RESEARCH ARTICLE

Improving students' metacognitive abilities and creative thinking skills through STEM-based in online learning

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Abstract: Creative thinking skills are crucial to current generations dealing with 21st-century challenges. However, studies on higher-order thinking skills remain limited. CTS can be easily empowered if students have good metacognitive abilities. This study analysed the effect of STEM-based online learning lesson plans on the CTS of students and metacognitive abilities on the inheritance of living things through online learning. The pretest-posttest research designs with a non-equivalent control group were used. The treatment given in the experimental class was the implementation of a STEM-based online learning lesson plan, while the control class was taught through traditional methods used by the teachers. The results of this study indicated that the CTS and metacognitive abilities of students in the experimental class were significantly higher than that of the control class [$F(1,54) = 105.287$, $p = 0.000$ and $F(1,54) = 103.943$, $p = 0.000$, respectively]. In conclusion, the STEM-based online learning lesson plan is effective in improving the CTS and metacognitive abilities of students.

Keywords: creative thinking skills; metacognitive abilities; STEM-based learning

Introduction

Learning strategies are one of the crucial aspects of achieving objectives during the implementation of the learning process. The Minister of Education and Culture, through the Minister of Education and Culture Number 22 of 2016 concerning Process Standards, suggested using integrated learning strategies based on thematic, scientific, inquiry, discovery, and projects that are in accordance with competency characteristics, environmental characteristics, and education levels. However, the COVID-19 pandemic has limited the physical interaction with educators to remote or online education to prevent the spread of the virus (Basilaia & Kvavadze, 2020; Hew et al., 2020; Nikou & Maslov, 2021).

Distance learning is a challenge for educators when helping learners achieve educational goals. These conditions drive the adjustment of commonly used learning strategies to the characteristics of distance learning. The research by Andrabi et al (2021); Srikongchan et al (2021) show that during the COVID-19 pandemic, many educators shifted traditional learning strategies such as lectures to distance learning, which limits the interaction between educators and students (Ahied et al., 2020). One of the fundamental aspects of traditional learning strategies is that they have teacher-centred characteristics (Cetin-Dindar & Geban, 2017; Felder & Brent, 2016).

Traditional learning methods, such as lectures that have teacher-oriented characteristics, can be carried out under several learning situations and conditions (Cetin-Dindar & Geban, 2017; Felder & Brent, 2016). However, the knowledge gained by students is not stored in long-term memory and may not be perceived as meaningful (Ilma et al., 2022; Nikou & Maslov, 2021; Pokhrel & Chhetri, 2021). Consequently, distance learning is ineffective and limits the achievement of the expected learning objectives (Hew et al., 2020; Mailizar et al., 2020). Therefore, educators need to design effective learning strategies and motivate student-centred involvement in distance learning (Hira & Anderson, 2021; McCullough et al., 2020; Schallert et al., 2021).

STEM-based learning is a student-oriented learning strategy that is known to be more effective than traditional learning (Honey et al., 2014; Mayasari et al., 2016; Schallert et al., 2021; Struyf et al., 2019). According to English (2016) and Sturyf et al (2019), STEM-based learning is more effective than other strategies in improving academic achievement and developing higher-order thinking skills. STEM-based learning can also develop the scientific skills of students (Sahin et al., 2014; Sutaphan & Yuenyong, 2019; Thomas & Watters, 2015). Moreover, metacognitive skills and creative thinking can be empowered by learning on a STEM basis (Mariano et al., 2021; Pollard et al., 2018; Santangelo et al., 2021; Shukri et al., 2020). Therefore, the results from this research can become the basis for applying STEM-based learning in education, especially in remote learning, so that students can cultivate meaningfulness in learning and empower higher-order thinking skills.

The process of creative thinking is a form of cognitive processing that refers to the efforts of an individual to come up with a creative solution or product (Fleischner et al., 2017). Such thinking is usually triggered by challenging tasks or open-ended problems that need to be solved from various points of view (Cargas et al., 2017; Çimer, 2012). By thinking creatively, students are expected to see the world through various points of view so that new solutions arise to overcome real-life problems (Chinedu & Olabiyi, 2015; Kose & Arslan, 2017). This ability is needed in the workplace and can provide added value (Zulkarnaen et al., 2017). Creativity in thinking about a problem will present easily if the person has good metacognitive abilities. Metacognitive development is one of the dimensions of knowledge that must be achieved, that is, how individuals can plan, monitor, and evaluate the learning process (Ndiung et al., 2021). This metacognitive ability is important for students to achieve a maximum learning experience. Based on the research by Wibowo et al (2018), junior high school students are unable to separate what is thought and how they think and do not seem to have awareness of thinking as a process. This happens because the efforts of students to comprehensively learn, prepare for efficient learning, and the ability to evaluate their weaknesses in learning and finding solutions is still very low.

Altogether, STEM is one of the learning strategies that is currently being intensely applied in learning (Choy et al., 2020). However, the challenges of distance learning that are carried out tend to be passive and teacher-centred. Students are given assignments, which are closely related to the questions given by the teacher (Ndiung et al., 2021). Learning is also limited to WhatsApp groups without utilising virtual face-to-face learning websites. Meaningfulness-based learning and focusing on scientific methods in distance learning remains limited in application, especially in Indonesia, which has limited internet network infrastructure quality and is not evenly distributed between regions, challenging distance learning in itself.

Therefore, designing student-oriented STEM-based learning strategies in distance learning requires careful consideration. Various influencing factors such as the availability of facilities and infrastructure, time, the skills of educators, and the ability of students to utilise technology as well as conformity with the learning curriculum should be considered to achieve the learning objectives. One way to evaluate the success of the learning process is to collect responses, perceptions, and learning outcomes from students. This study aimed to measure the learning outcomes in one or several aspects of higher-level thinking of students towards STEM-based learning in distance learning as an effort to improve the quality of education, especially during the COVID-19 pandemic.

Method

We used the pretest-posttest research design with a nonequivalent control group (O_2 - O_1 X O_4 - O_3). The O_1 and O_3 were the pretest scores, and X represented science learning on the topic of inheritance of living things using STEM in online learning, while O_2 and O_4 were the posttest scores. Before the application of natural science learning through STEM in online learning, two groups of ninth grade students of the Junior High School 2 of Ceper, Klaten Regency (Indonesia) in the first semester of the academic year 2019/2020 were given a creative thinking and metacognitive test (pre-test) in science subjects. A total of 102 students were involved as research subjects, consisting of 54 and 48 students in the experimental and control classes, respectively. The experimental class learnt using a STEM-based lesson plan, while the control class used student worksheets that are not STEM-based. The topic for both groups was the inheritance of living things. After the application of science learning with STEM, students were given the same test with the same items (posttest). The test consisted of four essay questions based on the indicators of creative thinking skills according to Guilford (1967) i.e fluency, flexibility, originality, and elaboration. In addition, the metacognitive skills assessment also consisted of eight essay questions based on MAI according to Schraw & Dennison (1994). The test used has been validated by experts and declared valid and reliable through statistical tests and has been verified for different power and difficulty levels.

The lesson plan development in this research used the 4Ds, namely, define, design, develop, and disseminate, adapted from Thiagarajan et al (1976). The instrument for collecting data on the feasibility of the lesson plan also used a validation questionnaire, a lesson plan practicality questionnaire, creative thinking skills questions, metacognitive skills questions, and an analysis of the creative thinking and metacognitive skills answers. Three experts carried out the lesson plan validation, including linguists, material, learning experts, and educational practitioners with an education qualification. Validation by linguists included aspects of graphic feasibility and language feasibility. Material expert validation included content feasibility, material feasibility, and STEM learning, while learning expert validation focused on lesson plan practicality.

Creative thinking skills and metacognitive score data of the students were obtained. The data analysis used ANCOVA with the pretest score as the covariate. ANCOVA was used to analyse whether there were differences between the pretest and posttest scores of the test instrument with a significance of 5%. The effectiveness of the lesson plan was tested with the ANCOVA after the data was declared normal and homogeneous. The lesson plan was effective in improving creative thinking and metacognitive skills if the value of $Sig_{count} < Sig_{table}$ with a significance of 0.05. This means that there was a difference in the average value of creative thinking and metacognitive skills between the experimental and control groups, which would indicate that the inheritance of living things based on the STEM lesson plan was effective in improving the creative thinking and metacognitive skills of the students. Whereas N-gain was used to determine the level of improvement in creative thinking and metacognitive skills after science learning based on the STEM plan. N-Gain was calculated using the formula and criteria adapted from Hake (1999).

Results and Discussion

First Stage: Define

The results of the analysis showed that the level of creative thinking skills of students had different scores (low (L), medium (M), high (H), and very high (VH)), as shown in Figure 1. VH levels of creative thinking skills had the lowest frequency of all categories. Figure 1 shows the level of metacognitive abilities of students.

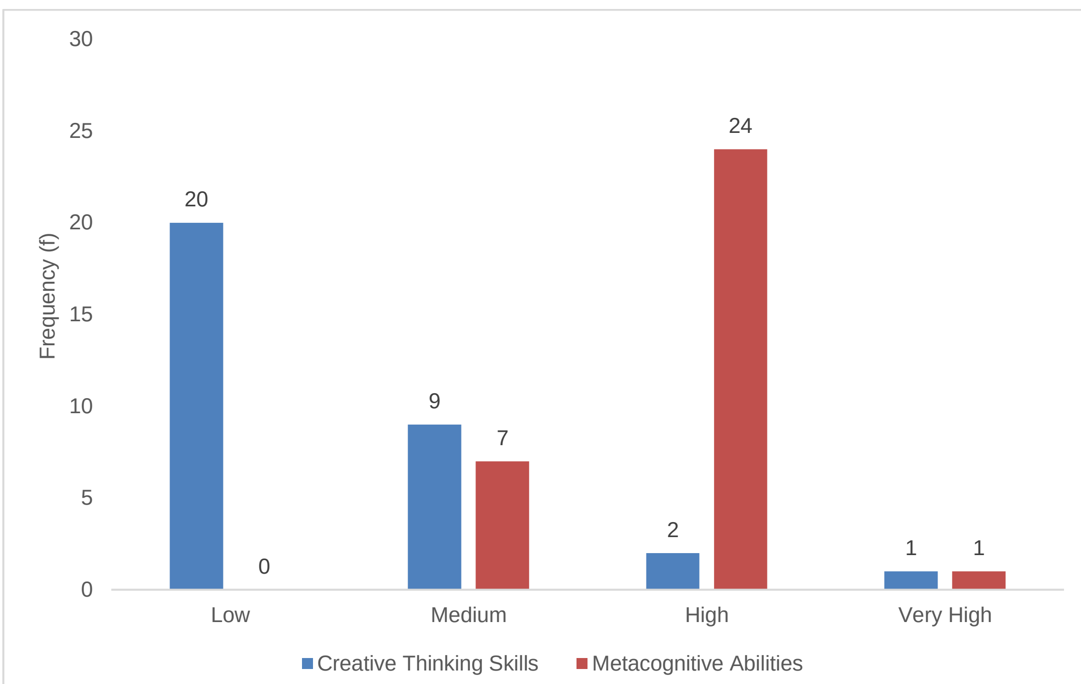

Figure 1. Creative thinking skills test

Based on Figure 1, 62.50%, 28.12%, 6.25%, and 3.12% of the students had L, M, H, and VH creative thinking skills, respectively. Moreover, none of the students had L or VH creative thinking skills levels. Nevertheless, 25.00% and 75.00% of the students presented M and H metacognitive abilities. Consequently, two of the four indicators of creative thinking were also L (<40.00). The two indicators included: (1) fluency and (2) flexibility. Meanwhile, others indicators were categorised as M under the score 41.00 – 60.00, namely: (1) flexibility and (2) originality. For the metacognitive abilities, all of the aspects are included as M, namely: (1) declarative knowledge (DK), (2) procedural knowledge (PK), (3) conditional knowledge (CK), (4) planning (P), (5) information management strategies (IMS), (6) monitoring (M), (7) debugging strategies (DS), and (8) evaluation (E). These results indicated that the learning process carried out so far had not improved the creative thinking skills and metacognitive ability of the students. Thus, significant efforts are needed to help improve creative thinking skills and maximise the metacognitive abilities of students. Creative thinking skills need to be improved because it is very fundamental in managing learning skills and empowering students to actively and creatively contribute in life. Students who have good and elevated creative thinking skills can easily solve daily-life problems. Creative thinking skills may explain the causal relationships of events that occur around them (Felder & Brent, 2016; Shukri et al., 2020). Creative thinking skills will be more easily empowered if students have good metacognitive abilities. At this stage, an analysis of the concept of inheritance of living things was carried out on the science basic competencies of junior high school.

Second Stage: Design

The results of the preliminary study stage (define) were used as a reference in designing learning tools. The reference created the learning tools to develop and have characteristics. There were five main characteristics, namely: (1) improving metacognitive ability and creative thinking skills, (2) concrete problem-based, (3) STEM-based online learning, (4) student-centred, and (5) using authentic assessment. Besides, adjusting the results of the preliminary and the five characteristics were carried out to the 2013 curriculum so that products (learning tools) could be more easily implemented at the level of junior high schools in Indonesia. Students were conditioned to actively interact with learning materials and carry out various learning activities and get feedback about what they were learning (Taskiran, 2021; Ylostalo, 2020). The design phase produced the first prototype of product (STEM-based learning tools).

Third Stage: Develop

Results of content validity

This stage was used to determine the feasibility of products that have been developed. The learning tools prototype testing phase was carried out involving several experts (language, material, media, learning expert validators, and educational practitioners). The results of the validation of the learning tools indicated that the STEM-based online learning product was suitable for use in learning with several revisions shown in Table 1. This stage produced the second prototype of product.

Table 1. Validation results of the learning tools prototype

Validator	Aiken V Score	Category
Language	0.63	Medium
Media and learning	0.66	Medium
Material	0.78	Medium
Educational practitioners	0.85	High
Mean of all aspects	0.73	Medium

Results on limited testing trial

Science teachers as practitioners and respective users of learning tools developed in this study responded to products through questionnaires that had been given after usage. Table 2 shows the response of the science teacher to the learning tools that had been designed in the previous stage.

Table 2. Results analysis of the teachers' questionnaires

Aspect	Percentage (%)	Category
Interface	100.00	Very valid
Content	93.75	Very valid
Language	87.50	Very valid
Media	100.00	Very valid
Learning resource	100.00	Very valid
Mean of all aspects	95.00	Very valid

Student responses were assessed from the implementation of learning using tools that had been developed. The results of the learning outcomes are shown in Table 3. This stage produced the third prototype that will later be considered for revision.

Table 3. Implementation of limited testing trial

Implementation	Percentage (%)
First meeting	84.09
Second meeting	94.67

Results of the operational testing

The student responses at this stage could also be assessed from the implementation of learning using learning tools that had been developed. This operational testing was carried out in two stages. Stage 1, the entire series of learning was carried out in accordance with the learning tools developed. If testing the entire learning process using the development product was declared feasible, then testing in stage 2 was carried out to determine the effectiveness of the developed product. The product used during this stage 2 was the final product that was declared valid and feasible to be applied. The results of the learning outcomes in stages 1 and 2 are shown in Tables 4 and Table 5, respectively.

Table 4. Implementation of operational testing stage 1

Implementation	Percentage (%)
First meeting	84.09
Second meeting	94.67
Third meeting	91.67
Fourth meeting	96.67
Fifth meeting	95.83
Sixth meeting	98.67
Average	93.60

Table 5. Implementation of operational testing stage 2

Implementation	Percentage (%)
First meeting	84.09
Second meeting	95.37
Third meeting	91.67
Fourth meeting	96.67
Fifth meeting	95.83
Sixth meeting	98.67
Average	93,71

This stage led to the results of the draft IV product or a STEM learning tool with an online learning scenario that was properly suitable for implementation in the classroom, and its effectiveness was measured.

Fourth Stage: Disseminate

The effectiveness of science learning tools based on STEM in online learning was determined in the disseminate stage. It was analysed and stride under the effectiveness analysis indicators. Moreover, the results of the preliminary test using the normality and homogeneity tests in the experimental and control classes indicate that the data are normally and homogeneously spread. Based on Table 6, the normality test using the Shapiro-Wilk test showed that the pretest and posttest were normally distributed (α > 0.05), while the Levene's homogeneity test in all classes showed homogeneous pretest and posttest because of the significance level (α > 0.05).

Table 6. Recapitulation of the results of the normality and homogeneity test

Aspect	Class	Test	Test	Result	
				Sig. pretest	Sig. posttest
Metacognitive	Exp.	Norm.	Shapiro-Wilk test	0.060	0.060
	Ctrl.	Norm.	Shapiro-Wilk test	0.244	0.149
	All Class	Homogeneity	Levene's test	0.459	0.246
Creative thinking	Exp.	Norm.	Shapiro-Wilk test	0.215	0.133
	Ctrl.	Norm.	Shapiro-Wilk test	0.063	0.696
	All Class	Homogeneity	Levene's test	0.253	0.155

The next test conducted was the ANCOVA to determine the difference in posttest values in the experimental and control classes. Based on Table 7, there was a significant difference between the posttest value between the experimental and control classes ($\alpha < 0.05$). Mariano et al (2021) and Pollard et al (2018) revealed that biotechnology learning with the STEM model is effective in improving metacognitive and creative thinking skills. Bokor et al (2014) and Schallert et al (2021) also found that learning with STEM syntax on science is accurately linked to metacognitive indicators and is suitable for the learning process. Students with good metacognitive abilities will find it easier to empower their creative thinking (Harrison & Vallin, 2017; Yusnaeni et al., 2017). In addition, students may easily follow the learning process when their metacognitive abilities are good. Learning in this case is interpreted as the ability of students to understand the material that has not been studied and to elaborate on it. Online STEM learning was used as an innovation in varying student learning processes during the pandemic. The problems presented are in the form of real phenomena that occur contextually, namely the existence of colour variations in Aglaonema leaves. In the first meeting, students were confused when following a series of learning processes. However, after the second meeting, the students can slowly adapt to the application of the series of STEM. The learning process that utilises nature around students will present concrete problems and real experiences for students to build sharp thinking and applicable scientific insights (Albantani & Madkur, 2018). The research and development carried out are therefore aimed at improving the metacognitive ability and creative thinking skills of students through meaningful learning by utilising the contextual phenomena around the topic or learning resources. Moreover, improving the metacognitive abilities in the learning process helps students improve their learning outcomes in the classroom (Mariano et al., 2021). Integrating contextual phenomena in biology learning through STEM can improve the cognitive abilities of students in so many different levels (Mariano et al., 2021). Table 8 shows the results of testing the effectiveness of the product of the following development, which is the learning tools.

Table 7. ANCOVA test results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6255.515a	2	3127.757	39.130	.000
Intercept	5813.468	1	5813.468	72.729	.000
Metacognitive	625.763	1	625.763	7.829	.006
Creative thinking	1427.033	1	1427.033	17.853	.000
Error	7913.358	99	79.933		
Total	338875.000	102			
Corrected Total	14168.873	101			

R Squared = .441 (Adjusted R Squared = .430)

Table 8 shows the significant differences in the creative thinking skills and metacognitive ability pattern or gap between the students who completed the science learning tools using STEM (experimental groups) and those students who were taught using conventional learning resources (control groups). The effectiveness of increasing metacognitive abilities and creative thinking skills is shown in Table 8.

Table 8. N-gain of metacognitive ability and creative thinking skills scores in the pretest and posttest

Aspects	Groups	N-gain	Category
Metacognitive	Exp.	0.45	Medium-high
	Ctrl.	0.18	Low
Creative thinking	Exp.	0.46	Medium-high
	Ctrl.	0.28	Medium-low

The effectiveness of the improvement in the metacognitive ability and creative thinking skills score of the experimental group was confirmed to be higher than the control group. This is because students became more accustomed to working with the scientific method to think creatively and without difficulty, probing and solving the problems according to the stages: define, learn, plan, try, test, and decide. The detailed perspectives from each indicator of metacognitive ability according to Schraw and Dennison (1994) due to the N-gain scores of the two groups are shown in Table 9, while Table 10 shows each creative thinking skills indicator.

Table 9. N-gain score on each indicator of metacognitive ability of students in the pretest and posttest

Indicator	N-gain			
	Experimental	Category	Control	Category
Declarative knowledge	0.45	Medium-high	0.22	Low
Procedural knowledge	0.49	Medium-high	0.15	Low
Conditional knowledge	0.51	Medium-high	0.25	Low
Planning	0.42	Medium-high	0.28	Medium-low
Information management strategies	0.36	Medium-low	0.14	Low
Monitoring	0.45	Medium-high	0.28	Medium-low
Debugging strategies	0.45	Medium-high	0.12	Low
Evaluation	0.47	Medium-high	0.13	Low

The experimental group had the upper medium dominant N-gain score, while the control group was dominated by the low N-gain score. From Table 8 to Table 10, the level of improvement in the mean value before and after the treatment in the two groups of students was different. Thus, learning the inheritance of living things through STEM in online learning has a medium increasing effect on metacognitive ability and creative thinking skills, as demonstrated by the students in the experimental group.

Table 10. N-gain score on each indicator of creative thinking skills of students in the pretest and posttest

Indicator	N-gain			
	Experimental	Category	Control	Category
Fluency	0.50	Medium-high	0.27	Medium-low
Flexibility	0.44	Medium-high	0.31	Medium-low
Originality	0.43	Medium-high	0.31	Medium-low
Elaboration	0.46	Medium-high	0.25	Medium-low

There are five main characteristics of STEM learning material inheritance of living traits that become a reference in the development of learning tools. The five characteristics are: (1) improving metacognitive abilities and creative thinking skills; (2) based on concrete problems; (3) STEM learning; (4) student-centred; and (5) using authentic judgments. These five characteristics are also adjusted to the 2013 curriculum that has since been applied in ninth grade, so that the learning tools can be more easily implemented at the junior high school level in Indonesia.

Metacognitive ability relates to thinking about their ability to accurately use certain strategies. Therefore learners can be taught using strategies that assess their understanding, calculate how much time it takes to learn something, and choose an effective plan for learning or solving problems (Dwyer et al., 2014; Harrison & Vallin, 2017; Kusuma et al., 2017). Practising these strategies will help students improve their higher-order thinking skills. Students with high metacognitive abilities will have a high level of thinking (Miharja et al., 2019; Yusnaeni et al., 2017). By completing or training with activities that encourage creative thinking, arguments, and independent ideas can be drawn as well as the ability to elaborate between fields of science and integrate them with contextual aspects (Suryawati & Osman, 2018; Teo et al., 2021). In the process, it will train students to know the intellectual aspects of themselves. The two aspects, namely metacognitive ability and creative thinking skills, support each other regarding the activities carried out to support the high-level thinking of students. (Shukri et al., 2020; Yusnaeni et al., 2017; Zulkarnaen et al., 2017) identified the influence of metacognitive strategies on the higher-level thinking skills of students, including creative thinking. The activity was carried out to raise many questions or answers and build and develop unique ideas in this study provided a problem and asked students to find solutions with activities to design, compile, and simulate protein synthesis processes, monohybrid and dihybrid cross problems, and predict the results of plant and animal breeding offspring with button crosses.

The context of concrete problems is presented to learners as a challenge to stimulate their thinking ability. The concrete problem chosen in the preparation of this learning design is the Aglaonema plant, considering the trendiness of the topic since the beginning of the study. The role of the teacher is to facilitate and provide space for students to think, provide freedom to take initiative in the problem-solving process, elaborate thinking, and diagnosis of difficulties. This is in accordance with (Tan et al., 2019; Teo et al., 2021), who stated that the development of high-level thinking can be obtained when a person encounters unusual problems, uncertainties, questions, and dilemmas.

STEM can place students at the centre of the learning process and plays an active role in solving concrete cross-field problems cooperatively so that students can gain a deep understanding of the content they learn (Reeve, 2013). In the context of using STEM learning as a teaching and learning model, learners are placed as learning subjects, which means that learners have more responsibility in determining the learning atmosphere and model. Every learner is encouraged to be actively involved in the teaching and learning process. This also applies to distance learning. One of the factors that greatly determines the success of distance learning is the understanding of the distance learning process and its structure (Ahied et al., 2020). This finding corroborates the results by Bezuidenhout (2019), the characteristics of flexible distance learning can be utilised to provide greater opportunities for learners to learn more deeply because they can adjust their time according to their needs. Long-duration online learning such as classroom learning needs to be avoided because it will cause fatigue and physical disturbances caused by the use of electronic devices. Group discussions are one of the key components of project-based learning. This follows the findings of Kuo et al (2015), who demonstrated that group discussion activities have an important role in the success of the project. However, distance learning requires the help of technology. Therefore, mastery of various digital platforms supporting the discussion process is one of the crucial factors. Frolova et al (2021); Lewin and McNicol (2015) stated that good digital literacy is a must in achieving learning success, which empowers higher-order thinking skills and discussions such as project-based learning.

In the experimental class, the use of STEM-based learning generated positive results for all indicators of improving metacognitive abilities. The abilities of students before STEM learning were low or very low. After STEM learning was applied, an increase in the metacognitive ability of learners was observed. The highest increase was in the conditional knowledge indicator with a difference of 42. Conditional knowledge is the knowledge of when and why we use certain learning strategies (Schraw & Dennison, 1994).

The preparation of learning scenarios by exposing students to a problem will stimulate them to think about how to overcome the problem. Problem-solving-based learning can train and improve the metacognitive abilities of students. In accordance with Purwaningsih et al. (2020), problem-solving activities are an ideal way to improve metacognitive strategies, as a good problem solver. The STEM learning stage in this study improved the metacognitive ability of students. Students were guided to: 1) identify and formulate the problem at hand (define), 2) find solutions with various information (learn), 3) design and compile props to solve problems (plan, try); and then 4) simulate props arranged based on the concept of trait inheritance material (test, decide). Students faced actual problems, such as with Aglaonema plants, crossing two Aglaonema plants of different colours/types, and predicting the offspring produced by the two Aglaonema plants. Identifying and formulating problems can train the declarative knowledge of learners. According to Schraw and Dennison (1994), declarative knowledge is the knowledge of the abilities possessed by oneself. Meanwhile, information-seeking activities for problem-solving solutions will train procedural knowledge, conditional knowledge, planning skills, and information management skills. Designing and compiling teaching aids is carried out to train declarative knowledge, planning, information management, monitoring, error correction strategies, and evaluation, similar to simulating props.

The highest increase in metacognitive ability is in the conditional knowledge indicator with a difference of 42. Meanwhile, the indicator of metacognitive ability with the lowest category of increase, namely the lower medium, is the information management system (information management system) with a difference between pretest and posttest scores of 28. Information management sorts the activities or strategies used to process information more efficiently (Schraw & Dennison, 1994), and has the lowest increase. In accordance with the video observations of the results, students do not elaborate knowledge and information from various literature correctly when writing answers to questions on problems and during simulations or discussions. Meanwhile, in the control classes, there is an increase in the score of each indicator of metacognitive ability. However, the difference between pretests and posttest is not too large so that the category remains the same between the pre-test and posttest, that is, the low category, except for information management strategies (IMS), which experienced the largest increase of 22. From the description, the metacognitive ability of students who used STEM-based learning tools is better when compared to the control classes. The use of STEM models can improve metacognitive ability (Mariano et al., 2021; Santangelo et al., 2021). This is reinforced by the results of the independent t-test as a hypothesis that shows that the experimental class has a better metacognitive ability value compared to the control class.

Metacognitive abilities that increase with the use of developed learning tools are not the ultimate goal, yet are expected to facilitate the learning process. This is in line with the results of Fauzi and Sa'diyah (2019), who stated that good metacognitive abilities will make it easier for students to follow the learning process. Learning in this case is interpreted as the ability to understand new material.

In addition to metacognitive abilities, this STEM-based science learning tool is also expected to improve the creative thinking skills of students. The results of this n-gain score show that STEM-based learning tools are better at improving creative thinking abilities compared to the control classes, which is in line with the results of (Shukri et al., 2020). Their study revealed that STEM-based learning can improve the creative thinking skills of students (Honeck et al., 2016; Mayasari et al., 2016; Ndiung et al., 2021; Yusnaeni et al., 2017). The indicators of creative thinking skills observed in this study consist of fluency, flexibility, originality, and elaboration. In the experimental class, the use of STEM-based learning gave positive results in improving creative thinking skills. Improvements occurred in all indicators of creative

thinking skills. Students' abilities before STEM learning were at a low level, and increase after STEM learning was applied, increasing the creative thinking skills of the students. The highest increase occurred in the fluency indicator with a score difference of n-gain 35. Fluency relates to how learners come up with many ideas, answers, problem or question-solving, and ways or suggestions to do things. The STEM model has several main stages that are relevant for learners and able to increase the motivation and interest of learners to complete tasks related to higher-level thinking (Sutaphan & Yuenyong, 2019). The STEM model stage in this study refers to the engineering design process (EDP) stage, which trains the ability to solve a problem (problem-solving) in a real-world context (English, 2016; Struyf et al., 2019; Teo et al., 2021). All stages in the EDP can train students to analyse problems or challenges, exchange ideas related to solutions, formulate the best solution, follow up on the chosen solution, and determine the final decision on the best solution after the design and testing stage. According to English (2016); Groshans et al (2019); and Tan et al (2019), there are several benefits of using STEM in education, namely, honing critical and creative thinking, logical, innovative, and productive skills; instilling the spirit of cooperation in solving problems; introducing the perspective of the working world and preparing for it; using technology to create and communicate innovative solutions; and a medium to cultivate the ability to find problems and solve problems. In addition, STEM also plays a role in addressing the gender gap (Groshans et al., 2019), improving teacher preparation in teaching (Ryu et al., 2019; Yıldırım, 2022), overcoming gaps in success or achievement between learners (English, 2016), making subjects more meaningful for students (Pluta et al., 2013), seeing the relationship between subjects and integrating different methods and analytical frameworks of various disciplines in studying a theme, issue, question, or topic (Tan et al., 2019; Teo et al., 2021).
Learning with STEM models requires both basic skills and the mastery of specific skills in making products (Yusnaeni et al., 2017). The basic skills that learners need to have to learn with stem models are: reading, writing, listening, speaking, and basic numeracy (Yusnaeni et al., 2017). The process of identifying problems and making products also requires thinking skills (Ndiung et al., 2021; Pressman, 2019) that students need to have, including: thinking creatively, solving problems, making decisions, creating ideas, reasoning, and knowing how to learn. Persistence and the ability to work together are also needed in completing projects (Hernawati et al., 2019; Young et al., 2013).

Conclusion

The treatment given to students was s science learning process with STEM-based online learning. Students in the two groups were given the same test (pretest and posttest). The results of this study indicated: 1) a significant difference between the posttest scores of metacognitive abilities and creative thinking skills of the students in each group with a significance value = .006 and .000, respectively; 2) the average n-gain of metacognitive abilities and creative thinking of the experimental group was higher. The development of natural science learning devices of the inheritance of living things using STEM-based online learning was effective in enhancing and improving thinking patterns as metacognitive and creative thinking learners.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding this paper.

Author Contributions

R. Wilis: Methodology; Writing ─ original draft, Writing ─ review and editing. **B. A. Prayitno:** Data analysis; Writing ─ review and editing. **W. Sunarno**: Writing ─ review and editing. **S. Anjirawaroj:** Writing ─ review and editing.

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