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Evoking 21st-Century Skills: Developing Instrument of Critical Thinking Skills and Mastery of Ecosystem Concepts

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Abstract: Instrument is one of the supports of learning success. Assessment of student knowledge will encourage students to get better grades and will have an impact on increasing student knowledge. This study aims to develop the instruments of critical thinking skills and the ecosystem concept mastery. The instruments produced were an essay test adopted from Facione and a multiple-choice test adopted from Anderson & Krathwohl. This research was conducted on September 2018 - October 2019 with 37 tenth-grade students as the sample. The research method used was the 4D model (Define, Design, Develop, and Disseminate), however this research did not do the disseminate stage due to the limitation of time. The results showed that the instruments are feasible with the results of expert validation of 81.03 and 85.00 respectively. Based on the results of the study, it can be concluded that the developed instruments could be used to measure the critical thinking skills and mastery of concepts. However, these tests must be developed further in large classes with more students.

INTRODUCTION

Education in some developed countries is getting more complex, resulting in new abstract knowledge. Widespread knowledge with presentations that are still abstract requires Indonesian students to have critical thinking skills which are skills demands in the 21st century (Prajoko et al., 2017; Ristanto et al., 2018; Teo, 2019). The attention of learning to critical thinking skills is also due to the development of technology that is developing very rapidly (Luthvitasari, N, Putra, N. M. D., & Linuwih, 2012; Pradana et al., 2017). Critical thinking is thinking logically which is focused on making decisions about what is believed and what will be done (Ennis, 1993). Critical thinking skills are cognitive strategies used in helping to effectively solve problems so that students need to be able to compete with changes and developments in the current information age (Ismail et al., 2018; Noviyanti et al., 2019), so students can use, understand, choose and sort the available information. Students who have critical thinking skills will be able to understand the world around them, improve performance, make wise decisions, and increase learning motivation (Ismirawati et al., 2020; Khasanah et al., 2019; Stobaugh, 2013) because people who think critically tend to think before they act and do not easily believe in something before they prove it themselves.

In studying a material, students are required to master the concepts and able to integrate them into everyday life, especially on ecosystem material. It is due

to the ecosystem material discusses the relationship between living things with the environment. The concept is an abstraction of the characteristics of something that facilitates understanding and communication between students and allows students to think (Ristanto et al., 2018; Rusilowati & Sopyan, 2012). Generally in the concept, some levels or levels are interconnected between one concept with another concept, so that simple concepts will support understanding of more complex concepts, so students can master the whole material (Pratiwi, 2016). For instance, by understanding ecosystem components that consist of biotic components (humans, animals, plants, and microorganisms) and abiotic components (water, air, soil, and light), it will make it easier for students to understand more complex materials such as the water cycle, carbon cycle, and others.

The ecosystem material requires students to understand the concept of ecosystems from the simplest to the most complex material. Likewise, critical thinking skills are needed by students to better understand the latest ecosystem material that is still abstract in its presentation. This requires the role of the teacher in creating opportunities for students to develop and improve critical thinking skills because critical thinking skills do not develop automatically (Fuad et al., 2016; Harjo et al., 2019; Istiyono et al., 2020; Permatasari et al., 2019) and students need instruction to improve their critical thinking (Arum & Roksa, 2011; Pascarella et al., 2012). The critical thinking skills and mastery of concepts can be improved by providing an assessment of students' learning outcomes using critical thinking skills indicators and concept mastery.

In the education process, teachers have to master the curriculum, learning process, and assessment (Santoso et al., 2011; Sumiyati, 2010). The teacher, as an evaluator, is required to be a good and honest assessor during the assessment. Assessment is a part of learning in determining the success or failure of learning (Permatasari et al., 2019). Assessment acts as a guide to the process assessment program, learning progress, and students' learning outcomes in achieving the expected competencies.

This ability is needed to determine the level of mastery of students towards the material, whether or not learning objectives have been set in the curriculum and to improve and enhance the learning process (Syarif & Kuswanto, 2019). This is in line with (Soleymanzadeh & Gholami, 2014). One way to increase students' knowledge is by holding a more emphasized assessment. Therefore, assessment is very important in learning because it can provide feedback for teachers and students, motivate students in improving achievement, and can influence student learning behavior to be more focused.

Assessment will be valid and reliable if the questions or instruments are constructed by considering the real-life condition (Saputri et al., 2020). Assessment instruments in learning are an integral part of the assessment process which consists of tests and assessment systems. The quality of the assessment instruments will directly affect the accuracy of achieving results. Therefore, instruments that can train, develop, and familiarize students in critical thinking are needed and are equipped with appropriate assessment rubrics so that students are accustomed to thinking critically in solving various problems. Four good instrument requirements include, valid, reliable, practical, economical. Instruments must be based on learning objectives so that students are ready to answer (Shermis, 2014). A good instrument has several steps for composing, among others: 1) referring to the syllabus, 2) arranging the questions grid, 3) arranging questions, 4)

conducting test trials, 5) making scoring guidelines (Kadir, 2015).

The results of interviews with 3 biology teachers related to learning instruments at Al-Hasra High School showed that teachers have not measured critical thinking skills and mastery of students' concepts. This is because the instruments used are only measuring the aspects of remembering (C1) and understanding (C2). Teachers do not have guidelines or instructions for developing critical thinking assessment instruments. To assess students' achievement on cognitive aspects, teachers usually take ecosystem questions from various biology textbooks or a collection of ecosystem questions. This has an impact on the quality of the instrument, namely the number of questions for each indicator is uneven so that the ecosystem instruments do not cover all ecosystem material. So that teachers also do not know for certain about ecosystem indicators that are most difficult for students to understand, whereas mastery of ecosystem material is very supportive of further material such as environmental pollution. Students and teachers need evaluation tools that are relevant to curriculum demands.

This is in line with the preliminary study conducted by (Dharmawati et al., 2016). To overcome this, an instrument of ecosystem material assessment is needed that meets the reference to the development of critical thinking skills tests and mastery of correct concepts. Students' critical thinking skills can be measured using original multiple-choice tests, skills tests, and essay tests (Ennis, 1993). The test that will be developed in this research is an essay test to measure critical thinking skills and a multiple-choice test to measure the mastery of the concept of the ecosystem.

The development of the essay instrument consists of several activities, namely, the preparation of the questions lattice, writing the formulation of questions, the preparation of answer keys, and scoring techniques. Compared to multiple-choice tests, essays are relatively more difficult (Forawi, 2016) and the number of essay questions is less than multiple choice questions because many things must be explained or expressed in essay questions. The assessment of essay tests is a very complex cognitive task and involves many conclusions, choices, and preferences for each level or weighting based on consideration of the scope or difficulty level of the item items. The teacher will also need a long time to analyze student answers (Zubaidah et al., 2015). Not only making questions that are appropriate to what will be measured, but also how to give the right score, giving further feedback to students (McNamara et al., 2015). Whereas in the multiple-choice problem there is only one correct answer. Giving a score on multiple-choice questions can be done with a dichotomous score that is a score of 1 for the correct answer and a score of 0 for the wrong answer. This certainly will facilitate teachers in evaluating students' answers (Bhakti et al., 2017; Little et al., 2012; Tan et al., 2008; Widiyatmoko & Shimizu, 2018), but the multiple-choice questions do not always indicate student understanding of certain concepts.

Before conducting an assessment, questions need to be validated to find out whether the questions are suitable for assessing critical thinking skills and mastery of students' concepts. The test is considered eligible if it meets the validity and reliability requirements (Baldinger & Lai, 2019). Therefore, we need a valid and reliable assessment instrument to be developed. The critical thinking skills instrument developed by (Putri et al., 2019) refers to the Ennis indicator aspect with the type of R & D used referring to the Sugiono development model. The concept mastery instrument developed by (Sukma et al., 2017) uses the ADDIE model, but only reaches the Develop

stage. Whereas in this study, the instrument of critical thinking skills refers to the Facione indicator with the 4D development model (Define, Design, Develop, and Disseminate) on ecosystem material. This research and development aim to produce an instrument of critical thinking skills and mastery of ecosystem concept that valid and reliable in class X, so that it can be used as an alternative in measuring, training, and improving critical thinking skills and mastering the learner's ecosystem concept.

METHOD

The method used in this research is research and development (R & D). This study was adapted from (Thiagarajan et al., 1974) development model used was the 4D development model (Define, Design, Develop, and Disseminate). However, this study only reached the Develop stage.

The population in this study were all tenth-grade students of Al-Hasra High School with a sample of 37 students in the 2018/2019 academic year. The following is the explanation of each stage of the development model.

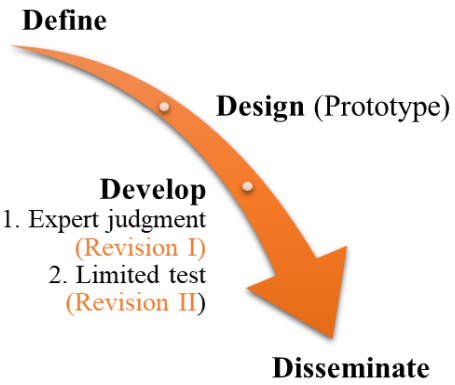


Figure 1. 4D Model

Define Stage

This stage aims to determine learning requirements which consist of the following steps: a) front-end analysis, b) student analysis, c) task analysis, and d) material concept analysis.

Design Stage

This stage is the initial planning or design stages such as making an outline, determining the indicators to be measured, and developing an essay instrument of critical thinking skills (Facione, 2011) and multiple-choice instruments of mastery concepts (Anderson et al., 2002).

Table 1. Indicators of Critical Thinking Skills and Concept Mastery of Ecosystem

Variable	Indicator	Question Description
Critical Thinking Skills	Interpretation	Interpreting and grouping food chains into food webs
	Analysis	Analyzing interactions between organisms
	Conclusion	Drawing conclusions based on the food chain in the paddy ecosystem
	Evaluation	Evaluating statements or opinions about the causes of energy loss in each energy pyramid
	Explanation	Explaining the nitrogen cycle
	Self-regulation	Responding to problems about forest ecosystems that are increasingly damaged
Mastery Concept	Remembering	Remembering the concept of the components of the ecosystem
	Understanding	Understanding and classifying types of interactions
	Applying	Eradicating pests and increasing food production
	Analyzing	Criticizing the impact of increasing levels of carbon dioxide gas in the atmosphere from motor vehicles, industries, and settlements
	Evaluating	Evaluating the causes of algae growth and other pests to become fertile in slow-flowing rivers
	Creating	Developing and formulating several organisms to form a food chain

Develop Stage

This stage consists of the assessment of instruments by the validator and empirical validation of students. The following is the order of development.

a. Expert judgment

The expert (validator) in developing this instrument was Doctorate lecturers of Biology Education who were the experts of critical thinking skills, mastery of concepts, ecosystem material, and environment.

b. Development test instrument

The instrument was validated by experts (construct and content validities). Then, the instrument was tested on a research sample that consisted of 37 students. The test results were used as a basis for determining the empirical validity and reliability of critical thinking skills tests and the ecosystem concept mastery.

RESULT AND DISCUSSION

Define

a. The front-end analysis

This analysis was conducted on biology teachers who taught in the tenth-grade in the form of unstructured interviews. Based on interviews, the teacher said that the learning models often used were presentations, discussions, and assignments. Students used to work on questions in the form of essays. The teacher had never accustomed the students to answer higher-order thinking questions.

b. Student analysis

Based on interviews conducted to the teachers, the students' critical thinking skills and mastery of concepts in learning were low. This was proved by the results of the preliminary test. The results can be seen in Figure 2.

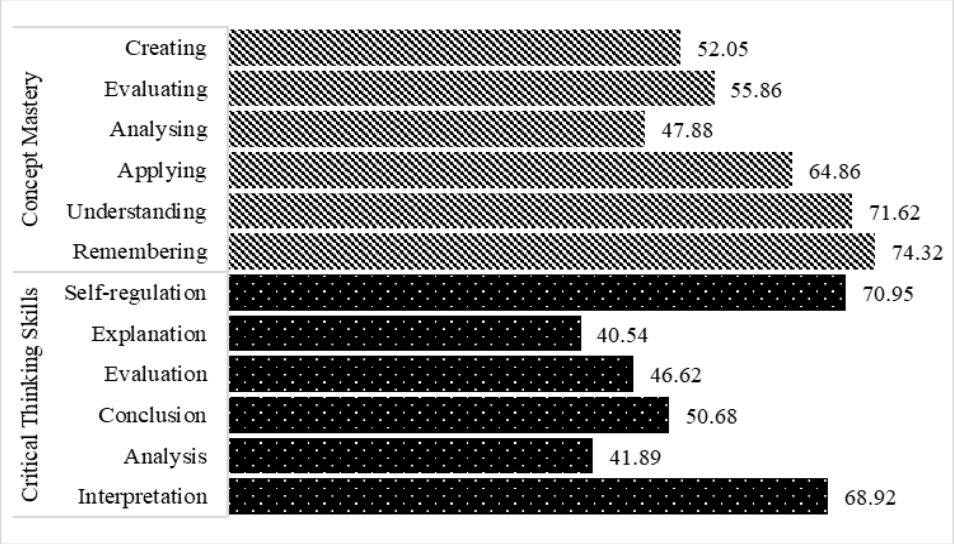


Figure 2. Average Student Answers from Indicators of Critical Thinking Skills and the Ecosystem Concept Mastery

There 26 questions of ecosystem material which consisted of 20 multiple choice items and 6 essay questions. These questions had been validated by expert lecturers and were relevant to the indicators of critical thinking skills and mastery of concepts.

The average result of students' critical thinking skills was 53.15 and the concept mastery was 61.10. These scores mean that the students were in a low category. For critical thinking skills, only 19 % of students passed while 35 % of the students mastered the concept. In the instruments, there were 2 common aspects, namely analysis, and evaluation. The results of the analysis and evaluation of the ecosystem concept mastery were higher than critical thinking skills.

c. Task analysis

Based on the initial and final analysis and analysis of students, an effort to improve the critical thinking skills and concept mastery was needed. One of them is by giving a higher-order thinking instrument. Through the higher-order thinking instrument, the students could be directed to think critically and make them easier to deal with more complex problems (Ichsan et al., 2020; Tajudin & Chinnappan, 2016). Questions that contain all learning material will make it easier for students to master the concept of the ecosystem.

d. Content concept analysis

The results of the analysis were obtained from competency standards and basic competencies.

Design

Design stage starts by determines making a phase outline and determines the indicators.

Table 2. Instrument Design and Indicator Determination of Critical Thinking Skills

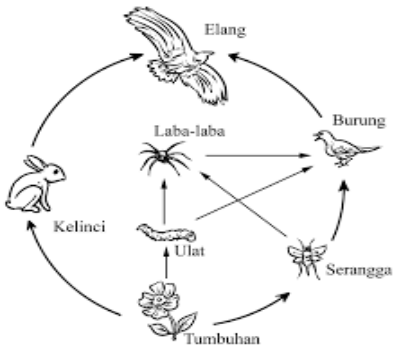
No	Indicator	Question	Answer
1	Interpretation	There is always a relationship of interdependence between living things, also between living things and their environment. One form of interdependence is the eating and eating relationship called the food chain. How many food chains are formed? Write down the food chain! 	Food webs are a collection of several food chains in an ecosystem and are interconnected. In the food webs consist of 5 food chains, namely: 1) plant→insect→bird→eagle 2) plant→insect→spider→bird→eagle 3) plant→caterpillar→bird→ eagle 4) plant→caterpillar→spider→ bird→eagle 5) plant→rabbit →eagle

Table 3. Design and Determination Indicators of Mastery of Ecosystem Concepts

Indicator	Cognitive Domains	Question	No	Answer Key
Identifying ecosystem components	C2	Organisms that act as producers in the aquatic ecosystem are …. a. Bacteria b. Phytoplankton c. Plankton d. Zooplankton e. All answers are wrong	1	B

Designing critical thinking skills instruments and mastery of concepts differ from each other because they had different indicators and types of questions, namely essays for critical thinking skills and multiple-choice for mastering the concepts. The ecosystem has a wide scope of material. If all questions were made in the form of essays, the instrument will not cover all ecosystem material. If all questions were made in the form of multiple choices, it will not sharpen or accustom students to think critically.

The developed critical thinking skills instrument consisted of 15 essay questions while the instrument for the ecosystem concept mastery consisted of 60 multiple-choice questions. All the items in the instruments had been tested for their validity and reliability so that they can represent all indicators of critical thinking skills and mastery of the concept of ecosystems.

The following is the sample question of measuring critical thinking skills and the sample question measuring the mastery of ecosystem concepts.

Question of measuring critical thinking skills. *In the flower garden area, there are several types of insects including bees, grasshoppers, butterflies, and whitefly. Which insects must be terminated in order not to damage the flowers and which insects must be maintained? Explain your reason!*
Question measuring the mastery of ecosystem concepts.

Biotic components that make up the pool ecosystem include ….

a. Water, mist, plankton, aquatic plants
b. Snails, oxygen, sunlight
c. Plankton, moss, snails, fish
d. Bacteria, green algae, snails, temperature
e. Mineral salt, temperature, water, oxygen

Figure 3. Sample Question

Develop

a. Expert Validation

The validators in this study were two Biology Doctorate lecturers who were experts in the areas of critical thinking skills, mastery of concepts, and ecosystem material. The validation process refers to indicators of Critical Thinking Skills and Mastery of Ecosystem Concepts, Syllabus, and Learning Implementation Plans (RPP). Table 4 provides comments and suggestions from the validator to improve the instrument.

Table 4. Comments and Suggestions Validator

	Critical Thinking Skills
1	Tables that have been made, better presented in the form of graphs/histograms.
2	Questions about the aspects of conclusions better present the data, the questions lead to the conclusions/meaning of the data.
3	Ladybugs also have their ecological functions, so it is not appropriate, it is better to present data on insects such as whitefly, borer, moth, etc.
4	The answer to the cause of a landslide must be more detailed, there is a root function that holds soil particles.
5	The question 'which one belongs to consumers I, II, III' is more appropriate in the aspect of analysis, not inference.
6	Decide which picture A and picture B.
	Mastery of Ecosystem Concepts
1	Learn how to create a question item for each cognitive level from the references that have been sent.
2	Questions marked in red have not been HOTS (C4, C5, C6).
3	This question is still in aspect C1. Living things that can make their food because they contain chlorophyll and can carry out photosynthesis are called living things .... a. Heterotrophs b. Microscopic c. Saprofit d. Unicellular e. Autotroph

Then the validation process took 2 months. The validator provided comments and suggestions regarding the accuracy of the questions, the presentation of the questions, the concept of ecosystems, the suitability of critical thinking skills

indicators and the mastery of the concept of the questions, and the suitability of the ecosystem material indicators for the questions.

The developed instruments were assessed by the validator. The aspects assessed consisted of the appropriateness of assessment techniques, instrument completeness, the suitability of contents, question construction, and language. Then, an average score was produced to determine the instrument's suitability as can be seen in Table 5.

Table 5. Expert Validator Scores for Critical Thinking Skills and Mastery of Ecosystem Concepts

Component	Type of Problem	Validator	Percentage of appropriateness	Total Average	Conclusions
Critical Thinking Skills	Essay	Validator I	77.05	81.03	Appropriate
		Validator II	85.00		
Ecosystem Concepts Mastery	Multiple choice	Validator I	82.50	85.00	Very Appropriate
		Validator II	87.50		

Based on Table 5 it can be concluded that the instruments developed are appropriate or feasible to measure critical thinking skills and mastery of the ecosystem concepts of students because they reach an average of 81.03 and 85.00. Therefore, empirical validation can then be done.

b. Empirical validation and reliability results

The validity of the developed instruments was investigated using Pearson product moments. The developed instrument has met the valid criteria because the $r_{critical}$ was 0.325. Using Alpha Cronbach, the reliability of the instrument was 0.855 with the reliable criterion of questions (Arikunto, 2013). The interpretation of reliability can be determined if it has $r_{11} \geq 0.6$. This shows that the instruments that have been developed have high reliability.

Using the Kuder Richardson-20 (KR-20), the instrument reliability was 0.739. This showed that the instrument had high reliability.

CONCLUSION

Based on the results of the study, it can be concluded that the developed instruments could be used to measure the critical thinking skills and mastery of concepts. The developed essay questions are expected to help the teacher in directing students to think critically because they are required to answer questions in complex and detailed manners. Similarly, the multiple-choice questions can facilitate the students in mastering the concept of the ecosystem because there is only one correct answer. The wrong answer or option will make students want to know more about the concept. This curiosity will direct students toward mastering the concept of the ecosystem. The ecosystem material requires instruments that are more than one form of test so that the instruments could cover all ecosystem material and can hone students' critical thinking.

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Apendix 1. The Results of Validating Students' Critical Thinking Skills

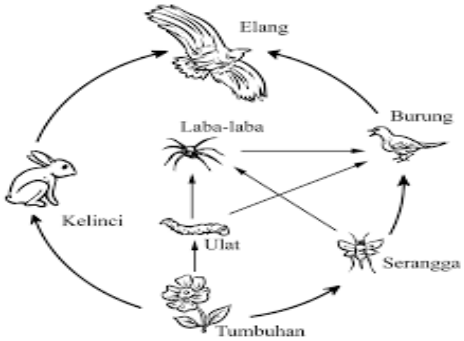
No	r_{count}	r_{table}	Conclusion
1	0.628	0.325	Valid
2	0.094	0.325	Invalid
3	0.243	0.325	Invalid
4	0.703	0.325	Valid
5	0.757	0.325	Valid
6	0.662	0.325	Valid
7	0.55	0.325	Valid
8	0.665	0.325	Valid
9	0.268	0.325	Invalid
10	0.517	0.325	Valid
11	0.366	0.325	Valid
12	0.256	0.325	Invalid
13	0.665	0.325	Valid
14	0.514	0.325	Valid
15	0.252	0.325	Invalid

Note: Assessment using *Pearson product moment* with criteria:
Valid, if $r_{count} > r_{table}$; Not Valid, if $r_{count} < r_{table}$

Apendix 2. The Results of the Calculation of the Validity of the Test Items

Criteria for Validity	Questions Number	Amount
Valid	1, 3, 4, 6, 7, 9, 12, 13, 14, 15, 17, 18, 19, 20, 22, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 37, 39, 41, 44, 45, 47, 49, 51, 52, 53, 55, 58	37
Invalid	2, 5, 8, 10, 11, 16, 21, 23, 24, 31, 36, 38, 40, 42, 43, 46, 48, 50, 54, 56, 57, 59, 60	23

Appendix 3. Development of Instruments for Ecosystem Critical Thinking Skills

No	Indicator	Subchapter	Question
1	Interpretation	Energy Flow	In nature there is always a relationship of interdependence between living things, also between living things and their environment. One form of interdependence is the eating and eating relationship called the food chain. How many food chains are formed? Write down the food chain! 
2	Analysis	Ecosystem Component	An experiment was carried out using two sand dunes. Sand dune I was planted with grass at a certain time while sand dune II was not given grass. When both sand dunes are doused with water, sand dune I is falling apart while sand

<table>
<tr><th>No</th><th>Indicator</th><th>Subchapter</th><th>Question</th></tr>
<tr><td>3</td><td>Conclusion</td><td>Ecosystem Component</td><td>dune II is still intact. From these experiments, explain the causes of landslides?
Following are the results of an experiment of a group of students who planted two similar tomato plants on different soil media, namely clay and sand.
<table><tr><td rowspan="2">Month</td><td colspan="2">Lots of Fruit</td></tr><tr><td>Clay</td><td>Sand</td></tr><tr><td>1</td><td>9</td><td>3</td></tr><tr><td>2</td><td>17</td><td>8</td></tr><tr><td>3</td><td>25</td><td>9</td></tr></table>From this data, how do tomato growths in clay compare to sand?</td></tr>
<tr><td>4</td><td>Evaluation</td><td>Energy Flow</td><td>If somewhere there are grass populations, zebra populations, rabbit populations, mouse deer populations, buffalo populations, deer populations, and grasshopper populations. So that all these organisms are not extinct, which population should be increased? Explain your reason!</td></tr>
<tr><td>5</td><td>Explanation</td><td>Interaction in Ecosystems</td><td>Consider the following organism interactions!
Ecosystems are composed of interacting components. Explain the kind of interaction between the components that occur in Figures A and B!
   </td></tr>
<tr><td>6</td><td>Self-regulation</td><td>Biogeochemical Cycle</td><td>The increase in human population is one factor that can disrupt the balance of the ecosystem. Human efforts to meet their needs sometimes have an impact on the destruction of an ecosystem. One of the human activities that have a negative impact on ecosystems is mining. Mining activities by clearing forest land cause forests to no longer be overgrown with plants and become damaged. Not to mention the pollution arising from mining activities also damage the forest ecosystem. Though forests are a source of oxygen for humans and other animals. As a student, what things can you do in response to these problems?</td></tr>
</table>

Appendix 4. Development of Ecosystem Concept Mastery Instruments

<table>
<tr><th>No</th><th>Indicator</th><th>Question</th></tr>
<tr><td>1</td><td>Remembering (C1)</td><td>Based on life categories in aquatic ecosystems, animals that actively swim without being affected by water currents are called ...
a. Nekton b. Plankton c. Neuston d. Bentos e. Perifiton</td></tr>
<tr><td>2</td><td>Understanding (C2)</td><td>Look at the picture below!
  </td></tr>
</table>

No	Indicator	Question
		The form of interaction that occurs between animals in the picture above is .... a. Parasitism, because if a buffalo dies, the starlings will also die b. Commensalism, because starlings benefit while buffalo does not affect anything c. Mutualism, because both animals both benefit and need each othe d. Protocooperation, because the two animals both benefit, but it is not mandatory e. There is no interaction, because there is no relationship between the two animals
3	Applying (C3)	In ecosystems the following food chains occur! Rice → Sparrow → Eagle → Tiger → Decomposer The statement that shows the role of the food chain is .... a. Rice as first-level consumer b. Sparrow as a level I consumer c. Eagle as level III consumer d. Tiger as level II consumer e. Decomposer as a manufacturer
4	Analyzing (C4)	In one area it was found that tigers and lions lived in adjacent habitats. In that place also found deer. If analyzed on the interactions that occur between living things, then the interactions that occur in tigers and lions are ... a. Mutualism Symbiosis b. Intraspesific Competition c. Interspesific Competition d. Commensalism Symbiosis e. Predation
5	Evaluating (C5)	These are the sources of CO_2 on the air, *except*…. a. Respiration human and animal b. Transpiraion human and animal c. Vulkanic Eruption d. Coal Combustion e. Crude Oil Combustion
6	Creating (C6)	Some students conduct environmental research in urban areas. Here are the observations obtained: 1. Houses are densely populated 2. Roads and yards are not maintained 3. Garbage disposal in any place 4. Poor drainage system Efforts that can be made to improve the environment are ... a. Make highways b. Burning rubbish c. Move all residents to another area d. Establish new settlements e. Rearrange the environment so it is livable