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Level of systems thinking competencies among senior high school students

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Abstract

Environmental issues are characterized by dynamism and complexity, which challenge traditional problem-solving approaches and demand adherence to sustainability principles. In this context, students need to be equipped with systems thinking competencies to better understand and address environmental problems. Systems thinking encompasses the ability to identify components within a system, understand their interrelationships, and manage uncertainty, diversity, and risks. However, there was a lack of empirical evidence on how secondary students conceptualize and apply systems thinking in real-world environmental contexts. This study aimed to assess the level of systems thinking competencies among senior high school students. The participants were 133 tenth-grade students enrolled in the 2024–2025 academic year in East Aceh. Data were collected using an essay-based test consisting of eight items developed from the systems thinking framework UNESCO. Criterion validity was analyze using Pearson correlation, while the reliability of the instrument was determined through Cronbach's Alpha (0.79, moderate). Descriptive statistics were used to analyze students' competencies levels. The results showed that most students were categorized at Level 1 (insufficient) and Level 2 (satisfactory), with a smaller portion at Level 3 (good). No students reached Level 4 (very good). These findings offer preliminary insights into students' systems thinking abilities and highlight the pressing need for effective educational interventions to strengthen their engagement with sustainable development. Therefore, the results provide a standard for designing targeted interventions aimed at advancing sustainable education.

Abstrak. *Isu-isu lingkungan yang terus berkembang menuntut penanganan yang kompleks dan berpihak pada prinsip keberlanjutan. Oleh karena itu, sangat penting untuk membekali siswa dengan kompetensi berpikir sistem sebagai bekal dalam menghadapi permasalahan lingkungan. Kompetensi berpikir sistem mencakup kemampuan mengenali dan memahami komponen serta hubungan timbal balik antarkomponen dalam suatu sistem yang kompleks, serta kemampuan menghadapi ketidakpastian dari tindakan yang diambil. Namun masih sedikit penelitian yang membahas tentang bagaimana siswa sekolah menengah mengonseptualisasikan dan menerapkan pemikiran sistem dalam konteks lingkungan dunia nyata. Penelitian ini bertujuan untuk mengetahui tingkatan kompetensi berpikir sistem siswa SMA. Sampel penelitian terdiri dari 133 siswa kelas X pada tahun ajaran 2024–2025 di Aceh Timur. Teknik pengumpulan data menggunakan instrumen tes berupa 8 soal esai yang disusun berdasarkan kerangka kompetensi berpikir sistem dari UNESCO. Analisi Data dengan uji Pearson dan Nilai Cronbach Alpha 0,79 (Sedang) dan Statistik Deskriptif untuk tingkatan berpikir sistem. Hasil penelitian menunjukkan bahwa sebagian besar siswa berada pada tingkat kompetensi kurang (Level 1) dan cukup (Level 2). Belum ditemukan siswa yang mencapai tingkat kompetensi baik (Level 3 dan 4). Penelitian ini memberikan gambaran awal mengenai kompetensi berpikir sistem siswa SMA serta menegaskan urgensi perlunya pengembangan intervensi pembelajaran yang tepat guna meningkatkan kemampuan berpikir sistem dalam rangka mendukung partisipasi aktif siswa terhadap pembangunan berkelanjutan. Oleh karena itu, hasil ini memberikan standar untuk merancang intervensi yang terarah dan bertujuan memajukan pendidikan berkelanjutan.*

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A. Introduction

Systems thinking competencies are defined as the ability to recognize and understand components in a system, the ability to analyse complex systems, the ability to understand how a systems is integrated in various domains and at various scales and the ability to deal with uncertainty (UNESCO, 2020). Environmental issues such as biodiversity loss, climate change and energy crisis that occur need to be handled as a whole from various interrelated components (Semiz & Teksöz, 2020). The presence of environmental problems that are still growing is the reason why systems thinking competencies should be embedded on students. Students with high goof systems thinking competencies contribute more to a sustainable future (Demssie et al., 2023). These international findings indicate the need to examine whether similar patterns occur among Indonesian students. This aligns with the goals of the Merdeka curriculum, which encourages students to respond to global issues and take action toward achieving the Sustainable Development Goals (SDGs).

Comparative results reveal that while some progress has been made in understanding systems thinking, significant gaps remain. For instance, Szozda et al. (2023) identified only basic systems thinking skills among chemistry students. Mambrey et al. (2022) reported even lower competencies at the primary level regarding ecosystems. Methodologically, Szozda et al. (2023) focused on general skill identification, whereas Mambrey et al. (2022) assessed students' understanding of ecosystem dynamics through structured tasks. These differences suggest that students' systems thinking competencies may vary depending on educational level and assessment method. However, little is known about whether these patterns persist in secondary education, particularly in biology contexts, highlighting a gap in the current literature. However, little is known about whether these patterns persist in secondary education, particularly in biology contexts.

Low competencies in systems thinking are also observed across various age levels. Students often face difficulties when working with complex systems, including comprehending how a system is connected and related overall (Keynan et al., 2014). Harangozo et al. (2018) further emphasized that several students fail to integrate causal relationship across environmental, economic, and social dimensions. As suggested by Mobus (2018) Systems thinking competencies requires one's ability to think causally, thus increasing students' tendency to question and think critically.

Evidence in Indonesia echoes these international trends, which is at level 1 (insufficient). The low competencies of students' systems thinking is because students have not been able to recognize and relate relationships between components, for example in the constituents of the ecosystem (Nuraeni et al., 2020). In addition, there is a gap in integrating the concept of systems thinking in schools (Haniyah & Hamdu, 2022). Similarly, Rustaman (2021) highlights that both school and university students have yet to develop systems thinking skills due to learning models that still emphasize fragmented content. The advancement of systems thinking abilities among Indonesian students continues to encounter significant obstacles (Azzahra et al., 2023).

Given the findings, there remains a notable gap in empirical studies assessing secondary-level students' systems thinking competencies through performance-based tasks, particularly within the Indonesian context. By enhancing their systems thinking abilities, students will be better equipped to analyse problems, make well-informed decisions, and play an active role in creating sustainable solutions. Cultivating this competencies are a fundamental element of science education standards and is crucial in preparing learners to face the complexities of real-world challenges (Stanfield et al., 2022; Woodin et al., 2010).

Systems thinking is essential in education because it helps students understand their place within broader ecosystems and fosters a deeper appreciation for sustainability (Azzahra et al., 2023; Ahmad et al., 2023). Systems thinking competencies help students understand how various environmental, economic, and social elements are interconnected within a larger system (Prayogo et al., 2024; Cebrián & Pubill, 2015). Systems thinking education aims to provide students with the knowledge, beliefs, and skills necessary to foster sustainability and make beneficial contributions to their communities (Sutanto, 2017).

Integrating systems thinking competencies among Indonesian students is crucial for addressing the complex challenges associated with sustainable development and enhancing educational effectiveness. Systems thinking, which emphasizes understanding interconnectedness and complexity within systems, aligns with national education goals aimed at developing critical thinking and problem-solving competencies while fostering a holistic perspective of knowledge (Kowch, 2019; Pasaribu, 2023).

Systems thinking fosters the ongoing enhancement of educational practices and facilitates contextualized learning experiences (Utomo et al., 2023; Juntunen & Aksela, 2014). Developing these competencies are essential to help achieve the SDGS. As one of the key competencies for sustainable development, systems thinking aligns with Indonesia's national vision to cultivate a generation that excels not only academically but also possesses a holistic awareness essential for building a sustainable future.

Mambrey's study underscores the critical need for systems thinking in comprehending ecosystems, particularly in equipping students to analyze the complexities inherent in ecological systems (Mambrey et al., 2022). The authors contend that addressing future ecological challenges effectively requires students to develop a deep understanding of ecosystem dynamics and the ability to identify the consequences of human actions within these systems. Similarly, research conducted by Sutinah et al. (2024) demonstrates that the integration of systems thinking within STEM education significantly enhances students' problem-solving abilities in environmental contexts. These findings further reinforce the essential role of systems thinking in ecological understanding.

Although the effectiveness of systems thinking in STEM education and educational leadership has been extensively explored (Flynn et al., 2019; Gunawan et al., 2023), a significant research gap remains in the comprehensive mapping of students' systems thinking competencies, particularly at the learner level. Existing studies tend to concentrate on curriculum design and the role of educators, while the availability of valid assessment tools and investigations into factors influencing students' systems thinking—such as cognitive styles, cultural background, and technological support—remain limited (Mahaffy et al., 2018; Mahsoon & Dolansky, 2019). Yet, a thorough understanding of these competencies are essential to prepare students for addressing global challenges (York et al., 2019). In addition, research on the factors influencing the mastery of this competencies—such as cognitive style, cultural background, or technological support—has not been thoroughly explored (Vidal, 2023). The urgency of this study lies in the pressing need to prepare future generations capable of addressing global challenges (such as the climate crisis or technological disruption) through systemic analytical skills. A comprehensive understanding of students' competencies profiles will serve as a foundation for developing targeted pedagogical methods, authentic assessments, and more effective education policies. The primary aim of this study is to assess the achievement of systems thinking competencies among senior high school students in Biology, particularly regarding the Ecosystem theme in Phase E.

B. Material and method

This study employed a quantitative research methodology with a cross-sectional design, which involves collecting data at a single point in time from a selected sample. The purpose of using this method was to obtain an objective and comprehensive overview of students' systems thinking competencies within the given period. This approach allows researchers to identify patterns, relationships, and differences among variables efficiently without the need for longitudinal observation (Creswell & Guetterman, 2019). The population of this study comprised Grade X senior high school students (Phase E) from 13 schools in East Aceh Regency. A total of 163 students participated during the 2024–2025 academic year. The sample was selected using purposive sampling, based on specific criteria such as the availability of mobile phones and internet access. Data on students' systems thinking competencies levels were collected using a research instrument comprising eight essay questions adapted to the UNESCO (2017) indicators of systems thinking. These indicators cover key aspects such as abilities to recognise, analyzing relationships and feedback, to think how system are embedded within different domains and to deal with uncertainty. Each question represented one indicator to assess students' understanding of system dynamics in relevant contexts.

The systems thinking competencies instrument used in this study underwent a construct validation process by expert lecturers, followed by a pilot test with relevant respondents. The validity of the instrument items was analyzed using the Pearson correlation test, while reliability was assessed using SPSS version 26. The validity test results indicated that the instrument items fell into the categories of very high, high, moderate, and some items required revision. From the eight items tested, seven were valid, consisting of two items with very high validity, four with moderate validity, and one requiring revision. The reliability analysis yielded a coefficient of 0.795, which is classified as moderate reliability. Students' responses were then scored using a systems thinking rubric developed based on the study by Feriver et al. (2019). The scores obtained by students were then interpreted based on the levels of systems thinking competencies adapted from the studies by Feriver et al. (2019) and Nuraeni et al. (2020) as presented in Table 1.

Tabel 1 Levels and criteria of systems thinking

Percentage value	Level	Criteria
76% - 100%	Level 4	Very good
51% - 75%	Level 3	Good
26% -50%	Level 2	Satisfactory
<25%	Level 1	Insufficient

(Source: Feriver et al., 2019 and Nuraeni et al., 2020)

C. Results and discussion

The validity and reliability of the instrument were tested on 30 pilot respondents selected randomly from a total of 163 participants, in accordance with the minimum sample requirements for instrument testing. The results of the validity test using SPSS version 26 are shown in Table 2.

Table 2 Student systems thinking item instrument validity test results

No question	Pearson correlation	Value sig.	Description	Criteria
1	0.822	0.000	Valid	Very high
2	0.147	0.437	Invalid	Revised
3	0.723	0.000	Valid	High
4	0.431	0.017	Valid	Enough
5	0.822	0.000	Valid	Very high
6	0.692	0.000	Valid	High
7	0.613	0.000	Valid	High
8	0.720	0.000	Valid	High

Table 3 Results of item reliability test

Reliability statistics	
Cronbach's alpha	**N of items**
0.795	8

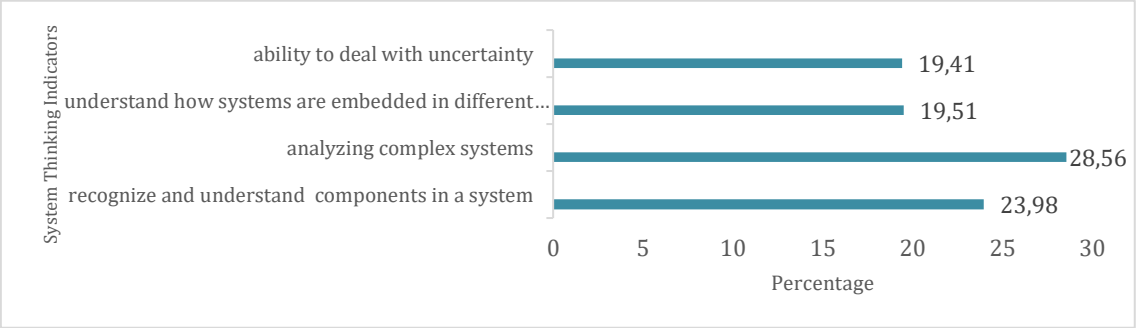

Figure 1 Percentage achievement of systems thinking competencies in each indicator

Based on the results of the validity test of student systems thinking competencies items displayed in Table 2, of the eight items tested, seven were declared valid because they had a significance value (sig.) smaller than 0.05, while one item was declared invalid because it had a significance value (sig.) greater than 0.05. The invalid item was subsequently revised to improve its clarity and alignment with the intended indicator before being retained in the final instrument. Based on the validity criteria according to Arikunto (2016), it is known that two items have very high validity criteria with Pearson correlation values (r) in the range of 0.80-1.00. This indicates that the items are of very good quality and can be used without the need for revision.

The reliability analysis produced a Cronbach's Alpha coefficient of 0.795, reflecting a moderate degree of internal consistency. This implies that the instrument is adequately reliable for research application, though additional revisions may further strengthen its reliability (see Table 3). Descriptive statistical analysis of this variable is necessary to provide an overview of the data, including the mean, maximum value, minimum value, standard deviation, skewness, and kurtosis to identify outliers. Descriptive statistical tests in this study were carried out using SPSS 26.

Based on the results of descriptive statistical tests on the systems thinking competencies variable, the number of valid data is 133, indicating that there is no missing data (missing value). The minimum value on this variable is 1, while the maximum value is 20, with a total overall value (sum) of 798. The mean was 6.00, indicating that in general the respondents' level of systems thinking competencies was in the moderate level. The standard deviation of 3.210 indicates a moderate variation in values, meaning that the distribution of data is not too small (homogeneous) but also not too large (heterogeneous) among respondents. The greater the Sd value, the greater the variation in the data.

The results of the normality analysis indicate that the data distribution is generally acceptable for further statistical testing. Although slight deviations from normality were observed, the distribution remains representative of the population, allowing subsequent analyses to be conducted without data transformation.

The percentage of achievement of systems thinking competencies for each indicator (UNESCO, 2017) are shown in Figure 1. Based on the criteria guide according to Feriver et al. (2019) and Nuraeni et al. (2020) the majority of the achievements of the four indicators of student systems thinking are at level 1. Pedagogically, the low scores on certain indicators, such as understanding how system are embedded in different domain and scales (19.51%) and dealing with uncertainty (19.14%) may be

attributed to limited opportunities for students to engage in learning activities that require higher order cognitive processes. For example, conventional instructional approaches that emphasize rote memorization or isolated concept learning may not provide sufficient experiences for students to anticipate outcomes in uncertain contexts.

Indicators that show percentages above 25% are indicators of systems thinking competencies, namely analyzing complex systems. While the indicators of systems thinking recognize and understand relationships, understand how systems are embedded in different domains and scales and the competencies of systems thinking to deal with uncertainty have a percentage below 25% or are in the insufficient criteria.

More specifically, the percentage was 23.98% for the first indicator, recognising and understanding the relationship between elements in a system. This indicates that the majority of the students were not able to fully understand the relationship between the components in a system. For instance, the interdependence of producers, consumers, and decomposers within an ecosystem, as well as the interactions between biotic and abiotic components, may not be fully understood by students. Students often perceive organisms in isolation from their environmental surroundings when they are unable to understand these systemic interactions. Ecological misconceptions, such as the belief that ecosystems are constant despite changes in their surroundings, are frequently caused by this fragmented understanding. From a cognitive point of view, this illustrates learners' difficulties integrating disparate ideas into cohesive mental models and conceptual integration. These misunderstandings occur when students base new information on incomplete or false preconceptions, according to constructivist learning theory, which highlights the necessity of teaching strategies that support conceptual development through inquiry and contextual learning. This is supported by research conducted by Feriver et al. (2019), understanding the relationships between components in the ecosystem is very important because it is the basis of systems thinking, which emphasises the ability to see how different elements in a system affect each other. Without a strong understanding of these relationships, it is difficult for students to comprehensively analyse problems and find effective solutions.

Furthermore, the second indicator of systems thinking, namely the analysis of complex systems, has a percentage of 28.56% at level 2 with satisfactory criteria. This shows a slightly better performance. However, there is still room for improvement. This can be achieved through learning activities that involve system modelling, simulations, or problem-based projects, which help students visualize relationships among variables and strengthen their analytical understanding of complex systems.

The third indicator scored 19.51%. This was achieved with insufficient criteria. This means that students were not able to understand how an ecosystem interacts with other systems around it, both on a larger scale and on a smaller scale, as well as how social, economic and environmental factors affect the dynamics of an ecosystem. For example, many students have not been able to explain how the impact of deforestation activities in one place can affect climate change on a local and global scale and can also affect the environment, the economy and the social life of the population. In other words, students need to understand that a system does not stand alone, but is part of a wider and more complex network of systems. This understanding will enable students to analyze problems from multiple perspectives and identify more holistic and sustainable solutions.

The fourth indicator of systems thinking is the ability to deal with uncertainty. 19.41% of the students scored at level 1 of systems thinking for the insufficient criteria. This indicates that most students could not demonstrate the ability to handle uncertainty. Students may lack experience in dealing with unexpected situations. They may be used to problems that have definite and clear answers. Uncertainty often arises because of system complexity. If students do not yet have an understanding of the interconnections and feedbacks in ecosystems, they will have difficulty in predicting or responding to unexpected changes (Semiz & Teksöz, 2020). It is therefore important to provide learning experiences that challenge students to manage uncertainty, develop adaptive strategies and understand system complexity (Feriver et al., 2019).

In the local context, students in this study demonstrated comparable challenges, particularly in recognizing interrelationships and managing complexity within environmental systems. The findings of this study are consistent with those of Feriver et al. (2019) which showed that lacking systems thinking skills is a widespread problem, even among individuals at different levels of education. Furthermore, identified a similar barrier, low understanding and application of systems thinking affects not only educational effectiveness but also professional teaching practices. Consistent with these findings, Jaiswal & Karabiyik (2022) found a systems thinking skill's gap among undergraduates, with only 16% demonstrating basic systems thinking skills. Collectively, these findings highlight the importance of enhanced education emphasising systems thinking skills development to face complex challenges across disciplines.

Integrating Education for Sustainable Development (ESD) into the curriculum is one method of instruction that can provide students the skills they

need to think in systems. In order to better educate students to handle the difficulties of sustainable development in the future, this approach has demonstrated promise in enhancing their capacity to analyze the interconnection and complexity of systems (Azzahra et al., 2023; Guerra et al., 2022). The use of inquiry-based learning models is also effective in fostering the development of systems thinking, as students are trained to connect concepts, analyse systems, and understand the relationships between components in depth through exploratory activities (Kaur et al., 2019). Another strong approach that supports the development of systems thinking is the project-based learning (PjBL) learning model. This model emphasises real-world applications and complex problem solving, which are important aspects in developing systems thinking competencies in students (Mazur et al., 2021).

The findings indicate that students' systems thinking competencies are still at a moderate level, highlighting the need for targeted instructional strategies to enhance these skills. The results reveal that students have a reasonable level of systems thinking competencies, highlighting the need for teaching methods that improve these abilities substantially. The educational experiences of learners can therefore be enhanced and their ability to comprehend and address difficult issues holistically improved by the use of multiple learning models as ESD Integration, Inquiry-Based Learning, and Project-Based Learning. These models encourage critical and reflective thinking, enabling students to connect knowledge across disciplines. In turn, this fosters a deeper awareness of sustainability issues and prepares learners to become responsible global citizens.

D. Conclusion

Based on the survey results of students' systems thinking competencies, it can be seen that the achievement of systems thinking competencies are in the insufficient category (Level 1) in the indicators of recognizing and understanding relationships, understanding how systems are embedded in different domains and scales, and the ability to deal with uncertainty. The level of competencies in systems thinking is satisfactory (Level 2) on the indicator of analyzing complex systems. Based on these findings and supported by previous studies, it is recommended to implement learning approach that integrate ESD principles and systems-oriented pedagogies through the use of inquiry-based learning, project-based activities, and contextual teaching materials. To address these gaps, future instructional designs should incorporate ESD principles through the integration of effective pedagogical methods, learning models, student worksheets (LKPD), and teaching modules. Such integration can help students strengthen their systems thinking competencies and progress toward higher proficiency levels aligned with sustainability-oriented education goals.

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