problem-Solving Skills

Variable	Relative Contribution (%)	Effective Contribution (%)
X_1	82.5	53.9
X_2	17.5	11.4
Total	100	65.3

X_1: Critical thinking skills; X_2: Concept mastery

The analysis results of the correlational regression equation between critical thinking and concept mastery toward students' problem-solving skills are presented in Table 5. This table shows that the multiple regression line equation between critical thinking skills and concept mastery toward students' problem-solving skills through the application of CS-PBL learning model is $Y = 0.723\,X1 + 0.324\,X2 + 10.03$. The 0.723 in X1 is the value of the regression coefficient of critical thinking toward problem-solving skills variable. This means that when the value of critical thinking skills rises by a unit, then the value of the problem-solving skills would rise by 0.723. Consecutively, 0.324 in X2 is the regression coefficient of the concept mastery variable toward problem-solving skills; when the value of concept mastery rises by a unit, then the problem-solving skills would rise by 0.324.

Table 5
Multiple Regression Equation Coefficient Analysis of Critical Thinking and Concept Mastery to Problem-Solving Skills

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig
		B	Std. Error	Beta		
1	(Constant)	10.031	13.718		.731	.471
	X_1	.723	.116	.703	6.237	.000
	X_2	.324	.138	.264	2.345	.026

X_1: Critical thinking skills; X_2: Concept mastery

Discussion

This study discovered that critical thinking skills and concept mastery contributed to students' problem-solving skills after applying the CS-PBL learning model. Table 4 displays that critical thinking skills and concept mastery have a relative contribution of 82.5% and 17.5%, respectively, toward students' problem-solving skills. CS-PBL learning model application in the learning process could effectively and significantly improve students' critical thinking skills and concept mastery that positively affect their problem-solving skills. The early activity of the CS-PBL learning model is the analysis of any phenomenon or problem that occurs in students' daily lives. Fiore et al. (Fiore et al., 2018) described that a learning model that could develop critical thinking skills and concept mastery during the learning process is the one that utilizes real-life problems. Analyzing real-life problems could help students actively build new knowledge. Students' real-life problems are complex, involve various variables, have reciprocal relationships and dependency between each variable, and have some degrees of analysis to solve the problems (Zhiwei et al., 2017).

The multiple regression equation in Table V shows a positive equation, which means that the relationship between critical thinking and concept mastery toward problem-solving skills goes one way. If the students' critical thinking skills and concept mastery increase, then their problem-solving skills will also increase. This is in line with Kim & Choi (Kim & Choi, 2014) and Memduhoğlu & Keleş (Memduhoğlu & Keleş, 2016), who discovered a positive and significant correlation between critical thinking skills, concept mastery, and problem-solving skills. The improvement of critical thinking quality is followed by the development of students' concept mastery which would affect their problem-solving skills (Tillman, 2016).

Critical thinking and problem-solving abilities are necessary skills in human and animal physiology as the fundamental aspects of clinical reasoning (Choi et al., 2014). The problems in human and animal physiology are closely related to complex and unstructured health problems (Kumlin et al., 2020; Laerum et al., 1998). Unstructured problems are the actual situation known as authentic problems and reflect the real challenges that people face (Barak & Assal, 2018). Solving unstructured problems needs a high level of understanding and reasoning and involves a variety of relevant disciplines as they have several interconnected factors (Merone et al., 2020).

Problem-solving skills involve critical thinking skills by processing existing information to create a solution (Batlolona et al., 2018). Problem-solving skills result from the complex concept mastery in the matter of intellectual capacity (Mitchell & Walinga, 2017). In general, students would need deep concept mastery to solve complex and complicated problems (Glazewski & Ertmer, 2020). Fries et al. (Fries et al., 2021) found that students with deep concept mastery could analyze relevant information to understand the problem they face and filter out irrelevant information when formulating the solution.

In general, concept mastery in the cognitive dimension consists of the application, analysis, evaluation, and synthesis. On the other hand, evaluation is a high-order thinking skill requiring a cognitive process that develops problem-solving skills (Cansoy & Turkoglu, 2017). According to Hyytinen et al. (Hyytinen et al., 2018), concept mastery and critical thinking skills are inseparable as both focus on students' thinking skills to solve a problem.

Students' critical thinking skills need to get trained in every learning process. Each learning process needs to be designed to help students develop their thinking skills. During learning, the thinking process always starts from the simple one to the complex. CS-PBL learning model rationally and comprehensively trains students' thinking skills to improve their critical thinking and problem-solving skills and help them gain the essential concepts from the learning materials.

CS-PBL learning model is multidiscipline in the foundation and facilitates students to train themselves to solve problems relevant to their lives. By applying the CS-PBL learning model, biology department students actively explore their thinking skills independently or collaborate with their groups. 21st-century education focuses on problem-solving learning models to train students' thinking and social skills (Górski et al., 2015). The fourth syntax of the CS-PBL learning model is investigating and seeking clarification from experts. This learning model invites an expert to help students solve complex problems in their daily lives during the problem-solving process (Song, 2018). The 21st-century education system is expected to produce human resources that could think critically, creatively, innovatively, and communicate and collaborate to solve a problem. Collaboration in solving a problem needs social and cognitive skills to develop understanding, make a decision, create a proper solution, and build and reserve teamwork (Häkkinen et al., 2017; Ali, 2018). The benefits of collaboration with experts during the problem-solving process are to 1) develop communication skills; 2) expand organizational/leadership skills; 3) improve respectful and ethical manner; 4) share information and knowledge;

and 5) enhance students' quality in making decision or solution to solve a problem (MacLeod & Nersessian, 2016; McMurtry et al., 2016).

A learning model based on multidiscipline is a vital and practical approach to improving students' complex problem-solving skills during the 21st century (Wake, 2008). Complex problem understanding requires a paradigm shift from linear and reductionist to dynamic and holistic approaches that utilize multi-aspects relationships (Colón-Emeric et al., 2006). Systematic and complex thinking helps students direct and widen their understanding of the problem so they can create a rational solution (Heinrich & Kupers, 2019). A systematic, dynamic, and comprehensive way of thinking is the core of the complexity science approach.

The CS-PBL learning model focuses on multidiscipline and transdisciplinary research that combines the components of biology, physics, socio-economy, mathematics, technics, and humanities to answer complex problems. A complex problem is a problem with multivalued logic, is unstructured, and consists of interconnected aspects, so any change in the problem could lead to a more complicated and more significant problem from time to time (Plsek & Greenhalgh, 2001), (Vidal, 2009). Even when students are required to focus on their field of knowledge, it would be significantly better if they could utilize the thinking skills from other relevant fields for the complex problems they face in their lives (Bialek & Botstein, 2004).

Conclusions

It could be concluded that there is a significant relationship between critical thinking skills and concept mastery with problem-solving skills. After applying the CS-PBL learning model, students' critical thinking contributed better to their problem-solving skills than their concept mastery. Therefore, further studies need to be conducted at the different levels of education, such as in high school or elementary school, to increase the understanding of the relationship between critical thinking and concept mastery in learners' problem-solving skills from various ages after being given the CS-PBL model.

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Kritinio mąstymo, sąvokų įsisavinimo ir problemų sprendimo įgūdžių koreliacija: mokslo sudėtingumo ir problemų sprendimo mokymosi modelio vaidmuo

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Santrauka

Kritinio mąstymo įgūdžiai ir sąvokų įsisavinimas yra būdingi ir būtini kiekvienam žmogui sprendžiant problemas XXI amžiuje. Tyrimo tikslas – nustatyti būtinų kritinio mąstymo įgūdžių ir sąvokų įsisavinimo ryšį sprendžiant problemas, kai taikomas mokslo sudėtingumu pagrįstas problemų sprendimo mokymosi modelis (angl. *CS-PBL*). Tyrimo imtį sudarė visi studentai, kurie studijavo žmogaus ir gyvūnų fiziologijos kursus valstybinio Malango universiteto Biologijos fakultete. Duomenys buvo analizuojami taikant daugialypės regresijos koreliacinę analizę. Rezultatai parodė ryšį tarp kritinio mąstymo įgūdžių ir sąvokų įsisavinimo bei problemų sprendimo, naudojant mokslo sudėtingumu pagrįstą problemų sprendimo modelį. Kritinio mąstymo ir sąvokų įsisavinimo indėlis į problemų sprendimo įgūdžius taikant mokslo sudėtingumu pagrįsto problemų sprendimo mokymosi modelį yra 65,3 proc. Galima daryti išvadą, kad mokslo sudėtingumu pagrįstas problemų sprendimo mokymosi modelis (angl. *CS-PBL*) yra taikytinas ugdant studentų kritinio mąstymo įgūdžius ir sąvokų įsisavinimą. Šis modelis daro įtaką problemų sprendimo įgūdžiams. Todėl primygtinai rekomenduojama įgyvendinti mokslo sudėtingumu pagrįstą problemų sprendimo modelį aukštojo mokslo institucijose.

Esminiai žodžiai: *probleminis mokymas, kritinis mąstymas, sąvokų įsisavinimas, problemų sprendimas, mokslo sudėtingumas, probleminis mokymasis.*

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