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Development of integrated STEM education learning units to access students' systems thinking abilities

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ABSTRACT

This research aims to develop a Biology Science learning unit based on Science, Technology, Engineering, and Mathematics (STEM) that is valid, practical and effective in accessing students' system thinking skills. The topic ,of the Biology Science learning unit is the water cycle. The development used the ADDIE model research and development for the research method. The research subjects were 32 grade VII students from State Junior High School in Jember. The research findings showed that the average validation result of STEM-based learning units was 95.3%. These can be considered valid. The Paired Sample Test result is <0.001 or less than 0.05, so there is a significant difference between the pretest and post-test results. The average effectiveness test score is 0.73, higher than the typical gain test score, and the results include the high criteria. Finally, the average percentage of practicality tests is in the high category of 89%. System thinking skills are needed in learning activities to describe and solve a problem using integrated STEM education. Therefore, the STEM-based learning unit on the water cycle topic could be applied in the learning process to acquire students' system thinking abilities in the Biology Science learning unit. Finally, assessing student responses during the learning using this learning unit is pivotal for future research.

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INTRODUCTION

STEM education is a learning innovation as needed skills in the 21st century. Farwati et al. (2017) stated that implementing STEM education in learning activities can encourage students to use technology in designing, developing, and improving cognitive operations and applying knowledge. One of the applications of STEM education in learning is an integrated STEM education approach. Suratno et al. (2020) state that an integrated STEM education potentially helps students gain good academic abilities, such as problem-solving, collaboration, innovation, and creativity. The expansion of integrated STEM education comes after being implemented in learning activities believed to improve knowledge skills, apply knowledge in problem-solving, and inspire students to create new things. One of the learning supports to achieve good academic abilities is to use quality learning units.

According to Nurdiana et al. (2021), learning units are teaching materials that can make it easier for teachers to learn the materials and how to teach them to students. Developing the sections of the learning units will help teachers facilitate students' understanding of the material, conduct analysis, and encourage students to acquire higher-order thinking skills. Research that develops integrated STEM education-based learning units on specific topics in junior high schools still needs to be completed. Wahono et al. (2018) have developed teaching materials based on a STEM approach encouraging students to engage with the world through activities such as identifying problems, gathering information to solve problems, considering solutions, and examining findings from an interdisciplinary perspective. Simarmata et al. (2020), in their book reveal that applying STEM for learning empowers students to design, develop and use technology to develop cognitive, manipulative, and affective skills and apply knowledge. On the other hand, other research states that developing system thinking skills through a logical approach and mastery of concepts can be an alternative strategy to maximize student performance in physiology learning (Nursani, 2014). However, these studies have yet to develop integrated STEM education learning units to access students' system thinking skills.

Systems thinking is holistic thinking about a problem. The ability to think of systems plays a crucial role in education (Kholil, 2018). The ability to think of systems becomes part of sustainable development efforts and STEM literacy and is one of the competencies needed in the 21st century (Rustaman, 2020; Wahono, Hariyadi, & Chang, 2022). Learning activities to describe and solve problems require a systematic mindset. One of the problems that can affect the current social and economic situation and require appropriate solutions is floods. Floods are one of the natural disasters that frequently occur almost every year in Indonesia. There are many causative factors. The phenomenon of floods at this time is one of the constant global changes that can affect the food market in the world. Flood disasters in Indonesia are a recurrent phenomenon and become a routine problem whenever there is high rainfall. Flooding can occur due to rainwater infiltration into watersheds and rainfall different from the river's ability to drain it into the sea.

Biology learning in natural sciences is a learning activity that interrelates science, technology, engineering, and mathematics. It is necessary for the learning devices with an appropriate approach. Education is supposed to facilitate students to be able to acquire student systems thinking. Therefore, innovations are needed in the form of learning units with a STEM approach. Based on this, researchers researched developing integrated STEM education learning units to access students' system thinking skills in flood phenomena.

METHOD

The type of research carried out here is development research (R&D) which aims to produce an integrated STEM education learning unit. This study used the ADDIE development model. This model has several stages (Analysis, Design, Development, Implementation, and Evaluation). This research was conducted in the Biology Education Study Program at the University of Jember with the participation of some grade VII students of a State Junior High School (SMPN 4) in Jember District in 2021/2022 as a product trial. This research involved two lecturers with minimum qualifications of master of education and one teacher of Biology Science from the same school as validators.

The data analysis technique selects data by sorting, grouping, and presenting information from qualitative data based on the ADDIE stage. Data analysis is also presented here with quantitative descriptive analysis based on validation tests using face and content validity with a 5-point Likert scale and construct validity based on literature studies. The assessment criteria for the learning units developed in this study can be seen in Table 1.

The researchers measured the effectiveness of learning units using pretest and posttest instruments. Then, the researchers measured the practicality of the learning units by providing a questionnaire instrument as feedback to find out whether the learning units developed here could work practically or not. The following is an example of a pretest/posttest problem *"What is the water cycle process that occurs if an area undergoes continuous deforestation?"*

Table 1. Criteria of Product Validity Assessment Score

Scores	Validity Criteria
85.01-100.00 %	Very valid
70.01-85.00 %	Quite valid
50.01-70.00 %	Less valid
01.00-50.00 %	Invalid

(Source: Fatmawati, 2016).

Before analyzing the effectiveness test in the integrated STEM education learning units, the researchers conducted a Paired Sample Test and a normal gain or N (gain) test. The quantitative criteria for the effectiveness of the learning units developed in this research can be seen in Table 2

Table 2. Product Effectiveness of N (gain) Score and Criteria

N-gain score	N-gain criteria
normalized gain ≥ 0,70	High
0,30 ≤ normalized gain < 0,70	Medium
normalized gain < 0,30	Low

(Source: Yulyatno *et al*., 2019).

Analysis of the practicality test of integrated STEM education learning units uses a 5-point Likert scale. The assessment criteria for learning units developed here can be seen in Table 3.

Table 3. Product Practical Assessment Score Criteria

Scores	Practicality criteria
76-100 %	High
56-75 %	Medium
40-55 %	Low
<40 %	Very Low

(Source: Fatmawati, 2016).

RESULTS AND DISCUSSION

Results

They are developing the education learning unit through five phases: analysis, design, development, implementation, and evaluation. The analysis stage contains material analysis activities, learning goals and learning objectives analysis, and task analysis. The materials selected for developing this learning unit is water cycle material using an integrated STEM approach (integrated STEM education). The analyzed water cycle materials include several subsections. These consist of the concept of the water cycle, various water cycles, problems in the water cycle (factors and impacts of the water cycle), flood disasters, and technology that can reduce disasters using an integrated STEM education approach. STEM education is a four-discipline approach (Science, Technology, Engineering, and Mathematics). It can train students to think at a higher level, one of which is the ability to think systems.

The design stage contains activities to compose a learning unit using integrated STEM education, research instruments, and learning tools. This water cycle material's integrated STEM education learning unit is intended for grade 7 junior high school. The learning unit consists of a learning unit cover, a preface, a table of contents, an introduction, material concepts, summaries, worksheets, RPP, and a bibliography. The development design results of integrated STEM education learning units are presented in Figure 1.

The development stage in this study contains product manufacturing activities, namely integrated STEM education learning units and product validation. This validation test aims to determine the validity of integrated STEM education learning units through a score obtained from experts of 95.3%. However, to achieve the perfection of the learning unit, the researchers made several minor revisions based on the suggestions of validators.

The implementation phase is the phase of conducting product trials. This phase determines whether the learning unit is effective and practical for accessing the student's system thinking skills. The researchers submitted a product trial with a limited-scale test of 32 students. The results in the implementation phase include pretest and posttest assessments and questionnaires of student responses to using learning units. The researchers analyze the obtained data to determine the effectiveness and practicality of the learning units developed.

The researchers carried out the evaluation stage at each phase of development. This stage is carried out from the analysis phase to the implementation phase by refining the learning unit products, learning tools, and learning activities in the classroom. The evaluation phase is the final stage of the learning unit development process. This phase aims to know that the learning unit product has been declared valid.

Figure 1. Integrated STEM Education Learning Units

Validity of The Integrated STEM Education Learning Units

The researchers validate three aspects of the product, including construct, face, and content validity. This study's construct validity results come from various literature. Table 4 describes the buildings or constructs that must appear on the instructional units developed. The researchers developed the items based on existing theories and literature starting from the cover page to the list of references. Table 5 shows the detailed result of the face and content validity from the experts.

Table 4. Results of Construct Validity

Elements of Learning Units	**Remarks**
Cover page (Azka *et al.*, 2019)	Contains in cover page provide context for use in product development. The title is "Integrated STEM-based learning unit (honing students' systems thinking skills)," and the topic of the water cycle and flood solutions.
Preface page (Azka *et al.*, 2019)	This preface page is a form of the author's gratitude for the preparation of the product and a thank you to the parties who have aided in making the product.
Introduction (Samsuddin, 2019)	The introduction page contains a general overview of aspects of the study in a paper.
Concepts of the material/content of the material (Syaifullah, 2019)	The breadth and depth of the content of a development product demonstrate the correctness of the content's scope. It seeks to be comprehended by students as users.
Summaries (Gunawan, 2017)	Summaries in the book generally contain the essence of learning materials.
Students' worksheets (Azka *et al.*, 2019).	Test questions are necessary to aid in student to comprehend the subject matter and to enable students to apply the knowledge to problems about the subject taught.
List of reference (Azka *et al.*, 2019).	The list of references shows the sources of material used in the product.

Table 5. Results of Face and Content Validity

No	Criteria	Expert (E) Validation Score		
		E 1	E 2	E 3
1.	Clarity of learning objectives	5	5	5
2.	Relevance of learning objectives to KI/KD/Curriculum	5	5	5
3.	Accuracy of making learning objectives from the reference of Basic Competencies	5	5	5
4.	Learning units used following the needs of teaching materials	5	4	5
5.	Visibility of STEM approach aspects (Science, Technology, Engineering, and Mathematics)	5	4	5
	a. Science inquiry			
	b. Mathematical thinking	5	4	4
	c. Technology literacy	5	5	5
	d. Engineering design	5	4	5
6.	Consistency of the systematics of the material description	5	4	5
7.	Contextuality and actuality of media in learning activities	4	5	4
8.	Learning unit framework:	4	5	5
	a. Description of the table of content			
	b. Description of instructions for the use of learning units	4	5	5
	c. Description of prerequisites in the introductory section of the learning unit	4	4	4
	d. Description of learning goals and learning objectives	5	5	5
	e. Description of the material	5	4	5
	f. Assignment	5	5	5
	g. List of reference	5	4	5
9.	Consistency in the use of fonts, spacing, and layouts.	5	4	5
10.	Proportional layout cover (text and image layout)	5	4	5
11.	Conformity of color proportions (color balance)	5	5	5
12.	Image display (image selection)	5	4	5
13.	Clarity of STEM learning unit titles	5	4	5
14.	The attractiveness of the cover design	5	5	5
15.	Synchronization between graphic, visual, and verbal illustrations	5	5	5
16.	Variations in the delivery of data information types	5	5	5
17.	Accuracy in the explanation of the material	5	4	5
18.	The attractiveness of the material in motivating users	5	5	5
19.	(breadth and depth) of the content of the material	5	5	5
20.	Coherent content of the material	5	4	5
21.	Factualization and actualization of the content of the material	4	4	4
22.	Clarity and adequacy of examples relating to the material	5	5	5
23.	Clarity and appropriateness of the relevance of the language used	5	4	5
24.	A comprehensive sequence of test questions presented to access systems thinking skills	5	5	5
25.	The level of difficulty of test questions according to the indicators of the ability to think systems	5	5	5
26.	A balance between the proportion of test questions and the content of the material	5	4	5
27.	Clarity of evaluation in providing problem-solving	5	5	5
28.	Clarity and accuracy of the learning unit summary	5	5	5
Total		180	168	181
Inter-rater agreement		95.3%		

Limited effectivity test

Figure 2 shows that students were learning with education learning units. The students fill out the pretest and posttest. Pretest and post-test results come from 32 students. These aim to determine the effectiveness of the learning units developed. The pretest and post-test results were analyzed using the paired sample t-test test presented in Table 6.

Table 6. Limited Scale Results of Systems Thinking Skills

	Paired Differences					**t**	**df**	**Sig.(2-tailed)**
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	**Upper**			
Pair 1 PRETEST - POSTTEST	-33.062	7.079	1.251	-35.615	-30.509	-26.417	31	<0.001

Based on the results of the paired sample T-Test, it shows the value of Sig. (2-tailed) is equal to <0.001 or less than 0.05, so there is a significant difference between the pretest and post-test results. Meanwhile, the results of the N (gain) test on a limited scale test had a score of 0.73 which showed that it was highly effective for acquiring students' systems thinking skills.

Figure 2. Students in learning activities

Limited practicality test

The practicality test of the learning unit is measured based on the value of the student's response to the use of the learning unit. This questionnaire aims to know the practicality of the learning unit developed after the students read and learn it. The questionnaire results of student responses to the learning unit show the results of 89% with a high category. It shows that using the learning unit to access students' systems thinking skills throughout learning activities can be claimed to be practical.

Discussion

The type of development research used in this study is the ADDIE development model. This development model comprises 5 phases (Analysis, Design, Development, Implementation and Evaluation). This development research resulted in a product in the form of an integrated STEM education learning unit to access students' system thinking skills on water cycle materials. Material analysis activities aim to achieve the competencies desired by students through developed learning units. Cahyadi (2019) stated that analyzing material in terms of facts, concepts, principles, and procedures is a form of identifying material, and it is relevant to develop teaching materials in learning activities. The analysis is carried out through a literature study method and aims to identify and systematically organize the main parts of the material taught in the classroom. The existence of learning units can provide concrete explanations for abstract material.

A validity test is a test to determine whether a measuring instrument is valid (valid) or not (Janna, 2021). Islamy (2022) stated that the validation test data were results after calculating the scores obtained and making improvements from experts' criticism and suggestions. The researchers used experts' criticism and suggestions to revise and improve the product for a better product according to the actual needs. The scores show the results of the inter-rater agreement from 3 expert validators totaling 95.3% with valid criteria. According to Fatmawati (2016), if the experts' agreement value has a minimum value of 70.01%, we can say that a product is valid and we can use it. We can say that this integrated STEM education learning unit is also valid. Using an integrated STEM education approach on the water cycle topic, we can use it in biology science learning activities to access students' system thinking skills. Construct validity in learning units is measured based on literature studies. The construct validity test aims to determine what aspects of the developed learning unit.

The researchers conducted effectiveness tests on 32 students. It aims to determine students' understanding of water cycle material with an integrated STEM education approach. The results of the paired sample t-test show that the value of Sig. (2-tailed) is equal to <0.001 or it is less than 0.05. Therefore, there is a significant difference between the pretest and post-test results. On the limited scale test, the N (gain) test result is 0.73. It shows that it is highly effective for accessing students' system thinking skills. According to Yulyatno et al. (2019), the N (gain) score has high criteria if it has a minimum score of 0.70. The data show that the average post-test value is higher than the pretest value, meaning that overall there is a difference in the average pretest and post-test results.

STEM education refers to the teaching, learning, and integration between natural science disciplines and science, technology, mathematics, and engineering skills in STEM topics by focusing on solving real-world problems (Wahono et al., 2020). STEM education focuses on hands-on activities to prepare students for the development of a new era of competition. Learning activities using a STEM approach can improve soft skills of problem-solving, higher-order thinking skills, and collaborative work. System thinking skills are closely related to higher-order thinking skills when juxtaposed with STEM. It is because systems thinking skills can improve students' retention of material and problem-solving skills with an integrated STEM approach (York et al., 2019). This research can access students' systems thinking abilities proven by real-world results. Therefore, the learning units developed effectively access students' systems thinking skills in biology science learning activities using an integrated STEM education approach on the water cycle topic.

The questionnaire results of student responses to the learning unit obtained 89% with high categories. According to Fatmawati (2016), the percentage of respondents can be mentioned as a high criterion if they have a minimum score of 76%. From the data obtained, a high percentage of respondents met the criteria. Therefore, the learning units developed in this research are practical to get students' systems thinking skills in learning activities through an integrated STEM education approach. According to Destiana et al. (2020), practical value is a factor to consider when developing a product. Practical value provides convenience in every development process carried out. We use the practicality of the learning unit under development as a benchmark for its feasibility.

The benefits of learning using integrated STEM education can provide the potential to develop the ability to argue and make decisions (Wahono et al., 2021). Integrated STEM education positively influences the student's thought development process because it involves multiple disciplinary perspectives. Students are familiar with convergent and divergent thinking in learning environments governed by integrated STEM education. Therefore, integrated STEM education is critical for increasing students' interest in learning and improving learning outcomes.

CONCLUSION

This research developed integrated STEM education learning units to access students' system thinking skills systematically and scientifically. The validity of integrated STEM education learning units to access system thinking skills has a very high value of inter-rater agreement from experts. Therefore, this learning unit is valid for use in learning activities. Based on the literature, the construction of the learning unit is also accurate. The results of the limited scale test of integrated STEM education learning units to access students' system thinking skills in the effectiveness test using the Paired Sample Test were significant. Therefore, thinking of systems is necessary for education to understand the multilevel structure of several concepts and their interrelationships. This research is expected to innovate integrated STEM education learning units on the water cycle material through relevant literature. It can utilize learning hours to create meaningful learning for students.

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