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Correlation between computational thinking skills and cognitive learning outcomes: Insights from genetic trait inheritance based on Mendel's laws

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ABSTRACT

Biology learning in the 21st century requires students to understand complex genetics concepts, particularly the inheritance of traits in living organisms based on Mendel's laws. Computational thinking skills are essential for helping students systematically analyze and solve these intricate genetic patterns. This study aims to analyze the relationship between computational thinking skills and cognitive learning outcomes on the material of the inheritance of living creatures' traits based on Mendel's law. The research method used is descriptive with a correlational study. This study employed a descriptive correlational research method, conducted at SMAI PB Soedirman with a sample of 87 twelfth-grade science students from 203 students with an average age of 17-18 years and a balanced proportion of male and female selected through simple random sampling. The instruments used included questionnaires to measure computational thinking skills and tests to assess cognitive learning outcomes in genetics. Data analysis involved descriptive statistics to summarize the data and correlational analysis using Pearson's Product-Moment to explore the relationship between variables. The tests that have been carried out show that there is a significant positive and linear relationship between computational thinking skills and cognitive learning outcomes of genetic trait inheritance based on Mendel's law. The strength level of the relationship between the two variables is moderate.

INTRODUCTION

The 21st century has witnessed significant developments in information and communication technology, affecting various aspects of human life. (Mardhiyah et al. 2021) explained that these technological advances demand more skilled and competent human resources. (Rahmah, 2023) added that this causes students' lives to become more complex and competitive, with education playing an important role in shaping the quality of human resources. (Darmawati, Nursal, and Arnentis, 2021) emphasized the importance of education in preparing a generation that is educated and ready to compete in the global arena, encouraging students to learn more and be proactive about change.

In the context of Biology education in the era of Industrial Revolution 4.0 and Society 5.0, students are required to master a series of skills summarized in the 6C concept which includes critical thinking, collaboration, communication, creativity, citizenship, and character education or connectivity (Fullan et al., 2017). According to (Greene et al. 2019) Biology lessons require students to master content and scientific knowledge, which involves various ways of thinking, including concept mastery. One of the important areas in Biology education is genetics. (Wahyono et al. 2016) underlined the importance of understanding genetics in Biology contexts and problems. Genetics is also important to explain various phenomena of life and states that a comprehensive understanding of genetics is important for students.

However, according to (Nusantari, 2013) and (Gusmalini, Wulandari, and Zulfarina, 2020), many students have difficulty in understanding the concept of genetics. Misconceptions about genetics are common, as shown in Wangintowe's research in (Suparyana, 2014). (Machová and Ehler, 2023) also found similar misconceptions. Difficulties in understanding genetics have an impact on low learning outcomes. (Malanchini et al. 2020) emphasized that students' thinking abilities strongly influence learning outcomes related to cognitive abilities.

Understanding genetic concepts, especially inheritance patterns based on Mendel's laws, requires advanced thinking skills to analyze complex information systematically. Computational thinking (CT) is one such skill that can help students approach genetic problems logically, break down complex inheritance patterns, and apply algorithms or models to predict genetic outcomes. This skill is essential in supporting students' cognitive learning outcomes, especially in areas involving calculations and genetic inheritance pattern predictions. Several studies suggest that CT aids in developing critical cognitive skills necessary for problem-solving in scientific contexts, especially in fields like genetics where complex calculations and data analyses are essential (Voogt et al., 2015; Yadav et al., 2016). Jannah, et al. (2024) highlight that implementing computational thinking in science and biology learning can improve students' learning achievement. This study references several international studies that show that strategies such as Problem-Based Learning, Flipped Classroom, and CT-4MAT can improve students' critical and computational thinking skills to be relevant to genetics learning outcomes.

Despite its potential, research directly linking CT skills with learning outcomes in genetics remains limited, creating a research gap that needs addressing to understand CT's role in enhancing cognitive learning outcomes in genetics. This study, therefore, addresses this gap by examining the direct relationship between computational thinking skills and cognitive learning outcomes in genetics, aiming to clarify how CT can enhance students' understanding of genetic inheritance patterns based on Mendelian laws. The urgency of this research lies in the need for effective learning methods that enhance students' understanding of genetics, specifically through computational thinking skills, and providing a foundation for the development of improved teaching strategies in genetics education.

METHODS

Research Design

This research uses a quantitative approach, with descriptive methods and correlational studies which are essential for understanding relationships and characteristics within data (Friedman et al. 2022). Descriptive methods focus on summarizing data to answer "What is X?" while correlational studies explore the relationships between variables, addressing "How are things related?". This framework is foundational in various research fields, utilizing surveys and observational methods for data collection. According to Sudjana & Ibrahim (2007), this approach is used to examine the relationship between two or more variables, assessing the extent to which variations in one variable are associated with variations in another. This research focuses on two main variables: the independent variable (X), which is computational thinking ability, and the dependent variable (Y), which is cognitive learning outcomes in the context of genetic trait inheritance based on Mendel's law. This study used the design shown in Figure 1.

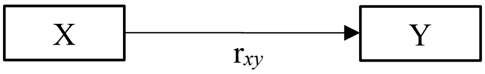

Figure 1. Research Design

Information:
X = Computational thinking ability
Y = Cognitive learning outcomes of genetic trait inheritance based on Mendel's law
r_{xy} = Relationship between the ability of computational thinking with cognitive learning outcomes of inheritance of the nature of living things based on Mendel's law

Population and Samples

The population in this study were all students of class XII SMAI PB Soedirman, Jakarta, Indonesia majoring in Mathematics and Natural Sciences. As grade XII science students, they had previously studied the inheritance of the nature of living things based on Mendel's law, so they were considered to have sufficient knowledge to participate in this study. The sample in this study was taken using simple random sampling. The minimum number of samples is determined using the Slovin formula (Sugiyono, 2019). From a population of 203 students, 87 people were determined as samples. The sample consisted of students with an average age of 17-18 years and a balanced proportion of males and females. Each member of the population has the same opportunity to be selected as a sample.

Instrument

This study used two main instruments for measurement. First, an instrument to measure Computational Thinking Ability is defined as the process of solving problems with an emphasis on understanding the problem before formulating a solution. This ability is measured in five different dimensions: problem-solving, algorithmic thinking, critical thinking, cooperative learning, and creative thinking. This instrument, developed by (Korkmaz, Çakir, and Özden, 2017), consists of 40 items measured using a 5-point Likert scale. To ensure the validity and reliability of this instrument, a validity test was conducted using the Pearson Product Moment formula, which resulted in 32 valid items, and a reliability test using Cronbach's Alpha formula, with a value of $\alpha = 0.922$, indicating that this instrument is highly reliable.

The second instrument used in this study was to measure the Cognitive Learning Outcomes of Genetic Trait Inheritance Based on Mendel's Law. This instrument was designed to measure students' mastery of the material on the inheritance of traits, using a multiple-choice test based on the cognitive dimensions (Anderson and Krathwohl, 2001). The instrument consists of 35 items covering six cognitive levels. To ensure the validity and reliability of the instrument, a validity test was conducted using the Biserial Point formula, which showed 32 valid items, and a reliability test using the Kuder Richardson 20 formula, resulting in a reliability coefficient of 0.952. These results indicate that this instrument is very accurate and reliable to measure students' cognitive learning outcomes of genetic trait inheritance based on Mendel's law.

Procedure

In this study, the data collection method was conducted through a survey addressed to the students. A non-test questionnaire was used as an instrument to collect data on computational thinking ability. In contrast, this study relies on a multiple-choice format test focusing on genetic material to obtain data related to cognitive learning outcomes in genetics. Both the questionnaire and the test will be distributed to students offline and conducted simultaneously to maximize the level of participation in the study.

Data Analysis Techniques

Data analysis was conducted using methods appropriate to the data collection techniques that had been selected. This process involved the use of SPSS version 29.0 for hypothesis testing. First, descriptive analysis was conducted to simplify the representation of quantitative data collected from questionnaires and tests. This data was then described in the form of minimum, maximum, range, mean, and standard deviation scores. Furthermore, to evaluate the prerequisites of the analysis, the Normality Test and Homogeneity Test were conducted. Normality test used Levene's test to determine the normal distribution of data from both variables, namely computational thinking ability and cognitive learning outcomes. The Homogeneity Test also used Levene's test to check the uniformity of variance between data groups. Finally, the Hypothesis Test was conducted through Linear Regression Test and Correlation Coefficient Test. Linear Regression Test was used to assess the significance and linearity of the regression model between computational thinking variables and cognitive learning outcomes. Meanwhile, the Correlation Coefficient Test, which uses the Pearson Product Moment formula, aims to measure the level of correlation between the two variables, followed by calculating the coefficient of determination and the resulting contribution.

RESULTS AND DISCUSSION

This study was conducted involving 87 high school students, who were selected based on calculations using the Slovin formula. The two main variables studied were computational thinking ability (X) as the independent variable and cognitive learning outcomes of genetic trait inheritance based on Mendel's law (Y) as the dependent variable. Descriptive statistics were calculated to analyze this data, including minimum, maximum, range, mean, and standard deviation, with statistical information summarized in Table 1.

The average scores for cognitive learning outcomes of genetic trait inheritance based on Mendel's law were higher than those for computational thinking skills. This suggests that students generally perform better in understanding genetic concepts than in applying computational thinking strategies. The standard deviation for cognitive learning outcomes was also higher, indicating that while the average performance is better, there is a wider range of scores. This variability suggests that some students excel in understanding genetics, while others struggle significantly, pointing to potential gaps in teaching methods or student engagement. The findings can be associated with Cognitive Load Theory, which posits that learners have a limited capacity for processing information (Sweller, 2024). If students are overwhelmed by complex genetic concepts without adequate computational thinking skills, their ability to learn effectively may be compromised. This theory supports the need for instructional strategies that balance cognitive load by integrating computational thinking into genetics education.

Table 1.
Descriptive Statistics of Research

Statistical Measures	Computational Thinking Ability	Cognitive Learning Outcomes of Genetic Trait Inheritance Based On Mendel's Law
Mean	74.70	82.80
SD	9.31	11.82
Variance	40.00	37.00
Minimum value	58.00	63.00
Maximum value	98.00	100.00
Number of samples	87.00	87.00

Cognitive Learning Outcomes of Genetic Trait Inheritance Based On Mendel's Law

Data related to cognitive learning outcomes of genetic trait inheritance based on Mendel's law were collected from 87 students of class XII at SMAI PB Soedirman using multiple-choice tests. This data was processed using five scoring criteria: excellent, good, fair, poor, and very poor, based on score intervals adapted from Arikunto's guidelines (Budiman and Riyanto, 2013), as shown in Table 2. The majority of students, with a percentage of 48.3%, achieved scores in the 60-79 range, and the percentage of students scoring 90-100 was 35.6%. Students at SMAI PB Soedirman performed quite well in this test, with no scores in the very poor category. Their average score was 82.8, with a standard deviation of 11.82.

Table 2.
Frequency Distribution of Cognitive Learning Outcomes of Genetic Trait Inheritance Based On Mendel's Law

Value Range	Criteria	Absolute Frequency	Relative Frequency (%)
0-39	Very Less	0	0
40-59	Less	0	0
60-79	Fair	42	48,3
80-89	Good	14	16,1
90-100	Very Good	31	35,6
Total		**87**	**100**

Table 3 presents additional information about the results categorized based on the Minimum Completion Criteria (MCC). From the results obtained, it was revealed that only 25.3% of the total learners had scores below the MCC. This is defined as the minimum standard of competency achievement that is used as a benchmark by educators, students, and parents (Prayitno, 2013). The main purpose of this arrangement is to ensure that learning outcomes in each subject achieve at least 75% completeness.

Table 3.
Percentage of Group Score of Cognitive Learning Outcomes of Genetic Trait Inheritance Based On Mendel's Law

Score	Criteria	Frequency	Percentage %
< 75	Tidak Tuntas	22	25,3
≥ 75	Tuntas	65	74,7
Total		**87**	**100**

The instrument of cognitive learning outcome variables of inheritance of the nature of living things based on Mendel's law is measured in six cognitive dimensions, namely remembering (C1), understanding (C2), applying (C3), analyzing (C4), evaluating (C5), and creating (C6). Each dimension calculated the average, and standard deviation, and the criteria seen from the average value of each dimension, which can be seen in Table 4. The highest average score was obtained in the remembering dimension (C1) which amounted to 98.56 and the lowest average score was obtained in the evaluating dimension (C5) of 68.58. The dimensions of remembering (C1) and understanding (C2) have very good criteria, while the dimension of applying (C3) has good criteria, and analyzing (C4), evaluating (C5), and creating (C6) have sufficient criteria.

Table 4.
Descriptive Data of Each Dimension of Cognitive Learning Outcomes of Genetic Trait Inheritance Based On Mendel's Law

Dimension	Mean	Standard Deviation	Criteria
Remembering (C1)	98.56	5.85	Very good
Understanding (C2)	90.80	12.51	Very good
Applying (C3)	87.36	17.83	Good
Analyzing (C4)	75.24	19.59	Fair
Evaluating (C5)	68.58	28.92	Fair
Creating (C6)	76.25	32.51	Fair

Computational Thinking Ability

Data regarding computational thinking ability was obtained from a questionnaire filled out by 87 students of class XII at SMAI PB Soedirman. From this data, the highest score achieved was 98, while the lowest score was 58, giving a range of 40 points. The average computational thinking ability of the students was recorded at 74.7 with a standard deviation of 9.31. These results were then classified into five assessment categories - very high, high, medium, low, and very low - based on the interval scores adapted from Iksan & Zakaria (2020), as displayed in Table 5.

Table 5.
Frequency Distribution of Computational Thinking Ability

Value Range	Criteria	Absolute Frequency	Relative Frequency (%)
0-39	Very Low	0.00	0.00
40-59	Low	2.00	2.30
60-79	Medium	52.00	59.80
80-89	High	29.00	33.30
90-100	Very High	4.00	4.60
Total		87.00	100.00

Based on the frequency analysis contained in Table 6, it was found that most students, 59.8%, had computational thinking ability at the medium level. This was followed by 33.3% of students with high levels of ability, 4.6% at very high levels, and 2.3% at low levels. Significantly, no students were rated very low in this ability. This computational thinking ability is measured through five dimensions, which include problem solving, algorithmic thinking, critical thinking, cooperative learning, and creative thinking, with detailed scores for each dimension available in Appendix 4c and their criteria in Table 8. Except for the cooperative learning dimension, which has the highest mean of 80.23 and is categorized as high, all other dimensions fall into the medium category. The dimension with the lowest average was critical thinking, with a score of 70.31.

Table 6.
Descriptive Data of Each Dimension of Computational Thinking Ability

Dimension	Mean	Standard Deviation	Criteria
Problem Solving	74.86	11.06	Medium
Algorithmic Thinking	70.39	12.87	Medium
Critical Thinking	70.31	11.91	Medium
Cooperative Learning	80.23	12.70	High
Creative Thinking	75.25	12.56	Medium

In hypothesis testing, a linear regression test was used to evaluate the relationship between computational thinking ability and cognitive learning outcomes of genetic trait inheritance based on Mendel's law. The regression model obtained was $\hat{Y} = 34.705 + 0.644X$, indicating that each one-point increase in computational thinking ability could potentially increase the cognitive learning outcome score by 0.644 points. This model proved to be significant and linear, with a significance value of 0.001 and a deviation from linearity of 0.357, both greater than 0.05, confirming the significance and linearity of the model. Furthermore, the correlation coefficient test using the Pearson Product Moment formula yielded a significance value of 0.001 and a correlation coefficient of 0.507, indicating a moderate relationship between the two variables. Furthermore, the contribution of the computational thinking ability variable to cognitive learning outcomes was measured through the R square value, which amounted to 0.257. This indicates that computational thinking ability contributes 25.7% to cognitive learning outcomes, while the remaining 74.3% is influenced by other factors.

The results showed that the computational thinking skills of grade XII students at SMAI PB Soedirman were on average at a moderate level with the highest score of 98 and the lowest of 58. The majority of students had moderate computational thinking skills, indicating room for further development. Factors such as access to technology, curriculum, and integration of computational thinking in learning influence these results. The role of teachers is crucial in this process, as described (Whittle, Telford, and Benson, 2015), given that they are the direct mediators between students and these concepts. The cooperative learning dimension of computational thinking skills showed the highest mean scores, signaling good social skills and student cooperation. Research by (Booysen and Grosser, 2014), (Devi, Musthafa, and Gustine, 2016) and (Saad, 2020) showed that cooperative learning encourages the use of higher-order thinking skills. Meanwhile, critical thinking was the dimension with the lowest mean score, indicating that this is a difficult skill to develop.

The cognitive learning outcomes of genetic trait inheritance based on Mendel's law in class XII students at SMAI PB Soedirman on average are good, with the majority of students achieving sufficient criteria. This shows that although students have learned the material before, they have not fully mastered the concept. Research by (Gusmalini et al. 2020) and (Murni et al. 2022) supports these findings, showing that students often have difficulties in understanding genetics. Factors such as individual differences in absorbing and processing information, as described by Khotimah, et al. (2019), contribute to this variation in learning outcomes.

Correlation analysis using the Pearson Product Moment formula showed a significant relationship between computational thinking ability and cognitive learning outcomes, with a regression model $\hat{Y} = 34.705 + 0.644X$. This shows a positive relationship between the two variables. According to Durak, et al. (2018), the National Research Council (NRC) considers computational thinking ability as an important cognitive skill, and (Wing. 2006) emphasizes the importance of teaching this ability in the curriculum. Studies by (Weintrop et al. 2016) and (Bower et al. 2017) also support the importance of computational thinking skills. The moderate correlation between the two variables, with a correlation coefficient of 0.507, indicates that computational thinking skills contribute 25.7% to cognitive learning outcomes, while the rest is influenced by other factors, as explained by (Murni et al. 2022).

This study examined the correlation between computational thinking ability and cognitive learning outcomes in genetics, specifically focusing on understanding inheritance patterns based on Mendel's laws. The findings indicate that students with stronger computational thinking abilities tend to perform better in genetics learning outcomes. This correlation highlights the importance of computational thinking skills—particularly problem-solving, algorithmic thinking, critical thinking, cooperative learning, and creative thinking—in mastering complex biological concepts, as they allow students to approach problems systematically and analytically. The study's timing is relevant to current educational needs in the 21st century, where computational skills are increasingly recognized as essential across disciplines, including biology. As science education evolves to include more interdisciplinary and computational approaches, integrating computational thinking into genetics education becomes increasingly relevant to prepare students for future academics (Ku et al., 2014; Sumarni et al., 2020; Wilde-Larsson et al., 2017).

Understanding the role of computational thinking components in genetics learning is crucial because genetics often involves intricate concepts, such as trait inheritance patterns and probabilities, which require structured problem-solving and critical analysis. Each component of computational thinking provides specific support for learning genetics. Problem-solving skills help students tackle complex genetics problems systematically (Carson, 2007; Gueldenzoph Snyder & Snyder, 2008; Kinay & Bagceci, 2016; Prastiwi et al., 2019), breaking down tasks and identifying solutions. Algorithmic Thinking enables students to develop step-by-step approaches to predicting genetic outcomes, aligning with the procedural nature of Mendel's law inheritance. Critical thinking allows students to analyze genetic information, question assumptions, and evaluate possible outcomes, which are necessary for accurate understanding (Miharja et al., 2019; Mulnix, 2012; Permana & Chamisijatin, 2018; Rizky et al., 2020). Cooperative Learning encourages teamwork and communication, helping students discuss and refine their understanding of complex concepts (Baloche & Brody, 2017; Miquel & Duran, 2017; Tran, 2014). Creative Thinking supports students in generating hypotheses and exploring novel approaches to genetic problems, fostering a deeper engagement with the material.

The mechanisms by which these computational thinking components enhance genetics learning can be explained as follows. Problem-solving and Algorithmic Thinking equip students with a structured approach to genetic problems, such as predicting genotypes and phenotypes (Ijirana & Supriadi, 2018; Yavuz et al., 2010). Critical Thinking enables students to evaluate genetic concepts critically, leading to fewer misconceptions and more accurate comprehension (Proulx, 2012; Zori, 2016). Cooperative Learning provides opportunities for peer interaction, where students can exchange ideas and clarify misunderstandings. Creative Thinking allows students to develop innovative approaches to understanding genetic patterns, making learning more engaging and applicable to real-world scenarios (Batlolona et al., 2019; Lazarowitz & Huppert, 2018; Martinsen & Furnham, 2019). By fostering these computational thinking skills, students are better prepared to handle the logical and analytical demands of genetics. This is supported by constructivist theories, which suggest that active, skill-based engagement with material promotes deeper understanding.

CONCLUSION

This study shows that there is a significant positive and linear relationship between computational thinking skills and cognitive learning outcomes of genetic trait inheritance based on Mendel's law. The relationship has a moderate level. In addition, the ability to think computationally has a contribution of 25.7% to the cognitive learning outcomes of genetic trait inheritance based on

Mendel's law. The results suggest that incorporating computational thinking into biology curricula, particularly in genetics, could improve learning outcomes. Future research should explore specific instructional strategies for embedding computational thinking exercises in genetics lessons to better support cognitive learning outcomes. Additionally, educational programs could focus on training educators to teach computational thinking in a way that directly supports students' understanding of genetics

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