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The Relationship between Conceptual Understanding and Students' Academic Achievement in Biochemistry Courses

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ABSTRACT

Biochemistry is one of the most challenging subjects for students to master, so a conceptual understanding is necessary to grasp its complex and broad concepts. Concept maps can help understand concepts and can also be used as an assessment tool. This study employed a quantitative correlational analysis to examine the relationship between students' conceptual understanding, as assessed through concept maps, and their academic achievement in Biochemistry. The concept map assessment utilized the University of Waterloo rubric, while the academic achievement assessment used the midterm exam results as a basis. Using the Spearman correlational test, it can be concluded that there was no statistically significant correlation between the concept map and the midterm exam score. The different knowledge content or depths likely caused this result compared to the exam. Differences in learning atmosphere, time allocated, and method of working may also contribute to the insignificant correlation between them. A further study was needed to explore the exact reason for it.

INTRODUCTION

Biochemistry is a course that encompasses many concepts, requiring students to develop a conceptual understanding. Conceptual understanding is defined as a process that enables students to connect and organize their knowledge, both in theory and in practice (Mills, 2016). Conceptual understanding is the foundation that students must have in learning science, including biochemistry.

The challenge in learning biochemistry is not only due to the complex nature of the material but also to the relationship between concepts. A study by Salame et al. (2022) showed that students rely on memorization methods for the material, which prevents them from developing a deeper understanding of the concept. In fact, unlike memorization, mastery of real biochemical material requires the ability to visualize, analyze, and synthesize information about various working systems. The breadth and complexity of concepts in biochemistry, encompassing both metabolic processes and chemical structures, as well as the terminology used, make it challenging for students to master them (Juwita et al., 2023). Conceptual misunderstandings can cause further errors and lead to knowledge gaps, which is why educators stress the importance of building strong conceptual understanding in learning.

Conceptual understanding in biochemistry courses is a common problem faced by lecturers, despite this course being one of the most challenging for students to grasp. Concepts that generally use many foreign terms and are almost similar to each other make it difficult for students to learn (Fauzi & Fariantika, 2018). Furthermore, the complexity of the material hinders students ability to assimilate and remember the various terms and concepts in biochemistry (Elhousni et al., 2023). Students also struggle to comprehend events or processes that occur at the molecular level (Salame et al., 2022). Understanding concepts in biochemistry is crucial to avoid misconceptions, especially since biochemistry is one of the foundational courses that students must complete before taking other courses, such as molecular biology.

One of the media that can help students organize the concepts they learn is a concept map. Concept maps can help assess understanding of functional systems (Schmidt et al., 2024). In addition to understanding the various concepts that exist, concept maps must also be able to logically organize and detail the relationships between concepts. Although it takes longer to compile, concept maps can help students formulate more effective propositions and describe more precise conceptual relationships compared to verbal explanations (Schmidt et al., 2024). According to cognitive theory, visual tools help students grasp abstract concepts by connecting new information to prior knowledge (Habsy et al., 2023).

Concept maps can also be used as an assessment tool in learning. Concept mapping enhances student engagement in self-assessment, thereby improving the quality of their learning (Chen & Allen, 2017). There are four methods for assessing concept maps: quantitative, by calculating the score for each aspect according to the rubric; qualitative, by describing the requested characteristics; comparing similarities with reference concept maps;

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and holistic, by assessing all aspects according to the rubric. The four assessment methods produce different conclusions but can be combined for a more comprehensive understanding (Ries et al., 2022).

RESEARCH METHOD

Method

This study was a quantitative correlational investigation that aims to examine the relationship between conceptual understanding ability and academic achievement among students in biochemistry courses. The study was conducted in the Biology and Biology Education study program at Universitas Negeri Semarang from March to April 2025.

Selection of Participants

The population of this study consisted of students enrolled in biochemistry courses within the Biology and Biology Education Study Program at Semarang State University, comprising seven classes. The research sample consisted of three classes, each with 35, 35, and 31 students, selected using the clustered sampling technique. The three classes were then used to collect data on the results of independent project work, namely, making concept maps and mid-semester exam results.

Data Collection

A concept map is used as an instrument to investigate conceptual understanding of glycogen metabolism. Data from the assessment of students' concept maps were collected using the concept map assessment instrument, as described by Waterloo (Centre for Teaching Excellence, University of Waterloo, 2014).

Table 1. Waterloo University Rubric of Concept Map Assessment

Criterion	Score			
	Excellent = 4	**Good = 3**	**Bad = 2**	**Failing = 1**
Breadth of net	Contains important concepts and describes domains at various levels	Contains important concepts and describes domains at limited levels	Some important concepts are missing or describe only one domain	Many important concepts are missing
Embedness and interconnectedness	All concepts are interconnected	Most concepts are interconnected	Some concepts are interconnected	Only a few concepts are interconnected
Use of descriptive link	All links between concepts accurately describe their relationships	Most links between concepts accurately describe their relationships	Some links are unclear or incorrect	Many links are incorrect and describe inconsistent relationships
Efficient link	Links are distinct from each other and describe consistent relationships between concepts.	Most links are distinct from each other, differentiate between concepts, and are used consistently.	Some links are similar, fail to differentiate between concepts or relationships, and are used inconsistently.	Most links fail to differentiate between concepts or relationships
Layout	On one page, a hierarchy is presented, and all examples are correct.	On one page, it has a hierarchy and has enough correct examples	Not on one page, hierarchy is not clear, and only a few examples are correct	Not on one page, confusing for readers without correct examples

Each criterion has a score of 1-4, as outlined in the rubric in **Table 1**. Meanwhile, the midterm exam results represent students' academic achievement in the biochemistry course for half a semester, covering five subtopics: enzymes, enzymatic breakdown of macromolecules, carbohydrate catabolism and anabolism, and lipid catabolism. The types of questions used in the midterm exam are short-answer questions and true-false analysis of a statement with a cognitive ability level of C2-C4.

Data Analysis

Descriptive analysis is used to provide an overview of students' abilities in compiling concept maps and academic achievement results. The concept map assessment data and midterm exams were analyzed for homogeneity and normality. The homogeneity test was conducted using Levene's test of homogeneity, while the normality test used the Shapiro-Wilk test. After confirming normality and homogeneity, a correlation test was conducted using Pearson's test for parametric data or Spearman's test for non-parametric data.

RESULT AND DISCUSSION

Student Concept Understanding

Students' understanding in this study was measured using concept maps. Concept maps are a tool that can be used to measure students' knowledge through the existence of concepts that form a meaningful hierarchical structure. Concept maps also support the development of metacognitive knowledge because students are allowed to express and evaluate their knowledge independently, thereby leading to the formation of new insights (Kelly et al., 2002). Three classes were used as samples, coded A, B, and C.

Concept maps were created manually using pen and paper, allowing students to express their thoughts more easily and freely. Assessments were conducted on the contents of the concept map to describe students' conceptual understanding using the concept map assessment rubric from the University of Waterloo, which includes five criteria: Breadth of net, Embedness and interconnectedness, Use of descriptive links, Efficient links, and Layout. The assessment results of the three sample classes are shown in **Table 2.**

Table 2. Concept Map Assessment Results

Class	Average Score					Total Score
	Breadth of net	Embedness and interconnectedness	Use of descriptive link	Efficient link	Layout	
A	3.00	3.31	3.03	2.94	3.83	16.11
B	3.00	3.29	3.03	2.94	3.82	16.09
C	3.00	3.25	3.04	2.92	3.79	16.00

Table 2 shows that the three classes have nearly identical scores or values in the five characteristics of the concept map assessment. The average score for each character is 3, which falls within the good category according to the rubric. Class A has a higher total score than classes B and C. In terms of network breadth, the three classes have the same average score, meaning that students' ability to identify main concepts and arrange them hierarchically in the map is almost the same.

In terms of embeddedness and interconnectedness, class A has a higher score, followed by classes B and C, indicating that the ability to link concepts in class A is greater than in other classes. It suggests that the systematic thinking skills of Class A students are superior. The concept maps from Class A students had a more connected network and more than one connecting link. It indicates a high level of cognitive organization that allows them to analyze, apply, and think critically about the relationships between concepts. Concept maps can be used to develop and measure students' critical thinking (Fonseca et al., 2024). In the third characteristic, namely descriptive link, class C has a slightly higher score than the other classes, meaning that class C can describe the relationship between concepts more precisely. In the efficient link characteristic, classes A and B are both able to utilize different links and differentiate between concepts, using them efficiently. In terms of layout characteristics, Class A has the highest score in compiling the map layout, so that, on average, it is presented on one page, has a proper hierarchy, and includes relevant examples. This finding indicates that, although the three classes possess nearly identical abilities in compiling concept maps, each class exhibits distinct characteristics and methods for creating them.

Table 2 shows that the efficient link has the lowest average among all characteristics. The students still use almost the exact words and repeat them when connecting concepts. It is because students are not accustomed to compiling concept maps, which limits their ability to expand their vocabulary. The concept map contains propositional learning where clear and precise propositions or efficient links can describe deep understanding and vice versa (Novak & Cañas, 2008). On the other hand, layout has the highest average among the characteristics because most students create the map from a single page, using the correct hierarchy and examples. This result suggests that the students possess sufficient creativity in designing concept maps. The use of the Concept Achievement Model (CAM) with a concept mapping measuring tool has a significant impact on creative thinking skills (Agustin et al., 2024).

Table 3. Mid-Semester Exam Assessment Results

Class	Average	Minimum	Maximum
A	41.48	20	76.67
B	32.67	18.33	43.33
C	31.85	16.67	45

Concept maps can be used as a tool to measure conceptual understanding because they help students identify the concepts they have understood and those they have not understood when asked to explain them graphically. Students who do not yet understand the material require assistance with keywords or key links from partial maps. In contrast, students with a better understanding of the material often feel limited by the existence of partial maps and prefer to create their concept maps freely (Zagaar & Chen, 2022). Thus, concept maps also help students develop their metacognitive knowledge.

Student Academic Achievement

In this study, the intended student academic achievement is limited to the mid-semester exam assessment data for the biochemistry course. Based on the results of the mid-term exam assessment, it is known that class A has a higher average than classes B and C **(Table 3)**. The maximum and minimum scores of class A are also higher than those of the other two classes. This midterm assessment contains material from half a semester of biochemistry courses, consisting of five subtopics: enzymes, enzymatic breakdown of macromolecules, carbohydrate catabolism and anabolism, and lipid catabolism. Based on these results, the average student still has relatively low academic achievement.

Correlation between Concept Understanding and Academic Achievement

In general, the difference in the concept map assessment scores for each characteristic is only slight, less than 0.1, so the three classes have almost the same conceptual understanding ability. However, to determine whether the data is normally and homogeneously distributed, statistical analysis is necessary. The data from the concept map and mid-term assessments were then tested for normality using the SPSS 25.0 application. The results of the normality and homogeneity tests for the data are presented in **Tables 4** and **5**.

Table 4. Shapiro-Wilk Normality Test Results Using SPSS 25.0

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Map_value	A	.260	35	.000	.896	35	.003
	B	.306	35	.000	.857	35	.000
	C	.280	28	.000	.853	28	.001
Mid_value	A	.154	35	.035	.935	35	.039
	B	.112	35	.200*	.955	35	.166
	C	.153	28	.091	.964	28	.443

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

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Table 5. Levene's Homogeneity of Variances Test Results Using SPSS 25.0

		Levene Statistic	df1	df2	Sig.
Map_value	Based on Mean	1.127	2	95	.328
	Based on Median	.842	2	95	.434
	Based on Median and with adjusted df	.842	2	90.903	.434
	Based on trimmed mean	1.052	2	95	.353
Mid_value	Based on Mean	7.026	2	95	.001
	Based on Median	4.586	2	95	.013
	Based on Median and with adjusted df	4.586	2	57.353	.014
	Based on trimmed mean	6.440	2	95	.002

The results of the normality test on the concept map values show that the data is not normally distributed, while the mid-semester value data is normally distributed. From the results of the homogeneity test, it is evident that the concept map values of the three classes exhibit homogeneous variance, whereas the mid-semester values do not. It can be concluded that the data does not meet the parametric requirements. Therefore, a correlation test was carried out using nonparametric correlation analysis, specifically the Spearman correlation test, in SPSS 25.0. The results of the correlation test are presented in **Table 6.**

Based on these results, it is evident that the significance value of 0.120 is greater than 0.05, indicating that there is no statistically significant correlation between the concept map score and the midterm exam score. Although concept maps help students organize their thoughts, there is no direct correlation between them and student achievement. This result is likely due to the concept maps used in this course containing different knowledge content or different depths of knowledge compared to other assessments (Macleod et al., 2024).

Conceptual understanding, as measured by concept maps, cannot continuously improve learning outcomes; instead, it must be adapted to students' learning needs and abilities (Anastasiou et al., 2024). In this case, concept maps are created by analyzing literature and then written out. The process of creating concept maps enables students to freely generate ideas and describe their understanding. In contrast, midterm exams rely more on the ability to analyze concepts and apply their understanding in answering questions from predetermined but broader material.

Another factor that may contribute to the lack of correlation between concept maps and midterm scores is the learning environment. The learning atmosphere also affects student learning outcomes. Concept maps used as project assignments, which are completed at home, provide students with opportunities to explore freely and optimally. In contrast, exams held in class with a limited time frame can put mental pressure on students, hindering their ability to complete assignments effectively.

Table 6. Spearman Correlation Test Results Using SPSS 25.0

			NilaiPeta	Nilai Mid
Spearman's rho	Map_value	*Correlation Coefficient*	1.000	.158
		Sig. (2-*tailed*)	.	.120
		N	98	98
	Mid_value	*Correlation Coefficient*	.158	1.000
		Sig. (2-*tailed*)	.120	.
		N	98	98

Although the learning environment and learning process have a positive relationship with student learning achievement (Hasibuan, 2018), in terms of tests, they can put pressure on students' mentalities, so that they cannot work optimally. Stress in taking tests can be caused by students' lack of preparation, study habits, and lack of information about the test (Sasikumar & Bapitha, 2019). Self-readiness in facing an exam, combined with good sleep quality, is expected to enhance fitness and cognitive function, thereby improving students' academic achievement (Yekti & Rambe, 2021).

Anxiety in facing exams encourages students to prepare themselves better, but excessive levels of anxiety can have negative impacts, for example, difficulty concentrating, thus affecting academic achievement (Hanifah & Abadi, 2018). Effective learning can be achieved by creating a comfortable and pleasant atmosphere that motivates students to learn (Yusuf et al., 2023). In addition, to make concept map-based learning successful, students must clarify the purpose of making it, which is not only to help improve academic performance in summative exams but also to support meaningful learning and deepen understanding (Zagaar & Chen, 2022).

The large amount of material tested in the mid-term exam may also cause the score to be less than optimal, resulting in the results being irrelevant to the concept map assessment results. Complex material with limited study time can cause students to perform suboptimally on the exam (Elhousni et al., 2023). Low student exam scores can be followed up by improving the lecturer's teaching strategy and the student's learning method, including using more animations, real-life examples, bringing more discussions and laboratory work to life, and providing more references and quizzes (Rahmatan, 2016).

Another cause of the lack of correlation is the difference in how students approach concept maps and exams. Some students may compile concept maps together with their peers, marked by the presence of almost the same characteristics in some of the students' work. Meanwhile, the exam is carried out by relying on one's abilities and understanding, so that, with limited time, the results of the concept map work differ from the exam. Concept maps are also often created to fulfill assignments and have not been widely adopted by students as a learning method. Biology learning using concept maps can be done with a cooperative model (Zubaidah & Pangestuti, 2016).

Concept maps facilitate collaborative learning through discussions, exchanges of opinions, and negotiations with peers (Machado & Carvalho, 2020). This finding is also in line with the research of Zaagar & Chen (2022), which suggests that academic achievement does not always correlate with deeper learning and lasting understanding. The use of maps as a tool to aid understanding should be reviewed and taught to students early on as a learning and self-assessment tool.

Another difference that may contribute to the non-correlative relationship between conceptual understanding and academic achievement is the selection of a concept map assessment method that is less effective in exposing the aspects being sought. According to Ries et al. (2022), there are four assessment methods that can be used to evaluate concept maps, namely quantitative, qualitative, similarity, and holistic. The quantitative method involves calculating a score for each aspect according to a specific rubric, such as Novak's criteria.

The qualitative method is by describing the characteristics requested. Maps can also be assessed by comparing the similarity of student work results with reference concept maps, whereas the holistic method involves assessing all aspects according to the rubric. This study employed a qualitative method, as outlined in the map assessment rubric prepared by the University of Waterloo, to facilitate assessments using other methods in future research and obtain more comprehensive results.

This study has limitations in that it has not analyzed the causes of low student midterm exam scores. Additionally, the definition of academic achievement used in this study remains limited to exam scores. This limitation presents an opportunity to also research academic achievement from alternative perspectives, such as competitions, scientific papers, and class performance, among others.

CONCLUSION

The results of this study indicate that there is no significant correlation between conceptual understanding, as measured by concept maps, and students' academic achievement. These results are likely due to differences in knowledge content or the depth of knowledge assessed in concept maps, which differs from that tested in tests. The different learning atmosphere between learning using concept maps and when the exam is conducted may also affect learning outcomes. In addition, the breadth and depth of material in biochemistry courses are the causes of learning difficulties experienced by many students. Learning with concept maps, carried out together, is also a factor that has the potential to affect learning outcomes compared to tests carried out independently within a limited time. Although the study's results indicate that there is no correlation, further research is needed to investigate the learning difficulties experienced by students in biochemistry courses and the factors that contribute to them.

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