RESEARCH ARTICLE

STEM learning design to train student's system thinking skills on climate change

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Abstract: Climate change in coastal areas is a complex problem that involves value systems and requires various scientific disciplines. Integration of Science, Technology, Engineering and Mathematics (STEM) approach is needed in learning so that it can train students to think holistically, structured and systematically. This research was carried out with the aim of producing an appropriate STEM learning design to train students' systems thinking skills on climate change material. The type of research is research and development using the analysis, design, development, implementation and evaluation (ADDIE) model. The trial subjects in this research were 28 class VIII students of SMP Muhammadiyah 12 GKB Gresik, East Java. The research instruments were validation sheets of lesson plan and student worksheets, observation sheets, and systems thinking skills assessment sheets. The research results show; (1) The Extraordinary Lesson Plan (ELP) and student worksheet of STEM learning design development which are measured through Aiken Validity with a value of 0.89 ≥ 0.6 in the valid category; (2) The STEM learning design developed is in the practical category with an average score of 3.5; and (3) students' systems thinking abilities in climate change material are in the good category. It can be concluded that the STEM learning design developed to train junior high school students' systems thinking skills was feasible to be used in learning.

Keywords: climate change; STEM learning; system thinking

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Introduction

Science and technology are developing very rapidly in the 21st century. Indonesia must be able to compete with developed countries. The 21st century framework prioritizes students mastering knowledge and various soft skills including thinking skills, problem solving skills, collaboration, innovation, communication, and information and technology skills (Stein, 2021; Stehle & Burton, 2019; Sarwi et al., 2019). Countries around the world in the global era need graduates who have Science, Technology, Engineering and Mathematics (STEM) skills who are able to compete globally and creatively solve problems (Martín-Páez et al., 2019). One of the educational innovations needed to face global challenges is integrating STEM approaches in learning. STEM education can also be defined as a learning approach between two or more STEM components (Jolly, 2016). STEM learning can train students to apply their knowledge in making designs as a form of solving problems related to the environment by utilizing technology (Martín-Páez et al., 2019). STEM learning activities involve students in defining and formulating solutions to authentic problems in real life and in cyberspace.

Various environmental problems such as climate change are complex problems involving various scientific disciplines. Students will think in a holistic, integrative way by connecting components so that students are accustomed to thinking in systems. The ability to think systems is one of the abilities in the decision-making process by looking at all problems as a whole so that the decisions taken are more

focused (Blatti et al., 2019; Johariah et al., 2023). These systems thinking ability is one of the skills needed in Education for Sustainable Development (ESD).

Climate change is a global issue that requires the attention of many parties. This scientific phenomenon affects the earth's warmer temperature and sea rise levels. Global warming changes the need for quality and quantity of water and health (Nurhayati et al., 2020), causing extreme weather (Kurniawan, 2022) and storm surges in various places in Indonesia and parts of the world (Panjaitan et al., 2017; Jensen et al, 2022; Leal & De Lima, 2022). The rise in seawater levels due to global warming also threatens marine biota's life and inhibits coral reef growth (Courtney et al., 2017). In addition, it increases the frequency of coastal erosion and sedimentation, and the loss of mangrove populations as a wave barrier to the sinking of the mainland was categorized as sufficient.

Indonesia has the longest coastline of around 81,000 kilometers, with 60 percent of Indonesia's population living in coastal areas. The immediate risks of climate change have been felt by local coastal communities, such as warming temperatures and sea rise levels, tidal waves, damaged coral reefs, and decreased mangrove biodiversity. This phenomenon has an impact on reducing the productivity of coastal fishermen, food security, and the economy of the local community (Novianti *et al*., 2016; Ali *et al*., 2019). The Paris Agreement stipulates that global warming is limited to 20C or 1.50C if possible. The findings show a phenomenal impact on the earth's ecosystems and socio-economic systems when global warming reaches 20^0C (Schleussner et al., 2016). This climate action needs to be continuously improved and it is urgent to deal with climate change through adaptation, mitigation, collaboration, and finance (Smith et al., 2022; Tang, 2022). This collaborative effort to deal the climate change has become a global agenda for Education for Sustainable Development which makes education an important part of sustainable development (UNESCO, 2020).

Climate change in coastal areas requires the involvement of all parties in the process of mitigation, adaptation, and control. Therefore, learning materials for climate change in coastal areas can be used to train students' thinking skills and strengthen students' socio-emotional abilities. Students are expected to be able to understand the phenomenon of science in coastal communities. They manage and express social and emotional feelings in helping solve everyday problems, build relationships, and actively contribute to action on local and global science issues. Students practice systemic thinking by combining analytical and synthetic thinking skills on interdisciplinary problems in science learning (Blatti *et al*., 2019). Systems thinking skills are part of today's educational transformation challenges. System thinking teaches students to understand, and find problems and efforts that must be made to support that change (Ndaruhutse et al., 2019). Students through systems thinking are expected to have awareness, concern and behavior change in protecting and preserving nature and its environment including sustainable goals in overcoming the effects of climate change.

Climate change in coastal areas is a complex problem that is bound by value systems, knowledge and involves various parties. This topic can be a source of student learning in practicing systemic thinking skills. System thinking skill is the ability to understand a complex problem by analyzing parts, and variables to find out the pattern of relationships in each element or constituent elements (Clark et al., 2017). Systems thinking involves capturing the system as a whole through the interaction of its parts Assaraf & Orion, (2005); Brandstädter et al.(2012); Casnan et al.(2022) and understand system stability through Causal Loop Diagrams (CLD). The ability of system thinking is important for students, they will make easy connections between the material that has been studied. Systems thinking contributes to developing students' understanding of dynamic living systems (Schuler *et al.*, 2017).

Meanwhile, the provision of knowledge in schools often still focuses on facts rather than training the systemic relationship of a process. The integration of systems thinking in learning is still limited (Gilissen et al., 2020). Middle school students aged 13-15 are categorized as the millennial generation who like the digital world, graphic visualization, and fast access to digital information (Yuniastuti et al., 2021). Several studies have stated that systems thinking skills can be trained through Inquiry-based learning (Haley et al., 2021; Assaraf & Orion, 2005), Discover learning (Kurniawati et al., 2022), Problem-based learning (Amaral & Fregni, 2021; Nagarajan & Overton, 2019).

The phenomenon of climate change is holistic, and complex and requires approaches from various sides to overcome it. Science, Technology, Engineering, and Mathematics (STEM) integrated learning can be a learning model that can be trained to strengthen education for sustainability. Students' scientific abilities are influenced by systematic, logical, and rational thinking and potential in mathematics. This is necessary so that students' critical thinking skills towards scientific phenomena and global issues require proper solutions. Research on the application of STEM learning has been carried out, including STEM learning that integrates artistic creativity and has been able to train critical thinking skills for junior high school students (Dewi et al., 2023), a STEM learning approach using digital worksheets can improve high school knowledge competencies (Zainil et al., 2022). STEM learning has been proven to also be

able to prevent misconceptions in understanding the structure of plant and animal cells at middle school, high school and university levels (Rustaman et al., 2018). In other research, STEM learning can train various skills such as collaboration, creativity and problem solving, systems thinking skills (Purwanti et al., 2021). However, there has not been much research on STEM learning that focuses systems thinking skills on the topic of climate change. Therefore, this research aims to develop a STEM learning design to train systems thinking skills on the topic of climate change for junior high school students.

Method

The research was conducted using design Research and Development (R & D) with the ADDIE Model. This model is structured systematically and effectively with clear learning objectives, structured and coherent content, workload that is measurable and organized by teachers and students (Branch, 2010). This model also has integrated visualization and media and assessment, which are related to targeted learning outcomes (Branch & Dousay, 2015). This study aims to produce a STEM learning design to train students' systems thinking skills on climate change material. The ADDIE model has five phases, namely Analyze, Design, Development, Implementation and Evaluation. The flow of the ADDIE development model can be seen in Figure 1.

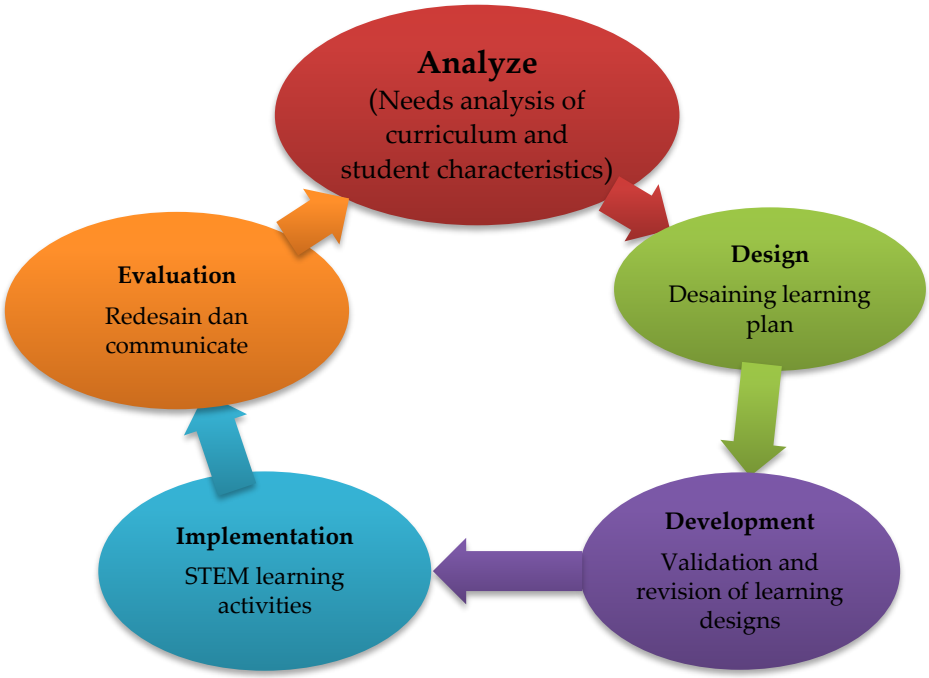

Figure 1. The flow of ADDIE development model (Branch, 2010)

The initial stage of research on learning design development is the analysis stage. This stage involves identifying needs, analyzing the Independent Curriculum and student characteristics, theory and previous related research results. At the design stage, prototype I was designed in the form of an Extraordinary Lesson Plan (ELP) and Student Worksheet. At the design stage, prototype I was designed in the form of an Extraordinary Lesson Plan (ELP) and Student Worksheet. Next, in the development stage, the Extraordinary Lesson Plan (ELP) and Student Worksheet were validated by several experts and practitioners, and revised the validation results to obtain Prototype II. The validity test was carried out by two expert validators and practitioners. Analysis data of content validity of lesson plans and student's worksheets using the Aiken's V technique with Formula 1 (Azwar, 2012):

$$V = \Sigma s / [n(c-1)] \quad (1)$$

With s=r-lo, lo=the lowest validity score (in this case 1), c=the highest validity score (in this case 4), and r=the number given by the expert review. The validity category can be seen in Table 1.

Table 1. Validity category

Value	Category
≥ 0.6	Valid
≤ 0.6	invalid

(Yulkifli et al., 2019)

In the implementation stage, the product was tested on 28 class VIII students of SMP Muhammadiyah 12 GKB Gresik, East Java Indonesia. In the evaluation stage, an analysis of the effectiveness of the development of STEM learning designs was carried out through measuring students' systems thinking competencies. In addition, measurements were made of the practicality of STEM-based learning in terms of implementation and constraints during implementation in the field. The research instruments are STEM learning design validation sheets, Extraordinary Lesson Plan (ELP) and Student Worksheets, observation sheets of students' system thinking skills, and questionnaires.

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Results and Discussion

Analysis

Activities to analyze the need for developing STEM learning designs at this stage include curriculum analysis and student characteristics. The results of interviews with school stakeholders stated that Science Project learning is one of the regular weekly extraordinary programs and focuses on students' talents and interests which emphasizes the applications of scientific concepts in producing scientific products and engineering. This learning is part of the implementation of Proyek Penguatan Profil Pelajar Pancasila (P5) from Kurikulum Merdeka. One of the topics is a sustainable lifestyle with the theme of climate change. Students are also expected to have 21st-century skills such as critical thinking, problem-solving, collaboration, and communication (Stein, 2021). This is in line with the framework of implementing the independent curriculum, especially in learning outcomes related to climate change (Kemendikbudristek, 2022). Technological developments and the characteristics of students who belong to the millennial generation with an age of around 13 to 15 years need to continue to develop students' systems thinking skills to make a positive contribution to climate change promotion actions.

The learning required is student-oriented through integrative learning activities and stimulates students to have 21st century skills such as systems thinking skills. Students are expected to be able to think comprehensively in finding the root of the problem of the current climate change phenomenon. Furthermore, students will be able to offer and have an impact on the actions of the climate change adaptation, mitigation and control movement. The results of observations and interviews show that learning by practicing systems thinking skills has never been carried out, so that students' sensitivity to environmental phenomena is not yet visible. Therefore, training students in systems thinking skills is important for today's millennial generation.

The curriculum analysis on the theme of climate change is integrative and holistic so it is very suitable for practicing systems thinking skills. Climate change, impacts and climate resilience mitigation and adaptation efforts are part of science. Designing the right media for climate change promotion and analyzing graphs of the influence of the media and the millennial generation in controlling climate change and promoting sustainable lifestyles are part of engineering and mathematics. Meanwhile, class VIII students are a generation that has a close relationship with technology in obtaining information and strengthening students' scientific literacy. Students can also use digital media in making videos through the video maker application, Capcut, Kinemaster, Filmora, and use appropriate social media to promote a sustainable lifestyle. So, the development of STEM learning designs is very suitable for the topic of climate change.

Design

The second stage of the ADDIE development model is the design stage. At this stage the researcher begins to design a STEM learning plan. STEM learning is a learning approach that integrates Science, Technology, Engineering and Mathematics into the real world and is relevant to students' learning experiences (Martín-Páez et al., 2019; Jolly, 2016). In this study the characteristics of STEM PJBL Laboy

learning used the more complex Engineering Design Process (EDP) developed by Jolly, (2016) which stimulated students to think critically and creatively (Hartini et al., 2020). The product design is in the form of an Extraordinary Lesson Plan (ELS), Student worksheet and design characteristics of a climate change promotional digital video developed by students.

To design the Extraordinary Lesson Plan (ELP) dan Student worksheet, the researcher arranged the lesson in nine meetings. Each meeting follows the Engineering Design Process (EDP) phase in STEM developed by Jolly, (2016) which include: 1) define the problem; 2) research; 3) imagine; 4) plan; 5) create; 6) test and evaluate; 7) redesign; 8) communication. Before entering the create stage, there is one meeting, namely the presenting design stage, which aims to communicate the activity plans that will be carried out by students which are the result of activities at the research, imagine and plan stages.

The ELP design refers to the EDP phase. The designed ELP consists of title, educational unit, activity name, activity theme, class/semester, time allocation, learning objectives, competencies, concepts of learning material characteristic of STEM, 21st century skills development, approaches, methods and media learning. The learning activity stages follow the syntax of the PjBL-Laboy STEM learning model which includes teacher activities, student activities and time allocation. Student worksheets are designed referring to the EDP stage indicators. Worksheets are given to students at each meeting. The worksheet is designed so that student activities are more focused. The worksheet designed consists of a title, group name, learning objectives, activity instructions, and questions. The STEM component contained in the worksheets is combined with the training of student system thinking skill.

Development

The development stage was carried out after the STEM learning design was validated by two experts and 1 practitioner with the results as shown in Table 2.

Table 2. The validity result of STEM learning design

Aspect	Validity	Category
The need for the development of STEM Learning Design	0.96	Valid
Current knowledge of STEM learning and systems thinking	0.85	Valid
Compatibility with the syntax of PjBL Laboy	0.88	Valid
Appropriateness of Implementation of Kurikulum Merdeka	0.86	Valid
Feasibility of material, appearance and language	0.89	Valid
Mean Validity	0.89	Valid

The product validity value of STEM learning design to measure system thinking skills is obtained through Aiken's Validity with a value of 0.89 ≥ 0.6 in the valid category and can be implemented in class.

Next, researchers revised the STEM learning design. These revisions and improvements were carried out based on suggestions and input from validators. Validation was carried out on the ELP and student worksheet designs and performance assessment guidelines for students' systems thinking skills. From the validation results, various responses and suggestions were obtained regarding the ELP design and worksheet that had been designed. Qualitative data in the form of responses and suggestions provided by validators such as providing strengthening material insight into prerequisites regarding adaptation, mitigation and control of climate change, Zero net waste and sustainable lifestyles. This results in a final STEM learning design that can be implemented in the classroom.

Implementation

The implementation stage aims to test the learning tools that have been developed on research subjects. Implementation of the tools developed was carried out with 28 students during nine meetings. During the EDP define the problem stage, teachers provide stimulation to students by showing various facts about the impact of climate change, especially in coastal areas. Students are expected to stimulate students' sensitivity to current climate change conditions. Furthermore, through worksheets students can find various main problems of climate change, especially in coastal areas. They collaboratively discuss to create connections between components related to climate change. They practice to think freely according to the understanding and depth of the concept of climate change. This activity aims to train

students to think systems by making connections between climate change and various lines of life from environmental, social, economic to cultural. Next, determine the best action to take to promote efforts to control climate change.

The implementation of STEM learning in the classroom aims to measure the systems thinking abilities. Systems thinking is an advanced transition strategy in helping to solve complex problems for sustainable development (Ndaruhutse et al., 2019). This system thinking competency is very important to train students, especially in climate change material, considering that this problem is a global issue that is familiar and relates to the current conditions of students' lives. The result of system thinking skill of junior high school students with the results as shown in Table 3.

Table 3. Student's System Thinking Skill

Code	Indicator of System Thinking				Mean
	Mindset	Content	Structure	Behavior	
1A	4	4	4	3	3.75
1B	3	3	4	3	3.25
1C	2	3	2	3	2.50
1D	3	4	4	3	3.50
1E	4	4	3	3	3.50
1F	4	4	4	3	3.75

(Arnold & Wade, 2017)

Based on the domain of systems thinking from Arnold & Wade (2017) in the content aspect, students are seen to have the ability to analyze between systems with an average score of 3.67 with a very good category. As described in group 1.E, the ability to analyze the behavior of using public transportation and socio-cultural life has an impact on climate change in coastal areas. In addition, the skills to analyze between these systems are classified as higher-order thinking skills (HOTS). This shows that through STEM-based learning, students can be trained to think HOTS with the ability to handle analysis and evaluate a problem and action on the current climate change phenomenon. This is in accordance with Blatti (2019) which states that systems thinking can be trained by combining analytical thinking skills and synthetic thinking about interdisciplinary problems for continuing science education. Students with systems thinking skills will be able to think complexly and holistically in identifying and understanding a system (Nagarajan & Overton, 2019), predict human behavior, and design and modify something to help human work. In addition, students with systemic thinking competencies will have an understanding of the dynamics of life that are developing (Assaraf & Orion, 2005). System thinking competence needs to be continuously trained for students so they are able to contribute, anticipate, adapt, and work toward disaster management, especially those related to climate change in the future.

On the implementation of STEM learning designs, providing a challenging and meaningful learning experience. This learning takes a long time so it is also important to build socio-emotional skills and the existence of positive dependencies between group members (Martín-Páez et al., 2019). This research is proven to be able to practice systems thinking skills on climate change material. Subsequent research can be carried out by testing it on other materials or students from other classes or schools.

Evaluation

Evaluation is the final stage to provide feedback on the product design that has been implemented. Students need to not only focus on the final product and one aspect of exploring science material or using technology alone. Because the implementation of STEM learning also involves integration with engineering and mathematics. This is in line with the statement made by the NRC, that STEM learning is an interdisciplinary approach that integrates Science, Technology, Engineering and Mathematics in learning (Jolly, 2016; Martín-Páez et al., 2019). Moreover, before participating in STEM learning, students need to strengthen their mastery of concepts on study topics and have learning experience in analyzing and interpreting data. This is to make it easier for students to think comprehensively.

Conclusion

It can be concluded that STEM learning design products such as learning action plans and student

worksheets that have been developed to train student's systems thinking skills are feasible to use. The STEM learning design research developed is limited to climate change material for the junior high school level. For further research development, it can be extensively tested on other materials and students from several schools, both public and private.

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Conflicts of Interest

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

Author Contributions

A. Shofatun: methodology, analysis, writing original draft preparation, review and editing. **E. Herniani:** writing original draft preparation, review and editing. **D. Mardiani:** analysis, review and editing.

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