RESEARCH ARTICLE

Developing system thinking skills through project-based learning loaded with education for sustainable development

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Abstract: High school students need to be introduced to and trained in system thinking skills as one of the implementations of Education for Sustainable Development (ESD). This study aimed to develop high school students' systems thinking skills through ESD-laden project-based learning on environmental change material. A pre-experimental method was applied with the One Group Pretest Posttest Design to 35 class X high school students in Bandung Regency who were selected by non-random sampling. The data were collected through open questions to evaluate students' systems thinking skills and were processed by scoring student answers based on the rubric for assessing system thinking skills. The N-Gain value was calculated to determine the magnitude of the increase in students' systems thinking skills before and after learning. The results showed that the N-Gain value was 0.64, which means that students' systems thinking skills moderately developed after project-based learning containing ESD. The development of system thinking skills can train students to change paradigms to view a problem from various perspectives to find a sustainable solution, encouraging them to pay more attention to their activities and take more responsible actions.

Keywords: education for sustainable development; environmental changes; project-based learning; system thinking skills; sustainable development goals

Introduction

Environmental problems are increasing due to increased industrialisation and urbanisation which depletes natural resources and produces urban and industrial waste. Rapid economic growth is the main goal of developing countries to reduce poverty and act without considering environmental problems (Gill et al., 2018). According to Harangozo et al (2018), businesses must also focus more on sustainability, adequacy, and changes in social aspects. Many people still do not closely connect cause and effect in problems that occur in ecological, economic and social aspects (Harangozo et al., 2018), thus, a paradigm shift/human perspective is needed to support sustainable development. Humans need to learn to develop knowledge, skills, values and attitudes that enable them to adapt in a changing world to support sustainability (Tarrant & Thiele, 2016). In this case, education has an important role in accelerating progress towards a sustainable future (Findler et al., 2019; Kohl et al., 2022). UNESCO established ESD (Education for Sustainable Development) to support the UN 2030 agenda for SDGs

(Sustainable Development Goals), one of which is in point 4 regarding quality education. The target is to ensure that all students acquire the knowledge and skills needed to promote sustainable development and this is also understood to be an important means of achieving the other 16 SDGs (Leicht et al., 2018).

Systems thinking is one of the main competencies for building a transition strategy towards sustainability (Tarrant & Thiele, 2016). Considering environmental problems/issues by focusing on the ecological dimension of a complex system is not enough to promote an understanding of sustainable development, it is also necessary to consider the sociocultural and economic dimensions. To encourage an understanding of these dimensions and their interactions, it is necessary to teach an understanding of systems thinking in schools (Riess & Mischo, 2010). This is in line with the role of ESD which is based on three pillars namely social, environmental and economic which are very important in changing the general perception and attitude of people (Tristananda, 2018).

In Indonesia, there is a lack of research on systems thinking skills. The few studies on ESD focus on developing systems thinking skills (Ateskan & Lane, 2018; Connel et al., 2012; Remington-Doucette et al., 2013; Wiek et al., 2011) and no study has examined systems thinking with ESD-laden project-based learning.

Students with systems thinking skills can think about the system as a whole by knowing and understanding the elements in the system and the relationships between these elements, as well as adapting knowledge about the system to solve problems or improve system functions (Arnold & Wade, 2017). Systems thinking is the ability to analyse complex systems across different domains (society, environment, economy, etc.) and scales (local to global) (Wiek et al., 2011). Assaraf and Orion (2005) proposed a System Thinking Hierarchical (STH) model including the ability to: (1) identify system components and processes; (2) identify the relationship between separate components and the ability to identify dynamic relationships between system components; (3) understand the nature of the system cycle and arrange the components and place them in a network of relationships, and make generalisations; (4) understand the hidden components of the system and the evolution of the system in time (predictions and retrospectives). Liu and Hmelo-Silver (2009) describe systems thinking in terms of structure, behaviour and function (SBF), with the structure representing the system components and the relationships between systems. Behaviour represents the dynamic interaction between the system components and mechanisms and functions represent the essence of the system and its components. This SBF model is refined into a conceptual representation of Components-Mechanisms-Phenomena (CMP)14 that supports students to think about the components (C) of a particular phenomenon (P) and how they interact to produce a specific mechanism (M) (Hmelo-Silver et al., 2017).

Several studies have explored the systems thinking skills in primary and secondary schools, even in preschoolers (Assaraf & Orion, 2005, 2010; Feriver et al., 2019; Keynan et al., 2014; Raved & Yarden, 2014; Shepardson et al., 2014), uncovering the many difficulties students of all ages face when dealing with complex systems. For example, difficulty understanding the various system levels and making connections between them (Keynan et al., 2014), as well as difficulties in managing components and processes within the system framework. This can happen because of the limitations of previous educational experiences, where things that are taught to students are presented as separate components rather than as a system (Shepardson et al., 2014). According to Raved (2014), developing learning requires a more significant and explicit emphasis on the relationship between various organisational levels in the system (Raved & Yarden, 2014). Sadira (2021) reported that experience-based learning did not significantly affect the students' systems thinking skills and concluded that further research is needed that can develop students' systems thinking skills with an approach that motivates students more in learning to develop these competencies. Therefore, other efforts are needed to introduce and train systems thinking skills in schools with different learning approaches.

Furthermore, the system thinking skills indicator used in this study is based on the study conducted by Semiz and Texoz (2019) which determines systems thinking skills in the context of ESD and science education to develop systems thinking skills of science teacher candidates. The present study evaluated systems thinking skills at a different level, namely of 35 high school students using a project-based learning approach with ESD content on environmental change. Learning tools in the form of project-based lesson plans and worksheets with ESD content that equip students with systems thinking skills were prepared by the researchers to study a natural system, its components and the interrelationships between them. Water, air and soil pollution problems were studied based on the three pillars of ESD (environment, economic and social) to find a sustainable solution and the students were required to design a poster as a media appeal to protect the environment.

Method

This study used a quantitative approach and open-ended questions were designed to evaluate students' systems thinking skills. The study involved 35 class X MIPA students at Telkom high school in Bandung Regency in August-September 2022 selected by non-random sampling. The One-Group Pretest-

Posttest Design adopted is shown in Table 1 (Fraenkel et al., 2012). ESD-laden project-based learning was designed by the researchers and is outlined in Table 2.

Table 1. Research design

Group	Pretest	Treatment	Posttest
Class X MIPA 1	O1	X	O2

Description:
O1 = Pretest (before learning)
X1 = ESD project-based learning
O2 = Posttest (after learning)

Table 2. PjBL syntax and its relation to ESD and systems thinking strategies

PjBL Syntax	Systems Thinking Strategy	ESD charge
Set the project theme	Students are invited to think about systems by starting with giving problems or questions that must be explained from various perspectives; the students were given a picture of environmental pollution and assisted with guiding questions	The problem of water/air/soil pollution is not only seen from an environmental perspective but also from a social and economic perspective At the beginning of the lesson, the teacher briefly explains ESD and SDGs related to the material to be studied i.e., environmental change
Syntax sets the learning context	Students in groups determine the steps for completion and develop a work programme guided by a project-based LKS that equips systems thinking skills	-
Activity plan syntax	Students make some decisions about projects, communicate them and express their ideas. They also plan project activities and prepare tools and materials for measurement, including exploring interview questions.	-
Process activity syntax	Students are involved in a collaborative inquiry process in small groups to solve problems by identifying variables, finding resources and applying information. Students are invited to think about systems by analysing the components that exist in the observed system, how the relationship between these components and how a change in the system occurs as a result of the interaction between these components Students analyze from various social, economic and environmental perspectives, as well as composting and planting trees to practice other system thinking skills	Students observe human and non-human activities around natural systems and analyse their relationships/interactions between aspects of sustainability (environmental, social, economic)
The syntax of implementing an activity to complete a project	Students present their results to their class and design posters to outline their system thinking and present the messages related to sustainable development	Reflection on learning by looking at a problem from various aspects of sustainability

The indicators of students' systems thinking skills were based on the study by Semiz and Texoz (2019). The material used was environmental change material in KD 3.11, namely analysing environmental change data and the impact of these changes on life and KD 4.11 by making product designs for recycling waste and efforts to preserve the environment. The environmental material was limited to water, air and soil pollution and an explanation of the system thinking indicators and their relationship to environmental pollution problems and their implementation in learning units is shown in Table 3. This was used as a reference for researchers in developing project-based learning with ESD content that can train systems thinking skills. The student answers were scored based on the rubric according to Semiz and Teksoz (2019) as shown in Table 4.

Table 3. System thinking indicator and its relation to environmental pollution problems and their implementation in learning units

System Thinking Indicator	Meaning in relation to environmental pollution problems, for example, water pollution	Implementation in learning units
Identify the meaning and aspects of sustainability (STS-1)	Ability to identify biotic (non-aquatic biota and aquatic biota) and abiotic components, and processes such as energy flow and biogeochemical cycles	At the beginning of the lesson, the teacher briefly explains ESD, SDGs and systems thinking related to environmental change
Seeing nature as a system (STS-2) Identify system components (STS-3) Analysing the linkages between aspects of sustainability (STS-4)	The understanding that nature as a system is composed of components with various processes/interactions between components For example, students understand that environmental pollution results from an imbalance of the system components and the processes/interactions, as well as affect other aspects An example of understanding that polluted rivers can directly affect water quality, that also affect other aspects of sustainability	Students experience a real sense of being a system component through direct observation in a natural system (a polluted river/factory/environment), observing system components and their interactions, measuring water/air/soil quality. Students are assisted with guiding questions in the LKS
Recognising hidden dimensions in a system (STS-5)	Understanding the transformation of matter in river systems involves identifying dynamic relationships within river systems such as human influences on river water through pollution by fertilisers and pesticides	Students are assisted with guiding questions in the LKS, for example: "What is the effect of human activities on plantations or agriculture through the use of fertilizers and pesticides on river water?"
Acknowledge own responsibility within the system (STS-6) Adapting systems thinking perspective to personal life (STS-12)	The understanding that humans are part of a living system so that they can make connections between problems/issues and their personal lives For example, by observing the river system, making compost and planting trees, the hope is to raise students' awareness of their roles and responsibilities towards the environment, fostering students' systems thinking skills	Students carry out sustainable activities such as sorting organic and inorganic waste, making compost and planting trees and then assisted with guiding questions in the LKS "What are the important learning moments from planting trees and making compost?"
Consider the relationship between past, present and future actions (STS-7)	Students analyse the impact of water pollution on the surrounding environment, is there a relationship between current conditions and past activities that will impact the future	Students conduct interviews to evaluate the environmental impact, acquiring information about environmental conditions in the area from the past, present and future
Recognising system cycle properties (STS-8)	An understanding of the cyclical nature of systems includes the idea that we live in a world of systems cycles	Students perform sustainable activities such as sorting organic and inorganic waste, making compost and planting trees to understand the cyclical nature of the system

System Thinking Indicator	Meaning in relation to environmental pollution problems, for example, water pollution	Implementation in learning units
Develop empathy (STS-9) Developing empathy with non-humans (STS-10) Develop a sense of place (STS-11)	By studying environmental changes (water pollution), students are expected to develop empathy and build multiple dimensions or some meanings of rivers	Students are assisted with guiding questions in the LKS "What is the relationship between these activities and natural cycles? Try to explain!" Students directly observe a natural system, human and non-human activities around the river and their interactions by paying attention to various aspects both from economic, environmental and socio-cultural aspects

Table 4. Rubric for assessing systems thinking skills (Semiz & Teksoz, 2019)

Systems Thinking Skills (STS)	Pre-aware (0)	Emerging (1)	Developing (2)	Mastery (3)
STS-1 Identify the meaning & aspects of sustainability	Students do not refer to one aspect of sustainability	Refers to one aspect of sustainability	Refers to two aspects of sustainability	Refers to more than two aspects of sustainability
STS-2 Seeing nature as a system	Students do not see a particular realm as a system	View nature as a system and consider it an integral ecological aspect and describe the human-nature relationship from a mechanistic perspective	Seeing nature as a system that considers two integral ecological aspects and describes the human-nature relationship holistically	Seeing nature as a system that considers most aspects of integral ecology and describes the human-nature relationship in a holistic manner
STS-3 Identify system components	Students cannot identify the system components	Identify one or two system components	Identify some of the system components	Identify some of the components of the system clearly
STS-4 Analyse the interconnections between sustainability aspects	Students cannot analyse the interconnections between aspects of sustainability	Analysing interconnections by considering one aspect of sustainability	Analyse the interconnection by considering two aspects of sustainability	Analyse interconnections between system components by considering all aspects of sustainability
STS-5 Recognise hidden dimensions	Students cannot identify hidden dimensions	Identifying one hidden dimension in a system	Identify some hidden dimensions and make a connection to the problem in a simple way	Identify some of the hidden dimensions by linking them to the problem
STS-6 Recognise self-responsibility within the system	Students do not make the connection between problems/issues to their personal lives	Make a connection between the problem/issue to their personal life	Make some connection between the problem/issue to their personal life	Make lots of connections between problems/issues to their personal lives
STS-7 Remembering the relationship	Students cannot make connections between past,	Students try to make connections	Students try to make connections between past,	Students make connections between past,

Systems Thinking Skills (STS)	Pre-aware (0)	Emerging (1)	Developing (2)	Mastery (3)
between past, present and future	present and future	between past, present and future	present and future. Most consider two timeframes (eg past and present)	present and future
STS-8 Recognise the cyclical nature of the system	There is no explanation of the cyclic nature of the system	Students try to recognise the cyclical nature of the system	Students try to recognise the cyclical nature of the system in a simple way	Students recognise the cyclical nature of the system by giving examples (eg., natural cycles)
STS-9 Develop empathy with others	Students cannot develop empathy with other people	Students try to develop empathy with others	Trying to develop empathy with others but they explain their needs or reasons	Able to develop empathy with others by explaining their reasons or needs behind their actions without blaming
STS-10 Develop empathy with non-humans	Students cannot make a relationship between themselves and non-humans	Students try to make connections with non-humans	Students try to express their relationship with non-humans in a simple way	Students express relationships with non-humans and all of nature
STS-11 Develops a sense of place	Students cannot construct any dimensions	Represents the place dimension as a single dimension	Try to build a multidimensional sense of place, representing places as two-dimensional	Connects many dimensions, a holistic sense of place, connect multiple meanings of place (biophysic, social, cultural, political)
STS-12 Adapting systems thinking to their life	Students are unable to adapt systems thinking to their lives	Students try to adapt the perspective of systems thinking to their lives with simple actions	Students begin to adapt systems thinking to their lives by taking small steps	Students adapt systems thinking to their lives by taking transformative actions

The data were analysed by calculating the magnitude of the increase before and after learning using the normalised gain formula developed by Hake (Sundayana, 2014) that presented in Formula (1). Furthermore, after the normalized gain value (g) was obtained, it was interpreted as shown in Table 5.

$$\text{Normalized Gain (g)} = \frac{\text{score posttest} - \text{score pretest}}{\text{score ideal} - \text{score pretest}} \quad \text{Formula (1)}$$

Table 5. Interpretation of normalized gain (g)

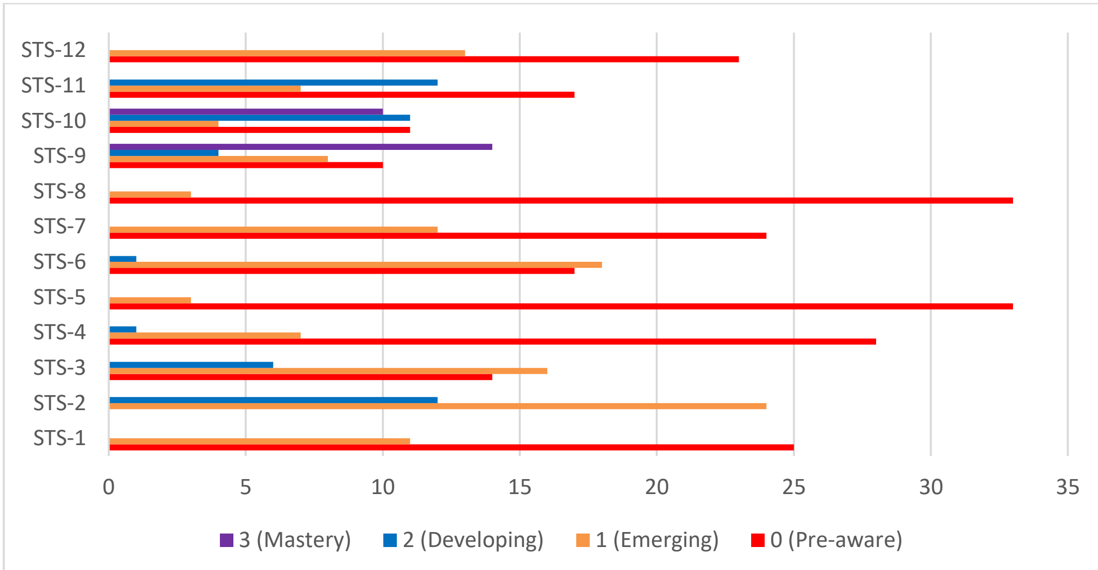
Normalized Gain Value	Interpretation
-1,00 ≤ g < 0,00	Decrease occurred
g = 0,00	No increase
0,00 < g < 0,30	Low
0,30 ≤ g < 0,70	Medium
0,70 ≤ g ≤ 1,00	High

Results and Discussion

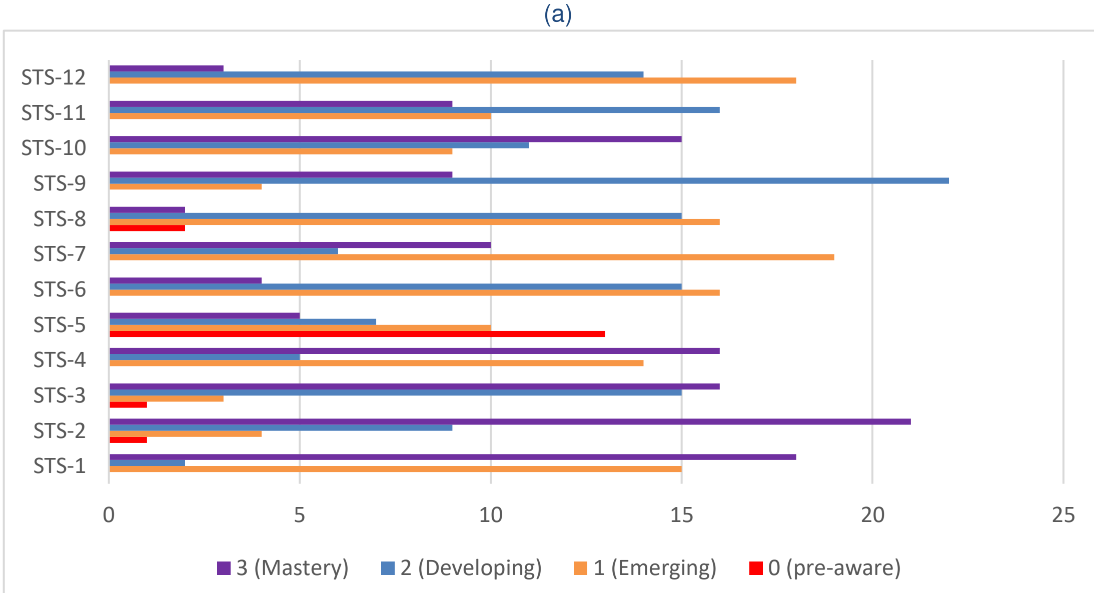
The data in the form of student answers were scored according to the rubric developed by Semiz and Texoz (2019) and are shown in Table 6. The average N-Gain score was 0.64 and was categorised as moderate indicating that students' systems thinking skills moderately developed after carrying out ESD-laden project-based learning. The main objective of this research was to explore how to develop students' systems thinking skills through ESD-laden project-based learning. Since ESD-laden project-based learning was designed by researchers to develop students' systems thinking skills at school, the system thinking skills were measured twice, namely before and after learning. The results show that most students improved their emerging, developing and mastery skills. According to the analysis of the pretest and posttest, students' systems thinking skills at the beginning and end of learning are shown in Figure 1.

Table 6. Descriptive statistics of gain index scores

Class	N	$\bar{X}$ Pretest	$\bar{X}$ Posttest	$\bar{X}$ N-Gain	Criteria
X MIPA 1	35	0,69	1,90	0,64	Moderate



(a)



(b)

Figure 1. Levels of students' systems thinking skills at the pretest (a) and posttest (b)

The pretest results show that most students are at the pre-conscious level, that is, their systems thinking skills at the beginning before learning are still relatively low. This low competence can be influenced by students' lack of environmental awareness thus affecting their way of thinking. Roslan et al (2021) stated that certain personality traits can increase systems thinking and promote students' abilities to solve complex problems because personality traits are developed based on the student's environment, culture and socioeconomic background.

Regarding the ability to see nature as a system (STS-2), no students were at the pre-conscious level but have reached the emerging–developing level, indicating that they already view certain nature as a system but view their relationship with nature mechanistically. This paradigm views the relationship between humans and the natural environment separately (Akib, 2014). For example, students consider that trees are important for life, such as providing oxygen but do not recognise that there is a connection between themselves and the tree whereby the role of humans is to maintain sustainability for the sake of the sustainability of the living system. This is one of the main reasons for the difficulty in realising sustainable and environmentally friendly community development and has given rise to exploitative attitudes and behaviour towards nature.

Furthermore, some students are also at the level of mastery (the highest level) to develop a sense of place (STS-11), empathy with non-humans (STS-10) and other people (STS-9), as well as identify system components (STS-3). This shows that some students feel a connection with the places they observe as well as with other living things around them so they can develop empathy.

Regarding the posttest results, most SMA students increased their systems thinking skills to emerging, developing and mastery levels. The highest level (mastery) was mostly achieved by students to see nature as a system (STS-2), identify the meaning and aspects of sustainability (STS-1), identify system components (STS-3), analyse the linkages between aspects of sustainability (STS-4), and develop empathy with non-humans (STS-10). The other skills of the average student are at the emergent-developing level with few students achieving the mastery level. This is in line with the research by Semiz and Texoz (2019) that STS-1, STS-2, STS-3, and STS-4 are the lowest-order skills that are easiest for students to develop. This suggests that the present ESD-laden project-based learning is relatively effective in developing these skills, as students were trained to develop their system thinking skills by making direct observations of natural systems and they felt they were part of the system. According to Keynan et al. (2014), learning about the system by directly interacting with it has advantages such as contextual learning in a complex real-world environment, is relevant and meaningful for students, and triggers a phase of student processing and reflection where new conceptualisations can develop.

This study also found several abilities that were difficult for students to master, including skills in understanding the nature of the system cycle (STS-8), adapting systems thinking to their life (STS-12), acknowledging one's responsibility in the system (STS-6) and recognise hidden dimensions in the system (STS-5). This is in line with Semiz and Texoz's (2019) research, that STS-12 skills are difficult for students to master.

To develop the ability to understand the cyclical nature of the system (STS-8), students performed sustainability activities such as sorting organic and inorganic waste, making compost and planting trees. It is hoped that students understand that by changing their actions (to be pro-environmental), this will affect the system to become cyclical or sustainable (Semiz & Teksoz, 2019). Regarding this STS-8 ability, the average student is at the developing level, and a few students are at the mastery level, some are even still at the pre-conscious level. Students understand the system cycle with a simple example by looking at the process of making compost from organic waste and that recycling occurs naturally by natural systems but have difficulties giving examples of natural cycles. Students may find it difficult to elaborate on their knowledge of biogeochemical cycles to the exemplary practice of sustainable activities associated with natural system cycles, possibly because of the limitations of previous educational experiences, where things that they were taught were presented as separate components rather than as a system (Shepardson et al., 2014).

Thus, STS-8, STS-12, STS-6 and STS-5 systems skills are difficult for high school students to master, with STS-5 being the most difficult skill to develop. This is because after learning (posttest), most students are at the pre-conscious level for STS-5, the skill of recognising hidden dimensions in a system. This is different from the results of Semiz and Texoz (2019) that the most difficult skill to develop is adapting systems thinking to personal life (STS-12) (Orgill et al., 2019).

The output of ESD-laden project-based learning in this study was posters as a media call for protecting the environment. It was hoped that with the knowledge that they acquired from the various project activities, they would be able to view the problem from different perspectives. This encourages students to pay more attention to the impact of the activities performed, thus, taking more responsible actions and finding sustainable solutions. An example of a student poster is shown in Figure 2.

The student posters do not describe sustainability in economic and social aspects, with the students only focusing on one aspect of sustainability, namely the environment. However, the students were aware of themselves as part of a system and that their actions will affect the system around them, for example, public consumption produces a lot of waste, as well as the construction of factories and the use of motorised vehicles which contribute to pollution and affect the surrounding natural systems. The students realised that they have personal roles and responsibilities in a system, therefore can determine what simple actions will be taken for sustainability.

Innovation is still needed in the ESD-laden project-based learning model to train students' system thinking skills, such as incorporating activities to introduce sustainable living. One example is using digital technology such as the internet, online applications or platforms as a means to facilitate student learning. Digital technology is a positive approach in education for sustainability (Kuntsman & Rattle, 2019). Mobile digital devices as a new portable pedagogical tool have the potential to transform classrooms and enable new ways for students to connect to outdoor environments, empowering their access to different forms of knowledge and experience and enabling location-based learning (Lock & Seele, 2017; Hesselberth, 2018). In addition, online platforms can also be used to test student knowledge, for example with online sustainability literacy tests (Kuntsman & Rattle, 2019).

Figure 2. An example of a student poster about air pollution

In this study, a website was also used to see the level of air pollution in an area, and students were allowed to find as many sources of information as possible on the internet. However, researchers feel the need to find alternative project activities so that students can connect knowledge from observing the system outside the classroom by exploring understanding through sustainability literacy tests by choosing problems that are close to the real world. This can trigger thought processing and reflection on the experiences gained by students. In addition, learning that instils creativity innovation and entrepreneurship into the classroom convention space can also help the successful implementation of education for sustainable development, whereby students are actively engaged in learning and are choice and change makers (O'Brien & Howard, 2016).
This study has some limitations. It involved class X high school students and was limited to one month. Students still need adjustments in carrying out project-based learning from the previous transition of online learning for 2 years due to the COVID-19 pandemic. The teacher must also master the project-based learning syntax for effective learning, so blended learning should be used to further optimise the acquisition of systems thinking skills. This research was also carried out in one class without using a control class as a comparison. It is important to hone students' ability to examine a problem that exists in the surrounding environment, both in the economic, social and environmental fields, so teachers should include examples of cases that are close to the real world from three aspects (social, economic, environmental) to enrich student literacy in terms of sustainable development. It is hoped that students will be able to combine knowledge from the environmental, economic and social domains and put it into practice later in everyday life. Other activities should be included to encourage student creativity and the impact is directly felt by students economically (building entrepreneurship), for example, recycling waste into something useful and worth selling. The guide questions could be more detailed, clear and comprehensive to reveal students' system thinking abilities. This study was also limited by the data obtained in the form of student's written responses. Furthermore, the measurement tools used to evaluate system thinking skills could be expanded using questionnaires, concept maps, scenario-based assessment tools (Grohs et al., 2018) or with some of the assessment tools such as formative

assessment, self-assessment and metacognition, summative assessment modules and system thinking essays (Gilbert et al., 2019). Further research can be conducted on students with different levels and materials.

Conclusion

ESD-laden project-based learning of environmental change can moderately develop high school students' system thinking skills. Based on the study findings, it is recommended that teachers use and understand the PjBL syntax as well as the tested lesson plans and worksheets to develop students' systems thinking abilities. Further research is required of students at different stages and to look for hierarchies among the twelve indicators of systems thinking skills. Specific measurement tools also need to be developed to evaluate system thinking skills such as concept maps and sustainability literacy tests.

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Conflicts of Interest

No potential conflict of interest was reported by the authors.

Author Contributions

R. A. Ekselsa: Methodology; Analysis; Writing — original draft; Writing — review and editing. **W. Purwianingsih**: Writing — original draft; Writing — review and editing. **S. Anggraeni**: Writing — original draft, Writing — review and editing. **A. G. C. Wicaksono**: Writing — review and editing.

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