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Promoting computational and higher-order thinking skills through problem-based learning with digital argumentation in biodiversity

Marheny Lukitasari[1], Agita Risma Nurhikmawati[2], Wasilatul Murtafiah[3], Akhmad Sukri[4], Jomar M. Urbano[5], Analiza B. Tanghal[6], Rusdi Hasan[7]

[1]*Universitas PGRI Madiun, Indonesia, Corresponding author, lukitasari@unipma.ac.id, ORCID ID: 0000-0001-6545-3922*
[2]*Universitas PGRI Madiun, Indonesia, ORCID ID: 0000-0003-0416-2683*
[3]*Universitas PGRI Madiun, Indonesia, ORCID ID: 0000-0003-3539-5332*
[4]*Universitas Pendidikan Mandalika, Indonesia, ORCID ID: 0000-0002-1588-8028*
[5]*PHINMA Rizal College of Laguna, Philippines, ORCID ID: 0000-0003-3221-1614*
[6]*NEUST, Philippines, ORCID ID: 0000-0002-5767-2161*
[7]*Universitas Padjadjaran, Indonesia, ORCID ID: 0000-0002-6005-6159*

ABSTRACT
Problem-based learning integrated with Digital Argumentation (PBL-DA) is a learning strategy for optimizing innovative learning in the digital era. This research aimed to investigate whether the application of PBL-DA can foster the Computational Thinking (CT) and Higher Order Thinking Skills (HOTs). A quasi-experimental design measured three aspects: skill (decomposition, algorithm design, evaluation), attitude (confidence, communication, flexibility), and approach (tinkering, creating, collaborating). The students' HOTs were measured through eight aspects: critical thinking, argumentation, problem-solving, problem-identifying, understanding concepts, analysing, making decisions, and creative thinking. The students' CT and HOTs scores of control and experimental classes were analyzed using Hotelling's T^2 test and Tukey's post hoc test. The Hotelling's T^2 test revealed a significant difference between the experimental and control classes for both CT and HOTs ($T^2 = 0.340$, $p < 0.001$ for CT; $T^2 = 0.718$, $p < 0.001$ for HOTs). Tukey's test further showed that PBL-DA significantly impacted the CT skill and attitude aspects ($p < 0.01$), while the approach aspect was not significant ($p > 0.05$). For HOTs, critical thinking, argumentation, problem-identifying and analyzing were significantly improved ($p < 0.01$), but problem-solving, understanding concepts, making decisions, and creative thinking showed no significant improvement ($p > 0.05$). Pearson's correlation analysis indicated a strong positive correlation ($r = 0.651$, $p < 0.001$) between students' CT and HOTs skills. These findings provide evidence of the effectiveness of the PBL-DA model in improving students' CT and HOTs, demonstrating its potential for fostering critical and higher-order thinking skills in the digital era.

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Introduction

The 21st century requires every country to create a society that can communicate and collaborate to solve problems through critical, creative and innovative thinking. It forces the educational system of many countries to focus on higher order thinking skills (HOTs) to prepare human resources to compete in the global digital era. The idea of incorporating computer thinking into the school curriculum as one of the essential skills for today's children is gaining ground around the world due to the widespread development of information and communication technology (ICT) in education and the skill demands of the 21st-century lifestyle. While the use of ICT in educational practices allows the enhancement of HOTs, thinking skills alone are inadequate to solve complex problems (Gordillo-Tenorio & Cabanillas-Carbonell, 2023). Computational thinking (CT) as a cognitive process involving reasoning is needed to solve problems and better understand processes and systems (Csizmadia et al., 2015).

HOTs are high-level skills that include the domains of analysis, synthesis and evaluation (Anderson et al., 2001; Hill, 2015). Critical thinking processes, analytical skills and creativity are the areas of HOTs that are crucial in developing human intellectuality. Practising HOTs in the learning process is essential because it affects the rate of thinking, problem-solving, and the effectiveness of student learning and will be triggered when someone is given a stimulus in the form of a problem (Liline et al., 2024; Srivastava & Mudholkar, 2001). As to HOTs, CT is a fundamental skill that not only people in the computer field ought to have. CT skills need to be taught in the classroom at the same level as HOTs. The issue is that most lessons in the classroom are not familiar with the practice of CT and HOTs. Therefore, involving CT and HOTs indicators in learning activities is essential in courses including Biology Education.

Training students for HOTs requires the integration of ICT to be relevant to the current digital era. Research on ICT-integrated HOTs showed significant results in supporting students' critical thinking skills (S. M. Lee, 2014). The existence of technology in learning drives students to become more independent in their learning activities, such as finding relevant learning resources, stimulating creative questions, and solving problems. Previous research showed that ICT is an appropriate and suitable means to stimulate and build students' understanding of learning materials (Kale et al., 2018; Williams et al., 1994). The process of integrating ICT to support student HOTs certainly cannot be separated from the form of learning in the classroom related to the learning model and learning tools used. However, the CT and HOTs of undergraduate students tend to be low (Giannetto & Vincent, 2014). The educational faculty must prepare their students as prospective teachers to become future professional teachers. Familiarizing students with CT (Hunsaker, 2020) and HOTs is essential for enhancing the quality of human resources. However, in this case, there is no information about the CT abilities of students at Universitas PGRI Madiun (UNIPMA), Indonesia, and Nueva Ecija University of Science and Technology (NEUST), Philippines.

The results of previous studies have shown that the HOTs of prospective biology teachers at UNIPMA still need to be improved (Cantona et al., 2023), specifically in the Biodiversity course. At the Department of Science in NEUST of The Philippines, the students found similar difficulties in this course as the students at the Department of Biology Education of UNIPMA. Most students have not been able to comprehend the classification and benefits of the plants that are found around them. This problem must be overcome so that the quality of graduates meets the standards to become the professional teachers. Improving the quality of learning continuously needs to be improved through the application of various innovative learning models (Montoneri, 2014). The application of the learning model designed to foster HOTs is expected to lead students to comprehend the biodiversity lecture material, find solutions to problems, and evaluate conditions and activities that have been carried out more creatively and dynamically at the same time.

A previous study reported that the PBL model had the potential to increase HOTs. The research that combined problem-based learning activities showed that the implementation of PBL enhanced students' HOTs through concept transfer in new situations, integrating concepts, increasing intrinsic learning interest, and training learning skills (Habók & Nagy, 2016). The application of technology-integrated PBL to support the ability of prospective teacher students to develop professional content knowledge and teaching skills (Kale et al., 2018), improved HOTs (Mubuuke et al., 2016) and problem-solving skills of students (Nantha et al., 2022). Previous studies indicated that the application of ICT-based PBL which prioritizes students' thinking through digital argumentation (DA) increased students' HOTs. The development of arguments from conventional patterns as digital format using ICT showed a significant change in generation in conveying arguments so that they can be traced by identifying, analyzing, and ways of thinking in building their arguments (Pereira et al., 2015). On the one hand, the pattern of argumentation changes made by students in the digitalization era greatly affects critical thinking skills, which are components of HOTs. The existence of ICT was a bridge for students to convey their arguments digitally without being limited by space or time (Tanujaya et al., 2017).

We initially designed PBL-DA as part of the syntax in the modified PBL model that can improve student CT and HOTs. The PBL-DA model allows students to train themselves to convey what they think by writing the argumentation on an ICT-assisted platform. Students with low ability to argue directly can be overcome by digital media. On the other hand, the arguments presented in the e-learning platform can still be observed by students both who write and other students who read the arguments. The quality of students' CT and HOTs and their correlation can be assessed. Therefore, it is necessary to know whether the implementation of PBL-DA can improve CT and HOTs, especially in learning Biodiversity. This study of implementation of PBL-DA was aimed to promote CT and HOTs in learning Biodiversity of students in two universities of Indonesia and The Philippines. By the implementation of PBL DA, students are given the opportunity to convey their thoughts or arguments digitally, especially in the context of problem solving based on the theme of biodiversity. Thus, this study was conducted to answer the research question "How does the implementation of PBL DA affect CT and HOTs abilities in the Biodiversity course?"

Literature Review

Computational Thinking (CT) and Higher Order Thinking Skills (HOTs)

Computational thinking (CT) is currently a trend in education and a cognitive process, a problem-solving process that reflects the ability to think in terms of abstractions, algorithms, decompositions, generalizations and evaluations (Lawshe, 1975). These indicators can be used effectively to improve learning process and its assessment. It can also be described as a focused approach applied by transforming real-world problems into computable parts and applying solutions efficiently (Gao & Hew, 2022; Tosun & Senocak, 2013). There is no single definition of computational thinking, but there are general concepts such as logic, abstraction, generalization, decomposition, and evaluation. Anyone, not just computer scientists, can apply one or a set of computational reasoning skills to these concepts. CT skills emerged around the 1980s era, along with the mainstream use of technology in many areas (Haryani et al., 2014). As one of the important indicators in the mechanism of rational thinking process, CT tends to be rarely used in learning activities. Therefore, it is important to include CT components as indicators as well as their assessment. The integration of technology such as computers, smartphones, and various other types of gadgets is increasing rapidly shows that encouraging CT skills is necessary in the learning process (Hopson et al., 2001). In a broader context, CT abilities with a computational thinking orientation to solve complex problems by finding problem-solving ideas using a computer (Kelly et al., 2016) is very closely affiliated with higher-order thinking skills which were trained with ICT support (Greenbank, 2010).

As with a CT, HOTs represent an advanced cognitive concept on the capacity for effective problem-solving. The HOTs paradigm encompasses four cognitive skills: problem-solving, critical analysis, innovative thought and decision-making (Alkhatib, 2019), which are essential cognitive processes that enable individuals to analyse, evaluate, and create new ideas or solutions. These skills are crucial for students to navigate complex problems and adapt rapidly to the changing demands of the 21st century (Bhaumik et al., 2024). Developing HOTS can equips students with the ability to make better decisions and think independently. It encourages innovation by enabling students to think beyond conventional boundaries and contribute positively to society. The challenge in implementing HOTS for the teacher is the need for deep understanding and preparedness. Therefore, the teachers need to develop effective learning designs and questioning techniques to facilitate HOTS in the classroom.

Problem Base Learning (PBL)

Problem-base learning (PBL) is a learning model that adopts problems encountered in everyday life as its advantage. PBL is a student-centred approach that involves groups solving open-ended problems to learn about a subject. This problem is what motivates and enables learning (Skelin et al., 2008). PBL plays a role in comprehending new situations, integrating concepts, and increasing learning motivation (Habók & Nagy, 2016) and is carried out in the following stages of activity: designing problems, presenting problems to students, discussing with facilitators, and presenting results (Milroy, 2021; Tsortanidou et al., 2019). Through the application of PBL, students will try to solve problems that require a lot of information from various sources. The application of PBL also has the potential to increase students' HOTs through the ability to understand the material better (Habók & Nagy, 2016) and develop content knowledge (Kale et al., 2018). Related to the development of ICT, the application of PBL with the support of these facilities will accommodate the development of education in university, including how students communicate and argue (Andrews, 2015).

A well-designed PBL allows students to develop skills such as teamwork, project management, and leadership roles, oral and written communication, self-awareness and evaluation of group processes, independent work, critical thinking and analysis, explaining concepts, self-directed learning, applying course content to real-world examples, researching and information literacy, and cross-disciplinary problem solving (Nilson, 2010). According to Duch et al., (2001), the general idea of creating PBL problems for classroom learning can be used in the following steps: First, choose a main idea, concept, or principle that is regularly taught in a lesson, and then think of a closed-ended problem, exercise, or task that will be given to students to help them learn that topic. List the learning objectives that students should achieve when solving problems. Second, consider the overall context of the project to motivate students to solve problems by studying real cases where they can develop or apply narrative features to the problems at the end of each chapter. More complex problems require students to solve problems beyond simple plug-and-chug. Third, problems should be included in the sections so that students understand the learning problems that lead them to learn the target topic. Fourth, write a teacher's guide that summarizes the teaching plan for using the problems in the lesson. If the course is a medium to large class, mix small talk, whole class discussions, small group work and regular discussions. The teacher's guide may indicate plans or options for going through pages of problems in different disciplines. Finally, identify key resources for students. Students must learn to identify and use study materials on their own, but instructors may want to point them to some reliable sources to get them started. Many students prefer to limit their research to the internet, so it is also important to direct them to the library.

Digital Argumentation (DA)

Digital argumentation (DA) is the result of the development of communication patterns through ICT-based student logical arguments (Hajj & Harb, 2023; Karami et al., 2013). Students' arguments are conveyed by writing their opinions on the material on a platform that has been prepared. The DA delivered by students can be an indicator of their level of understanding as well as the way they think about the topics discussed. This digital presentation of arguments has the advantage of being more structured in the sentences composed by students. Students will have more time to evaluate each argument that will be presented. Therefore, students will tend to repeat the material before presenting their digital arguments. The weakness that arises with the use of DA is the expression or spontaneity of thoughts that cannot be directly observed. The pre-existing DA track record is also an important part of assisting the evaluation process when needed. Arguments from time to time are shown in digital formats such as cassette tapes and compact discs until now, based on databases such as the Internet. With the advancement of technology, the argumentation format is more concise and has many functions, including helping develop students' HOT skills (Fan et al., 2020).

Theoretical Framework of PBL-DA to Cultivate Students' CT and HOTs

CT and HOTs have connectivity in supporting students as a problem solver as a vital component in modern education. CT provides a structural approach to problem-solving that aligns closely with the development of HOTS, which include analysis, evaluation, and creation. The way CT stages such as decomposition, pattern recognition, abstraction and algorithm design mirror the cognitive processes that involved in HOTs. The PBL-DA design is developed from a problem-based learning model that is integrated with technology through Digital Argumentation (DA). Model development is carried out by modifying and integrating the syntax with other components with a specific purpose, based on the needs analysis and literature review (Viyanti et al., 2020). The PBL-DA model uses basic PBL syntax which are then integrated with information technology to accommodate the DA tasks submitted by students that can be implemented in group or individual learning (Lukitasari et al., 2020). The PBL-DA syntax can be presented as follows: problem orientation; student organization; brainstorming or submitting stimulus questions; data collection through research; shared information and discussion to find solutions to problems; presenting the results of problem-solving; and analysis and evaluation of problem solutions (Lukitasari et al., 2021). By integrating PBL and DA, students are encouraged to engage deeply with content, develop critical and creative thinking, and apply computational strategies effectively. PBL-DA can significantly improve students' CT skills by providing a structured yet flexible framework for dealing with complex problems (Aryan et al., 2022). PBL encourages students to actively participate in their learning process, fostering critical thinking and problem-solving skills, which are important components of CT. Digital Argumentation, on the other hand, supports the development of scientific literacy and reasoning, which further enhances CT skills (Voon et al., 2022). This approach creates a comprehensive learning environment that encourages the development of CT and HOTs skills.

Methods

Research Design

This research is a mixed methods which is a combination of qualitative and quantitative research. This type is carried out by collecting qualitative data which is explored based on the conditions of implementing PBL-DA in the classroom. Then the qualitative data was converted to quantitative data to explain the result comprehensively.

This study was a quasi-experimental research with a counterbalanced design (Hopson et al., 2001). The research involved two groups of students treated with different learning models. The control group was subjected to the conventional learning model that applied with classroom discussion. The experiment classroom used the PBL-DA learning model (Lukitasari et al., 2018). The PBL-DA accommodates PBL syntax with modification by using Learning Management System (LMS) to facilitated arguments presented by students during the learning process.

Population and Sample

The population of this research were students of biological science study program from two universities, Nueva Ecija University of Science and Technology (NEUST) of the Philippines and Universitas PGRI Madiun (UNIPMA) of Indonesia, in total 439 students, consisted of 246 students at NEUST and 193 students at UNIPMA. The research sample were 2 classes at each university to be used as a control and experimental class. Class selection was carried out using purposive random sampling based on classes that in the odd semester of 2022/2023 contained biodiversity courses. The number of students in either control and experimental classes were 25 students so that the total number of sample were 100 students.

Research Procedure

Research activities began with synchronization of Biodiversity course material which was implemented for one semester at NEUST and UNIPMA. Thereafter, PBL-DA learning model applied was carried out by the lectures both universities for the topic of Biodiversity. Detailed course plan is presented in appendix 1, with sample lesson plan and worksheet in appendix 2 and 3, respectively, as shown in Table 1.

Table 1

Control and experiment classes

Unit classes	Condition	
	Experiment	Control
UNIPMA (Indonesia)	PBL-DA	Conventional
NEUST (Philippines)		

The PBL-DA learning method was implemented in the experiment class for one semester. The stages of PBL-DA (Lukitasari et al., 2018) Meanwhile, the control class was taught using discussion and presentation methods following the material.

Instrument

The instrument for measuring CT skills was an essay task that consisted of five components: abstraction, algorithmic reasoning, decomposition, evaluation and generalization (Haryani et al., 2014). Essay task was given on each topic of biodiversity during the lecture period. The CT skills were gathered using the 4 -point marking keys that was developed by Jensen et al. (2014). The development of HOTs and CT instruments were validated by eight experts (Kelly, 2016) using CVI and CVR (Williams et al., 1994). The validation result for the CT instrument shows that the number of CVI and CVR is > 0.79 and = 0.75 consecutively.

The instrument to measure the students' HOTs was given twice to the control and experimental classes, as a pretest and post-test. The pretest was used to determine the students' existing knowledge and homogeneity between the two experimental and control classes about the subject before any intervention. The post-test was used to test the effectiveness of the PBL-DA method in improving students' understanding compared to conventional methods. The HOTs instrument was developed using 30 multiple-answer validated test questions following the lecture material.

Data Analysis

CT and HOTs data in ordinal form were converted into interval scale form through the method of successive intervals (Gilbert & Prion, 2016). The data were then analyzed descriptively to reveal students' CT and HOTs abilities. To determine the effect of the PBL-DA model on CT and HOTs analyzed by Hotteling's T2 test (Nantha et al., 2022; Pereira et al., 2015) continued by Tukey test (Nirbita et al., 2018). The correlation between CT and HOTs of the student was analyzed with the Pearson correlation test. All statistical analyses used IBM SPSS version 26.

Findings

Students' Computational Thinking Skills

Computational thinking skills at Table 2 shows three components of CT skills of the students in both control and PBL-DA classes. The average and each aspect of students' CT skills in the PBL-DA class are relatively higher than control class, with the highest difference is shown in skill aspect.

Table 2

Students' computational thinking in control and PBL-DA classes in biodiversity course (N = 50)

No	Aspects of students' Computational Thinking	Classes		Mean Diff. (Control-PBDL DA)
		Control (Mean±SD)	PBL-DA (Mean±SD)	
1	Skill (Decomposition, Algorithm Design, Evaluation)	59.58±0.73	71.47±0.56	11.89
2	Attitude (Confidence, Communication, Flexibility)	68.35±0.67	73.33±0.58	4.98
3	Approach (Tinkering, Creating, Collaborating)	68.35±0.67	68.99±0.54	0.64
	AVERAGE	65.43±0.69	71.27±0.56	5.84

The effect of PBL-DA on Students' Computational Thinking Ability

To determine the effect of the PBL-DA model on CT and HOTs, the Hotteling's T2 analysis was conducted. Normality and homogeneity tests were carried out as prerequisites for Hotteling's T2 test followed by the Tukey, as the results are shown in Tables 3 and 4.

Table 3

Normality test of students' CT

Variable	Normality Test (Kolmogorov-Smirnov)	
	KS-Z	Sig
CT	0.857	0.455

Table 3 shows that the *p-value* for the normality test on the students' CT variables is 0.455. The *p-value* > 0.05 indicates the variable has normally distributed data.

Table 4

Variance analysis of CT aspects and PBL-DA control group

Box's test of equality of covariance matrices		Levene's test of equality error variances				
Box's M = 1.633		CT Aspect	F	df1	df2	Sig.
df1	= 6	Skill	0.779	1	98	0.380
df2	= 69583.698	Attitude	0.005	1	98	0.942
Sig.	= 0.954	Approach	0.013	1	98	0.911

The results of Box's Test of Equality of Covariance Matrix in Table 4 show that the variance-covariance matrix between the PBL-DA model and the control classes were homogeneous (Sig. = 0.954 >0.05). Table 4 also shows that each aspect of DT has a homogeneous data variance (Sig. = 0.380; 0.942 and 0.911 > 0.05). Based on these results, the Hotelling Test T2 analysis followed by Tukey test can be performed.

Table 5 shows that the Hotelling Trace value is 0.340 with a Sig. 0.000 (Sig. <0.05). This result indicates that there was an influence of the PBL-DA on students' CT abilities. Moreover, Tukey test results show that PBL-DA significantly influences two aspects of students' CT, which were skill and attitude (p-value <0.05), while for the approach aspect, the effect of PBL-DA did not affect it significantly (p-value >0.05).

Table 5

Hotteling's T2 and Tukey test results of students' computation thinking abilities.

Effect (Group)	Value	Sig.	Variable	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Hotelling's Trace	0.340	0.000	Skill	6.0902	0.001	Significant
			Attitude	4.2160	0.003	Significant
			Approach	0.3083	0.833	Insignificant

Students' High-Order Thinking Skills

Table 6 shows the students' high-order thinking which is divided into eight aspects in control and PBL-DA classes.

Table 6

Students' HOTs in control and PBL-DA classes in Biodiversity course (N = 50)

No	Aspects of Students High Order Thinking Skills	Classes		Mean Diff. (Control-PBDL DA)
		Control (Mean±SD)	PBL-DA (Mean±SD)	
1	Critical Thinking	58.65±0.78	85.52±0.52	26.87
2	Argumentation skills	55.06±0.73	71.46±0.64	16.4
3	Problem Solving	61.44±0.69	66.68±0.68	5.24
4	Identifying Problems	63.02±0.65	74.63±0.57	11.61
5	Understanding Concept	68.87±0.67	63.02±0.74	-5.85
6	Analyzing	66.68±0.69	78.86±0.57	12.18
7	Making Decisions	71.46±0.63	74.63±0.61	3.17
8	Creative Thinking	60.00±0.70	64.75±0.68	4.75
	AVERAGE	63.15±0.69	72.44±0.63	9.29

The Effect of PBL-DA on Students' High-Ordered Thinking Skills in Biodiversity

As previously carried out on students' CT data, the Hotteling's T2 analysis was carried out to determine the effect of the PBL-DA model on CT and HOTs. Normality and homogeneity tests were carried out as prerequisites for Hotteling's T2 test followed by the Tukey, as the results are shown in Tables 7 and 8.

Table 7

Normality test of students HOTs data.

Variable	Normality Test (Kolmogorov-Smirnov)	
	KS-Z	Sig
HOTs	0.826	0.503

Table 7 shows that the *p-values* for the normality test on the students' HOTs variables was 0.503. The *p-value* > 0.05 indicates the variable has normally distributed data.

Table 8

Homogeneity analysis of PBL-DA control group and HOTs aspects

Box's test of equality of covariance matrices	Levene's test of equality error variances				
Box's M = 12.978	HOTs Indicator	F	df1	df2	Sig.
df1 = 36	Critical Thinking	0.749	1	98	0.389
df2 = 32316.056	Argumentation	1.481	1	98	0.226
Sig. = 0.060	Problem-Solving	0.763	1	98	0.385
	Identifying Problem	0.373	1	98	0.543
	Understanding concept	0.000	1	98	1.000
	Analyzing	0.428	1	98	0.515
	Making decision	0.053	1	98	0.818
	Creative thinking	0.476	1	98	0.492

The results of Box's Test of Equality of Covariance Matrix in Table 9 show that the variance-covariance matrix between the PBL-DA model and the control is homogeneous (Sig. = 0.060>0.05). Table 8 also shows that each HOTs aspect has a homogeneous data variance (Sig.>0.05). Based on these results, the Hotelling Test T2 analysis followed by Tukey test was carried out (Table 9).

The results of the analysis in Table 9 show that the Hotelling Trace value is 0.718 with a Sig. 0.000 (Sig. <0.05). This result indicates that there was an influence of the PBL-DA treatment group on students' HOTs abilities in general. Moreover, the Tukey test results show that PBL-DA influenced four aspects of HOTs, that were critical thinking, argumentation, identifying problems, and analyzing (p-value < 0.05). Meanwhile, PBL-DA did not affect significantly (p-value >0.050 on the other four aspects of HOTs, including problem-solving, understanding concepts, making decisions, and creative thinking aspects.

Table 9

Hotelling T2 and Tukey tests of students' HOTs.

Effect (Group)	Value	Sig.	Variable	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Hotelling's Trace	0.718	0.000	Critical Thinking	8.9544	0.001	Significant
			Argumentation	5.1970	0.001	Significant
			Identifying Problem	3.7409	0.009	Significant
			Analyzing	4.0342	0.005	Significant
			Problem-Solving	1.6547	0.244	Insignificant
			Understanding concept	1.8904	0.184	Insignificant
			Making decision	1.0316	0.467	Insignificant
			Creative thinking	1.5153	0.286	Insignificant

The Correlation Between Students' CT and HOTs

Pearson correlation analysis has Sig value < 0.05. The result of this study indicates a positive correlation between students' CT and HOTs abilities with a strong correlation level (0.651) as shown in table 10.

Table 10

Correlations analysis between student' CT and HOTs

		HOTs	CT
HOTs	Pearson Correlation	1	0.651**
	Sig. (2-tailed)		0.000
	N	100	100
CT	Pearson Correlation	0.651**	1
	Sig. (2-tailed)	0.000	
	N	100	100

Note. Correlation is significant at the 0.01 level (2-tailed).

Discussion

The implementation of the PBL model that developed into PBL-DA through technology integration in this study showed a significant increase in HOTs and CT skills in several aspects. PBL encourage students to be involved and seek their learning through problem-solving (Allchin, 2013; Greenbank, 2010). In practice, the problems raised and resolved by student groups were based on the theme or sub-theme of the biology course, that were integrated science and Biodiversity. The lecture process, with the support of technology, encourages students to be able to convey arguments both in writing and in person.

The result shows that CT and HOTs abilities significantly difference between experiment and control classes. These results indicated that the PBL-DA learning model (Lukitasari et al., 2018) that was used can encourage an increase the students' CT and HOTs abilities. The submission of problems based on narratives from many sources to be resolved in groups provides facilities for developing the capabilities of CT and HOTs. Discussions to accommodate opinions as well as possible alternative solutions to problems (Milroy, 2021) are an important part of implementing PBL-DA. During lectures and when practicing CT skills, especially when solving problems, students use a lot of computer support. Then, with their groups, they hold discussions and then sort out the material obtained to analyze the possibilities of solving the problems presented. Technically, student groups optimize resources starting with computers, mobile phones, supporting software programs, and internet networks. In this process, it is consistent that learning conditions using many technological sources were part of CT capabilities, especially from a computational perspective (Lukitasari et al., 2021) nurturing students' CT of pattern recognition and decomposition concepts (Jawawi et al., 2022). On the other hand, students' HOTs abilities also experienced significant differences between the experimental and control classes. The PBL-DA combination trains students in solving problems that have an impact on increasing HOTs. With the clear stages of PBL, students can think critically, present arguments online and offline, identify problems, carry out analysis, and find possible solutions to problems with the help of technology. Connectivity between individuals in social interactions, both directly and indirectly, was a determining factor in the growth of student HOTs (S. M. Lee, 2014).

The interesting results on this study were obtained after Hotteling’s test carried out on the two variables, CT and HOTs. Based on the aspects measured on CT, the approach was the only aspect that is not significant compared to the other two aspects: skill and attitude. The approach aspects, which consists of the sub-aspects of tinkering, creating and collaborating, were possible because the communication process has not been optimal in the groups that have been formed, although, on the other hand, the existence of groups should be in line with optimizing collaboration within the group. In this case, it was very important to pay attention to the approach aspect when the learning process is carried out, both between lecturers and students and between students who were members of groups. The approach process was an important part to be maintained as a way of providing a sense of comfort for students to express the ideas they get. It was because the ideas conveyed in the form of computational-based work as a form of CT are a form of communication that requires complex skills such as thinking, being creative (Fields et al., 2021), and collaboration in groups. It can be further explained that group collaboration plays an important role in developing students' HOTs abilities.

The Hotteling’s test measures HOTs ability, which was the dependent variable of this study, based on eight aspects, showing four aspects (critical thinking, argumentation, identifying problems, and analyzing) were significant, while four other aspects (problem-solving, understanding concepts, making decisions, and creative thinking) were not significantly affected by the implementing PBL-DA. Many factors, such as mindset, background understanding, and the ability to overcome obstacles (Green, 2017), can influence and explain why the four aspects of HOTs were not significant. Practicing HOTs in learning activities simultaneously in many forms, such as getting used to working on HOTs-based questions and the process of working on assignments to solve problems, was an important part of learning. Therefore, the role of educators as interventions to encourage students' thinking levels is an important part that needs to be pursued (Labak et al., 2024; K. Lee & Cho, 2021). The habituation factor in practicing HOTs in the learning process was very significant for increasing aspects of understanding concepts (Jazuli et al., 2020). These interesting results demonstrate the complexity of HOTs capabilities, which have the potential to be developed specifically in many ways (Lye & Koh, 2014).

Conclusion and Implications

In conclusion, the results of this study indicate that there was a significant difference in CT and HOTs performance between the experimental and control classes after applying the PBL-DA learning model. The PBL-DA model, with most of the lecture time being conducted online, is motivated using technology to support the learning process. Even though the overall test results showed significant results, when additional tests were carried out to determine the results of CT and HOTs in each aspect, several aspects were found to be not significant. Thus, it can be concluded that the successful application of PBL-DA for CT and HOTs does not only require technology as the main foundation but also requires habituation and active communication in the form of collaboration between students and other students and also between students and lecturers. Furthermore, the results of this study suggest a wider and more diverse sampling to facilitate and encourage more comprehensive results from the CT and HOTs.

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References

Alkhatib, O. J. (2019). A framework for ımplementing higher-order thinking skills (problem-solving, critical thinking, creative thinking, and decision-making) in engineering & humanities. *2019 Advances in Science and Engineering Technology International Conferences (ASET)*, 1–8. https://doi.org/10.1109/ICASET.2019.8714232

Allchin, D. (2013). Problem and case-based learning in science: An ıntroduction to distinctions , values , and outcomes. *CBE—Life Sciences Education*, *12*, 364–372. https://doi.org/10.1187/cbe.12-11-0190

Anderson, L. W., Krathwohl Peter W Airasian, D. R., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2001). *A taxonomy for learning, teaching, and assessing a revision of bloom's taxonomy of educational objectives*. Addison Wesley Longman, Inc. https://www.uky.edu/~rsand1/china2018/texts/Anderson-Krathwohl - A taxonomy for learning teaching and assessing.pdf

Andrews, R. (2015). Critical thinking and/or argumentation in higher education. In M. Davies et al. (Ed.), *The palgrave handbook of critical thinking in higher education*. Palgrave Macmillan. New York. https://doi.org/10.1057/9781137378057

Aryan, Hegade, P., & Shettar, A. (2022). Effectiveness of computational thinking in problem based learning. *Journal of Engineering Education Transformations*, *36*(Special Issue 2), 179–185. https://doi.org/10.16920/jeet/2023/v36is2/23025

Bhaumik, K., Sudhakara Reddy, S., Datta, A., Ismayel, G., & Mabu Sarif, B. (2024). Fostering higher-order thinking: Pedagogical strategies in engineering education. *Journal of Engineering Education Transformations*, *38*(1), 86–99. https://doi.org/10.16920/jeet/2024/v38i1/24177

Cantona, I. G. E., Suastra, I. W., & Ardana, I. M. (2023). HOTS oriented problem-based learning model: Improving critical thinking skills and learning outcomes of fifth grade students in science learning. *Thinking Skills and Creativity Journal*, *6*(1), 19–26. https://doi.org/10.23887/tscj.v6i1.61654

Csizmadia, A., Curzon, P., Dorling, M., Humphreys, S., Ng, T., Selby, C., & Woollard, J. (2015). *Computational thinking: A guide for teachers*. Hodder Education. Hachette. United Kingdom

Duch, B., D., G., & Allen, D. (2001). *The power of problem-based learning: A practical 'how to' for teaching undergraduate courses in any discipline.* Stylus Publishing LLC

Fan, Y. C., Wang, T. H., & Wang, K. H. (2020). Studying the effectiveness of an online argumentation model for improving undergraduate students' argumentation ability. *Journal of Computer Assisted Learning*, *36*(4), 526–539. https://doi.org/10.1111/jcal.12420

Fields, D., Lui, D., Kafai, Y., Jayathirtha, G., Shaw, M., Fields, D., Lui, D., Kafai, Y., Jayathirtha, G., Walker, J., & Walker, J. (2021). Communicating about computational thinking : understanding affordances of portfolios for assessing high school students ' computational thinking and participation practices Communicating about computational thinking : understanding affordances of portfoli. *Computer Science Education*, *00*(00), 1–35. https://doi.org/10.1080/08993408.2020.1866933

Gao, X., & Hew, K. F. (2022). Toward a 5e-based flipped classroom model for teaching computational thinking in elementary school: effects on student computational thinking and problem-solving performance. *Journal of Educational Computing Research*, *60*(2), 512–543. https://doi.org/10.1177/07356331211037757

Giannetto, M. L., & Vincent, L. (2014). Motivating students to achieve higher-order thinking skills through problem solving. *Mathematics Teacher Learning and Teaching*, 95(9), 718–723

Gilbert, G. E., & Prion, S. (2016). Making sense of methods and measurement: lawshe's content validity ındex. *Clinical Simulation in Nursing*, *12*(12), 530–531. https://doi.org/10.1016/j.ecns.2016.08.002

Gordillo-tenorio, W., & Cabanillas-carbonell, M. (2023). Information technologies that help ımprove academic performance: A review of the literature. *International Journal of Emerging Technologies in Learning (IJET)*, *18*(04), 262–279

Green, B. (2017). *The method of successive ıntervals: A sourcebook for behavioral scientists*. Routledge. https://doi.org/10.4324/9781315128948-13

Greenbank, P. (2010). *Developing decision-making skills in students: An active learning approach*. Edge Hill University

Habók, A., & Nagy, J. (2016). In-service teachers' perceptions of project-based learning. *SpringerPlus*, *5*(1), 1–14. https://doi.org/10.1186/s40064-016-1725-4

Hajj, M. El, & Harb, H. (2023). Rethinking education: An ın-depth examination of modern technologies and pedagogic recommendations. *IAFOR Journal of Education*, *11*(2), 97–113. https://doi.org/10.22492/ije.11.2.05

Haryani, S., Prasetya, A. T., & Permanasari, A. (2014). Developing metacognition of teacher candidates by ımplementing problem based learning within the area of analytical chemistry. *International Journal of Science and Research*, *3*(6), 1223–1229

Hill, S. (2015). *Understanding "computational thinking."* *4*(3), 74–75. https://www.mendeley.com/catalogue/405e343d-f9e0-3bf2-8422-0848effdbaa9/?utm_source=desktop

Hopson, M. H., Simms, R. L., & Knezek, G. A. (2001). Using a technology-enriched environment to improve higher-order thinking skills. *Journal of Research on Technology in Education*, *34*(2), 109–119. https://doi.org/10.1080/15391523.2001.10782338

Hunsaker, E. (2020). The K-12 educational technology handbook computational thinking. *Edtech Books*. https://new.edtechbooks.org/k12handbook/author_list

Jawawi, D. N. A., Jamal, N. N., Halim, S. A., Sa'adon, N. A., Mamat, R., Isa, M. A., Mohamad, R., & Hamed, H. N. A. (2022). Nurturing secondary school student computational thinking through educational robotics. *International Journal of Emerging Technologies in Learning*, *17*(3), 117–128.

Jazuli, I., Rahmayanti, H., Purwanto, A., Vivanti, D., Miarsyah, M., & Weslem, P. (2020). HOTS-AEP-COVID-19 and ILMIZI learning model : The 21 st -century environmental learning in senior high. *Jurnal Pendidikan Biologi Indonesia*, *6*(2), 265–272.

Jensen, J. L., Mcdaniel, M. A., Woodard, S. M., & Kummer, T. A. (2014). Teaching to the test or testing to teach : Exams requiring higher order thinking skills encourage greater conceptual understanding. *Education Psychology Rev*. https://doi.org/10.1007/s10648-013-9248-9

Kale, U., Akcaoglu, M., Cullen, T., Goh, D., Devine, L., Calvert, N., & Grise, K. (2018). Computational what? Relating computational thinking to teaching. *TechTrends*, *62*(6), 574–584. https://doi.org/10.1007/s11528-018-0290-9

Karami, M., Karami, Z., & Attaran, M. (2013). Integrating problem-based learning with ICT for developing trainee teachers' content knowledge and teaching skill. *International Journal of Education & Development Using Information & Communication Technology*, *9*(1), 36–49. http://search.ebscohost.com/login.aspx?direct=true&db=ehh&AN=88933218&site=ehost-live%5Cnhttp://content.ebscohost.com/ContentServer.asp?T=P&P=AN&K=88933218&S=R&D=ehh&EbscoContent=dGJyMNXb4kSep7I4yNfsOLCmr02eprRSsqe4TLCWxWXS&ContentCustomer=dGJyMPGrski3r7J

Kelly, K. L. (2016). Emergent arguments: Digital media and social argumentation. *Journal of Chemical Information and Modeling*. https://doi.org/https://doi.org/10.1017/CBO9781107415324.004

Kelly, K. L., Crosswhite, J., & Bivins, T. (2016). *Emergent Arguments; Digital Media And Social Argumentation*. [Unpublished doctoral dissertation]. University of Oregon

Labak, I., Kujundžić, I., & Bognar, B. (2024). The effect of changes in teaching methods on pupils ' academic performance in biology. *Journal of Turkish Science Education*, *21*(3), 448–466.

Lawshe, C. H. (1975). A quantitative approach to content validity".Personnel Psychology. *Personnel Psychology*, *28*, 563–575.

Lee, K., & Cho, J. (2021). Computational thinking evaluation tool development for early childhood software education. *International Journal on Informatics Visualization*, *5*(3), 313–319. https://doi.org/10.30630/joiv.5.3.672

Lee, S. M. (2014). The relationships between higher order thinking skills, cognitive density, and social presence in online learning. *The Internet and Higher Education*, *21*, 41–52. https://doi.org/10.1016/j.iheduc.2013.12.002

Liline, S., Tomhisa, A., Rumahlatu, D., & Sangur, K. (2024). The effect of the Pjb-Hots learning model on cognitive learning , analytical thinking skills , creative thinking skills , and metacognitive skills of biology education students. *Journal of Turkish Science Education*, *21*(1), 175–195. https://doi.org/10.36681/tused.2024.010

Lukitasari, M., Handhika, J., & Murtafiah, W. (2018). Higher order thinking skills : Using e-portfolio in project- based learning. *Journal of Physics*, *983*, 1–7.

Lukitasari, M., Handhika, J., & Murtafiah, W. (2021). *Model pembelajaran berdasarkan masalah melalui digital argumentation (PBM-DA)*. AE Media Grafika

Lukitasari, M., Handika, J., Murtafiah, W., & Nurhikmawati, A. R. (2020). Examining students' self-assessment of digital argumentation (SADA) in e-biology class: A rasch analysis. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *6*(2), 209–216. https://doi.org/10.22219/jpbi.v6i2.11919

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? *Computers in Human Behavior*, *41*, 51–61. https://doi.org/10.1016/j.chb.2014.09.012

Milroy, S. P. (2021). *Field Methods in Marine Science*. Garland Science. https://doi.org/10.1201/9781317302292-8

Montoneri, B. (2014). Teaching ımprovement model designed with DEA method and management matrix. *IAFOR Journal of Education*, *2*(1), 125–156. https://doi.org/10.22492/ije.2.1.05

Mubuuke, A. G., Louw, A. J. N., & Van Schalkwyk, S. (2016). Cognitive and social factors ınfluencing students' response and utilization of facilitator feedback in a problem based learning context. *Health Professions Education*, *3*(2), 85–98. https://doi.org/10.1016/j.hpe.2016.09.003

Nantha, C., Pimdee, P., & Sitthiworachart, J. (2022). A quasi-experimental evaluation of classes using traditional methods, problem-based learning, and flipped learning to enhance thai student-teacher problem-solving skills and academic achievement. *International Journal of Emerging Technologies in Learning*, *17*(4), 20–38.

Nilson, L. (2010). *Teaching at ıts best teaching at ıts best: A research-based resource for college ınstructors*. John Wiley & Sons, Inc.

Nirbita, B. N., Joyoatmojo, S., & Sudiyanto, S. (2018). ICT media assisted problem based learning for critical thinking ability. *International Journal of Multicultural and Multireligious Understanding*, *5*(4), 341. https://doi.org/10.18415/ijmmu.v5i4.295

Pereira, D., Afonso, A., & Medeiros, F. (2015). Overview of Friedman’s test and post-hoc analysis. *Communications in Statistics-Simulation and Computation*, *44*, 2636–2653. https://doi.org/10.1080/03610918.2014.931971

Skelin, S., Schlueter, B., Rolle, D., & Gaedicke, G. (2008). Problem-based learning (PBL). *Monatsschrift Kinderheilkunde - Monatsschr Kınderheılk*, *156*, 452–457.

Srivastava, D. K., & Mudholkar, G. S. (2001). Trimmed T2: A robust analog of hotelling’s T2. *Journal of Statistical Planning and Inference*, *97*(2), 343–358. https://doi.org/10.1016/S0378-3758(00)00239-1

Tanujaya, B., Mumu, J., & Margono, G. (2017). The relationship between higher order thinking skills and academic performance of student in mathematics ınstruction. *International Education Studies*, *10*(11), 78. https://doi.org/10.5539/ies.v10n11p78

Tosun, C., & Senocak, E. (2013). The effects of problem-based learning on metacognitive awareness and attitudes toward chemistry of prospective teachers with different academic backgrounds. *Australian Journal of Teacher Education*, *38*(3). https://doi.org/10.14221/ajte.2013v38n3.2

Tsortanidou, X., Daradoumis, T., & Barberá, E. (2019). Connecting moments of creativity, computational thinking, collaboration and new media literacy skills. *Information and Learning Science*, *120*(11–12), 704–722. https://doi.org/10.1108/ILS-05-2019-0042

Viyanti, C., Sunarno, W., & Prasetyo, Z. K. (2020). Reconstruction of higher order thinking skill through enriching student’s argumentation skills. *Jurnal Pendidikan Progresif*, *10*(2), 327–335. https://doi.org/10.23960/jpp.v10.i2.202016

Voon, X. P., Wong, S. L., Wong, L. H., Khambari, M. N. M., & Syed-Abdullah, S. I. S. (2022). Developing computational thinking competencies through constructivist argumentation learning: a problem-solving perspective. *International Journal of Information and Education Technology*, *12*(6), 529–539. https://doi.org/10.18178/ijiet.2022.12.6.1650

Williams, M., Lively, M., & Harper, J. (1994). Higher order thinking skills : tools for bridging the gap. *Foreign Language Annals*, *27*(3), 405–426

Appendix 1

Course Plan Outline

COURSE OUTLINE OF PLANT BIODIVERSITY	
What is this course about?	
In this course you investigate diversity of the plant: Plant biodiversity & Biodiversity levels, Genetic, species and ecosystem biodiversity, Biodiversity & Ecological distribution of Chryptogamae, Biodiversity & Ecological Distribution of Angiosperm, and Biodiversity & Ecological Distribution of Gymnosperm	
How will this course be delivered?	
Learning activities are carried out using blended learning by utilizing the existing learning management system (LMS), as e-learning UNIPMA (eLMA). Apart from that, the implementation of learning is framed using problem based learning (PBL) and encourages active student communication online or digital argumentation (DA) in the (eLMA).	
Learning materials	The learning material will introduce and invite the students to carry out investigations and observations about plant diversity. Students will carry out activities in groups by working on assignments that have been designed according to the material. Students will explore plant biodiversity of Chryptogamae, Angiosperm and Gymnosperm. Students also learn how the ecological distribution plans and the interaction each other.
Observation/ Practicum	Practical activities are carried out in groups which are useful for expanding knowledge and understanding of the material. Students make observations and describe plant types according to their anatomical and morphological characteristics. Students also directly improve their ability to make detailed drawings of plants, from roots, stems, leaves and even their reproductive organs. For a wider range, students have the skills to identify and classify the types of plants observed.
Tutorial/Mentor ing	This mentoring and tutorial help students develop critical thinking skills, use of scientific vocabulary, and scientific writing in the form of activity reports. Students are trained to convey arguments well using LMS facilities in hybrid learning.
Course Topic	
Plant biodiversity & Biodiversity levels. Anatomy, morphology and characteristics of major taxon of the plant. Laboratory skills (identification, botany, microbiology). Scientific drawing and writing skills (laboratory report) Field investigation skills	
Schedule	
Period	Activities
Week 1	**Pretest** Learning material; Course introduction; Origins and patterns of global plant biodiversity. Tutorial; Evolution and biodiversity levels
Week 2	Learning material; plant diversity at genetic, species and ecosystem levels Tutorial; analysis of genetic, species and ecosystem diversity problems

Week 3	Learning material; Biodiversity & Ecological distribution of Chryptogamae (Thallophyta, Bryophyta) Practicum; observation anatomy and morphology, microscopes and scientific drawing
Week 4	Learning material; Biodiversity & Ecological distribution of Chryptogamae (Bryophyta, & Fungi) Practicum; observation anatomy and morphology, microscopes and scientific drawing
Week 5	Learning material; Biodiversity & Ecological distribution of Chryptogamae (Pteridophyte) Tutorial/Mentoring; discussion, problem solving and presentation
Week 6	Learning material; Biodiversity & Ecological Distribution of Angiosperm (*Ranunculaceae, Caryophyllaceae* dan *Rosacea)* Practicum; observation anatomy and morphology, microscopes and scientific drawing
Week 7	Learning material; Biodiversity & Ecological Distribution of Angiosperm (*Solanaceae, Acanthaceae* dan *Lamiaceae)* Practicum; observation anatomy and morphology, microscopes and scientific drawing
Week 8	**Midterm test** Tutorial/Mentoring; discussion, problem solving and presentation practicum report.
Week 9	Learning material; Biodiversity & Ecological Distribution of Angiosperm (*Orchidaceae, Liliaceae* dan *Poaceae)* Practicum; observation anatomy and morphology, microscopes and scientific drawing.
Week 10	Learning material; Biodiversity & Ecological Distribution of Gymnosperm. Tutorial/Mentoring; discussion, problem solving and presentation
Week 11	Learning material; Biodiversity & Ecological Distribution of Gymnosperm. (Cycadidae, Konifer) Practicum; observation anatomy and morphology, microscopes and scientific drawing.
Week 12	Learning material; Biodiversity & Ecological Distribution of Gymnosperm. (Ginkodidae, Gnetophyta) Practicum; observation anatomy and morphology, microscopes and scientific drawing.
Week 13	Learning material; Biodiversity & Ecological Distribution of Gymnosperm. (Reproduction System of Gymnospermae) Tutorial/Mentoring; discussion, problem solving and presentation
Week 14	Learning material; Biodiversity & Ecological Distribution of Gymnosperm. Tutorial/Mentoring; discussion, problem solving and presentation
Week 15	Learning material; Refreshing all material of plant biodiversity Tutorial/Mentoring; reflection, discussion and presentation
Week 16	**Final exams (Posttest)**

Assessment tasks
Delivery mode: ALL

Task No	Product	Process	Weighting (%)	Condition
1	Pretest	Individual	0	Online
2	Written laboratory report	Group	25	Online and Offline

				submission
3	Digital argumentation	Individual	20	Online submission
4	Practical/ Laboratory skills	Group	25	Offline
5	Final exam	Individual	30	Online submission

Appendix 2

Simple Lesson Plan

Semester: Second semester Subject: Bryophyta Topis: Moss (Bryophyta)	
Objective At the end of the lesson, the students will be able to 1. After working on the worksheet, students are able to convey arguments to solve problems 2. After working on the worksheet, students are able to prepare problem solving in stages regarding bryophytes using CT stages	
Syntax of PBL-DA	**Activity**
1. Problem orientation	Students pay attention to the presentation of material about bryophytes. Answering several questions asked by the lecturer: 1) How can we differentiate between the types of plants we encounter? 2) Have you ever observed moss plants? 3) Describe mosses and their role in life.
4) Student organization	Students are grouped according to regulations. Start a discussion to provide responses to apperception questions. Students also group according to regulations. Start a discussion to provide responses to apperception questions. Students also open the material provided in the LMS, eLearning UNIPMA (eLMA).
5) Brainstorming	In groups, students pay attention to the worksheet about bryophytes presented by the lecturer. Based on the problems presented, each group looks for relevant supporting references. Students work on worksheets with computational thinking (CT) stages for moss material. The **abstraction** stage is carried out by identifying factors that influence the diversity of bryophyte. The discussion continued by **decomposing** the main problem regarding the decline in bryophyte diversity (for general).
6) Data collection through investigations	The student group worked out a way to solve the problem based on the **decomposition** of moss plants and developed a problem-solving **algorithm** in the form of a flowchart.
7) Sharing information and discussion to find a solution of problem	The student group submitted a flowchart (**algorithm)** for solving the problem about current moss populations and environmental conditions. The **evaluation** stage is carried out with a presentation of the flowchart to get suggestions for improvements.

8)	Presenting troubleshooting results	The results of the evaluation stage are presented again to obtain strengthening of the best problem solving for issues regarding moss populations and environmental conditions.
9)	Analysing and evaluating problem solutions	The results of the worksheet are a planned as problem-solving effort to overcome the low diversity of moss populations, environmental conditions and Bryophyta diversity. Each stage in CT is completed sequentially by groups of students.

Assessment

No	Type of assessment	Assessment form
1	Diagnostic	Trigger questions during apperception
2	Assessment for learning (AfL)	The results of worksheet work according to the CT stages Presentation of arguments during presentations Submission of digital arguments (DA) in discussion forums in LMS

Reflection

1. How effective was the lecture process using the PBL-DA learning model?
2. Were the CT-based worksheets that have been prepared able to help students' understanding of the bryophyte material?
3. Have all students carried out their lectures well?
4. How did students utilize the discussion forums in the LMS?

Appendix 3

Worksheet

Worksheet - (Week 3 & 4)

Bryophyta Biodiversity and Conservation

Instruction:

1. Complete the tasks in group discussion and send it to the 'discussion forum' on the LMS provided.
2. Every argument presented in the discussion forum should be accompanied by supporting data as evidence.
3. Follow the steps in the table to complete the task.
4. To investigate the decline in Bryophyta biodiversity in a specific ecosystem and propose solutions using computational thinking (CT) skills with each step.

Case study about moss

A local forest ecosystem has experienced a significant decline in Bryophyta (moss) biodiversity over the past decade. Scientists have observed that moss populations, which once thrived in the area, are now scarce. In Indonesia, particularly in Sumatra and Borneo, deforestation for palm oil plantations and logging is leading to the loss of epiphytic mosses and liverworts. Moss has an important role in the ecosystem, such as providing habitat for microfauna which is important in the litter decomposition process and as a bioindicator plant because it is sensitive to air pollution, especially heavy metals. Several types of moss which can be indicators of air quality can be seen in the following image.

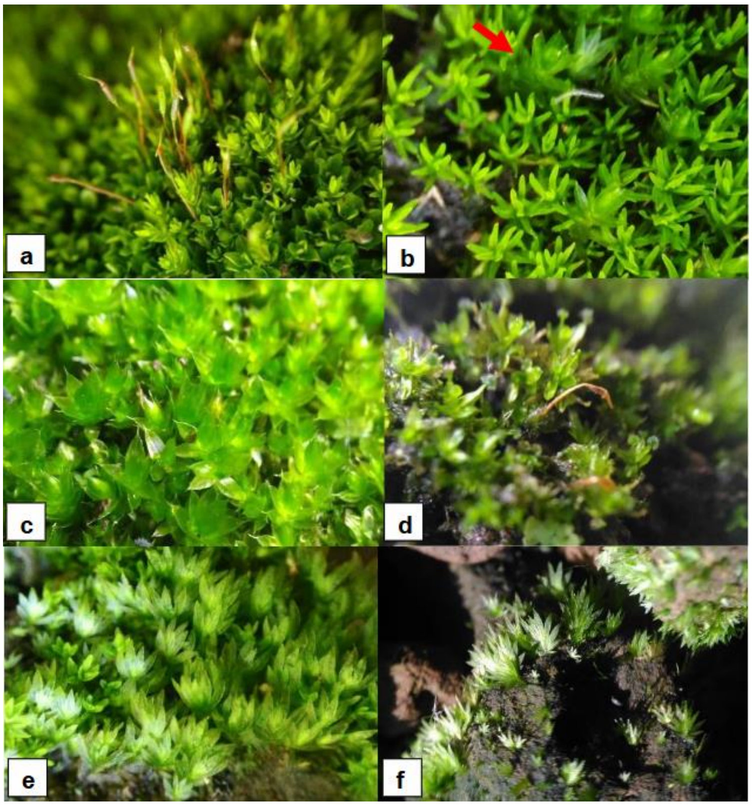

Figure 1. a. Barbulla indica, b.Gemmabryum apiculatum(panah merah), c. Bryum coronatum, d. Calymperes tenerum, e. Fissidens atroviridis,f. Fissidens biformis.abcdef

Source; Fastanti, Wulansari (2021), https://jurnalbiologi.fmipa.unila.ac.id/index.php/jbekh/article/view/194/158

These Bryophytes, which grow on trees, are critical for maintaining humidity and supporting biodiversity in tropical rainforests.

- Indonesia has lost over 25% of its forest cover since 2000.
- Epiphytic Bryophyte diversity has declined by 50% in deforested areas.

This decline is affecting the ecosystem's ability to retain water, support microorganisms, and stabilize soil.

Your task is to investigate the causes of this decline and propose actionable solutions to restore Bryophyta biodiversity.		
CT Skills	**Task/ Activity**	**Questions**
Abstraction	Identify the key factors affecting Bryophyta biodiversity in the forest ecosystem. 1. Research the environmental conditions required for moss growth (e.g., moisture, shade, soil pH). 2. List the key factors that could contribute to the decline (e.g., deforestation, pollution, climate change). 3. Ignore irrelevant details (e.g., specific moss species names unless critical).	- What are the most critical factors influencing Bryophyta biodiversity? - Why is it important to focus on these factors when addressing the problem?
Decomposition	Break down the problem into smaller, manageable parts. 1. Divide the problem into smaller components: - Environmental factors: How have changes in moisture, temperature, or soil quality affected mosses? - Human activities: What role do deforestation, pollution, or urbanization play? - Biological factors: Are there invasive species or diseases impacting moss populations? 2. Assign each component to a group or individual for further investigation.	- How does breaking down the problem help you understand it better? - Which component do you think is the most critical to address?
Algorithmic Reasoning	Develop a step-by-step plan to investigate and address the decline in Bryophyta biodiversity. 1. Create an algorithm (step-by-step plan) to solve the problem: - Collect data on current moss populations and environmental conditions. - Analyses the data to identify the primary causes of decline. - Propose solutions (e.g., reforestation, reducing pollution, creating protected areas).	- Why is it important to follow a structured plan when solving environmental problems? - How can you ensure your plan is realistic and actionable?

	- Implement and monitor the solutions. 2. Use a flowchart to visualize your plan.	
Evaluation	Evaluate the effectiveness of potential solutions for the problem. 1. Propose 2-3 solutions to restore Bryophyta biodiversity (e.g., creating moss-friendly habitats, reducing air pollution, educating the public). 2. Evaluate each solution based on: - Feasibility (cost, resources, time) - Impact (how effectively it addresses the problem) - Sustainability (long-term benefits) 3. Rank the solutions and justify your choice.	- Which solution do you think is the most effective, and give reason argumentation? - What challenges might you face when implementing these solutions?
Generalization	Apply your findings to other ecosystems facing similar biodiversity issues. 1. Research another ecosystem where Bryophyta or other non-vascular plants are declining. 2. Compare the causes and solutions to those in the forest ecosystem. 3. Write a generalization about conserving biodiversity in fragile ecosystems.	- How can the lessons learned from this case be applied to other ecosystems? - Why is it important to generalize solutions for biodiversity conservation? - Use visuals (e.g., graphs, flowcharts, images) to support your arguments.