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EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD) COMPETENCY IN PHYSICS LEARNING ASSESSMENT: PRE-SERVICE TEACHERS' THINKING SKILLS BASED ON ETHNO-SOCIO-SCIENTIFIC CONTENT

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ABSTRACT

This research examines the ESD competency levels—specifically systems thinking, anticipatory thinking, and critical thinking—among pre-service physics teachers within ethno-socio-scientific content, aiming to equip future educators with the skills, knowledge, and attitudes needed to promote sustainability and address global environmental and social challenges. A quantitative approach was employed, with a sample of 83 pre-service physics teacher students from a Physics Education program at a university in Aceh, Indonesia. This research instrument consists of eight multiple-choice questions for each competency. Validity and reliability analyses, using the Rasch model, confirmed the instrument's robustness, yielding high-reliability scores (person reliability = 0.82, item reliability = 0.84, Cronbach's alpha = 0.85). The results reveal variations in competency levels: anticipatory thinking is the strongest, critical thinking is the least developed, and systems thinking is moderate. Correlation analysis indicates positive and moderate relationships among the competencies, highlighting the importance of integrated ESD competency development. The success of Education for Sustainable Development (ESD) requires a holistic approach that fosters the development of all relevant competencies. Prioritizing critical thinking is essential, as it is a foundation for enhancing other competencies. Educational systems should focus on cultivating systems thinking and anticipatory thinking, as these are interconnected and mutually reinforcing in the transformation toward sustainability. Additionally, the findings suggest that the comprehensive integration of ESD into the physics education curriculum can enhance pre-service teachers' capacity to engage effectively with sustainability issues. By incorporating ethno-socio-scientific contexts, this approach deepens the ethnic, social, and contextual relevance of physics concepts, thus preparing future educators to address sustainability challenges.

Keywords: critical; system; anticipatory; thinking

INTRODUCTION

Achieving the Sustainable Development Goals (SDGs) requires transforming the education system to equip future generations with critical competencies in solving global problems, such as climate change, social inequality, and environmental conservation. Education, especially in science, is central to forming a sustainability-based mindset (UNESCO, 2017). Quality education is fundamental to achieving the Sustainable Development Goals (SDGs). To support this vision, one key educational approach is Education for Sustainable Development (ESD), which integrates the principles, values, and practices of sustainable development into all aspects of education and learning. ESD aims to equip individuals, especially pre-service teachers, with the knowledge, attitudes, and skills necessary to build a more sustainable society. It fosters environmental awareness and critical thinking about pressing global challenges such as climate change, envi-

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ronmental degradation, and biodiversity loss. By engaging with ESD, students gain a deeper understanding of how education connects with broader SDG components, particularly Goal 4 (Quality Education), Goal 13 (Climate Action), Goal 14 (Life Under Water), and Goal 15 (Life on Land).

UNESCO has formulated key competencies for Education for Sustainable Development (ESD), particularly from the perspective of thinking. These include systems thinking, anticipatory thinking, and critical thinking, which are essential for addressing sustainability challenges. Systems thinking, in particular, is crucial for helping pre-service teachers understand the complexity of global problems (UNESCO, 2017). This ability represents an interdisciplinary skill that reflects cognitive flexibility in identifying and solving real-world societal issues (Grohs et al., 2018; Marcos-Sánchez et al., 2022; Uskola & Puig, 2023) . ESD integrates systemic thinking to help pre-service teachers recognize the interconnections between environmental, social, and economic dimensions (Widarti & Roshayanti, 2021).

Furthermore, ESD encourages creative and critical thinking in responding to ongoing global challenges (Aisyah et al., 2024). The successful implementation of ESD depends not only on curriculum integration but also on the strategic role of educators in higher education institutions (Mardian, 2023; Vioreza et al., 2023). Developing ESD competencies in pre-service teachers is therefore vital, as these competencies prepare them to face increasingly complex global issues in the context of sustainable development (Azzahra et al., 2023). Anticipatory competence in ESD is adapting creativity and effective decision-making. By considering future scenarios, pre-service teachers with anticipatory skills can be better prepared to face risks and challenges that have not yet occurred (Lestari et al., 2024b).

Critical thinking in ESD is a person's ability to think rationally with good, logical, and factual reasoning as a basis for making decisions. (Razak et al., 2022). Pre-service teachers require critical thinking skills to analyze problems thoroughly and question the assumptions underlying arguments (Sutiani et al., 2021; Phillips, 2023). This results in pre-service teachers being able to find effective and appropriate solutions.

Implementation of ESD competencies, which include systems thinking competencies, anticipatory competencies, and critical thinking, can be applied in learning in all subjects, including physics. Learning physics can develop an in-depth understanding for pre-service teachers of natural and technological phenomena and their implications for the environment and society (Masruro et al., 2021; Lestari et al., 2024a). Physics also plays an important role in developing environmentally friendly science and technology. The resulting technological products are based on applying physical principles (Suryanti et al., 2021).

Physics learning has a very significant role in supporting ESD competencies. It aims to equip learners with the knowledge, skills, values, and attitudes to contribute to a sustainable future. To achieve this, physics education must go beyond abstract theories and become more contextualized, engaging students with real-world issues such as energy use, climate change, and sustainable technology (Prayogi & Verawati, 2024). Integrating ESD in the physics curriculum enriches pre-service teachers' knowledge and trains their skills as an internal preparation to face various global challenges in the future (Jauhariyah et al., 2021). The application of ESD in physics learning requires adjustments in learning assessment. Ethno-socio-scientific-based learning assessments are needed to support ESD competencies by making physics learning more relevant and contextual (Febrian et al., 2024). These assessments connect scientific content with local cultural (ethno-) practices and societal (socio-) issues, making learning more relevant to students' lived experiences and community contexts. In essence, ethno-socio-scientific approaches serve as a bridge between physics content and the goals of ESD by ensuring that learning is not only scientifically accurate but also socially and ethnically grounded. This prepares pre-service teachers with knowledge and the ability to apply physics in meaningful, inclusive, and sustainable ways for diverse communities.

Ethnoscience-based learning integrates learning materials with the local environment and culture (Saro et al., 2022; Siyati & Kamariyah, 2022). Ethnoscience-based learning is an approach that uses local knowledge (ethnoscience) as the basis for science learning—integrating Indigenous community science with scientific science and utilizing all richness and local wisdom to enhance student understanding (Sudarmin et al., 2017). It aims to obtain meaningful learning where students are directly involved with the environment during their activities. Local wisdom-based learning (ethnoscience) needs to be implemented in the curriculum to improve the quality of education (Muliani et al., 2022). Meanwhile, socio-scientific learning relates science to social and everyday life issues (Högström et al., 2024). This learning uses an approach where socio-scientific becomes more valuable, and students can apply scientific knowledge to life to develop critical thinking skills (Falah et al., 2024).

However, integrating Education for Sustainable Development (ESD) in physics learning remains limited, particularly in assessments that evaluate ESD competencies, such as critically connecting scientific concepts to sustainability challenges within ethno-socio-scientific contexts. Current assessments often focus narrowly on theoretical knowledge, failing to measure how pre-service teachers apply physics principles (e.g., energy conservation, climate dynamics) to address real-world issues that intertwine cultural practices (ethno), societal needs (socio), and scientific inquiry. This research urgently addresses this gap by designing assessments that embed ethno-socio-scientific contexts into their framework. This approach measures ESD competencies and cultivates educators capable of fostering interdisciplinary, ethnically responsive solutions to planetary challenges.

Learning assessments are implemented under current curriculum developments. The curriculum was adopted to lead to autonomous learning to improve the quality of education (Jauhariyah et al., 2021). Curriculum Independence, which is currently applied to universities, implements the Education for Sustainable Development (ESD) program. However, ESD implementation has not been carried out optimally. One is marked by the absence of a learning assessment to explore ESD competency in pre-service teachers' thinking abilities.

Previous research results stated that the implementation of ESD has only been applied to aspects of the learning model, modules used, learning media, and learning tools (Pradipta et al., 2021; Fibonacci et al., 2020). However, these studies have not in-depth explored aspects of learning assessment as a tool for measuring and mapping ESD competencies, especially at the tertiary level. Learning in higher education on the independent curriculum has used various learning models to build the thinking skills of pre-service teachers with problem-solving and project-based learning. However, the assessment form is still limited to assessing learning outcomes, projects, and student activity. This shows that existing assessments have not fully measured ESD competency holistically, especially regarding thinking ability. Moreover, no assessment measures ESD competencies that include ethnoscience and social-science contexts. This gap highlights the need for further research to develop assessment instruments that comprehensively map ESD competencies.

Based on the analysis, the novelties in this research include using learning assessments to map ESD competencies, especially from thinking abilities, and integrating ethno-socio-scientific content in physics learning assessment. This study focuses on the context of higher education and pre-service teachers, which has not been widely explored in previous studies. This research is expected to contribute significantly to developing theory and practice in implementing ESD, especially in the context of assessment in higher education. It can become a reference in strengthening the capacity of pre-service teachers to realize science education that is responsive to the SDGs while preserving local wisdom values as the foundation of sustainable development.

METHODS

A quantitative research design was used to measure the ESD competencies possessed by pre-service teachers in terms of thinking ability. The population in this study were pre-service teachers in the physics education study program in Aceh. The sample for this research was 83 pre-service teachers who had completed the introductory physics course. The instrument consists of 8 multiple-choice questions explaining each ESD competency. These questions refer to the ESD competency indicators based on aspects of thinking consisting of systems thinking competence, anticipatory competence, and critical thinking (UNESCO, 2017).

Table 1. Thinking Competency in Ethno-Socio-Science

ESD Competency	Indicator
System thinking	Recognize and understand relationships in ethnoscience or social science in life.
	Analyze complex systems in social science.
	Discuss how systems are embedded in various domains and scales by linking physics concepts with social science.
	Face uncertainty by linking physics concepts with ethnoscience and social science.

Anticipatory competency (Future thinking)	Understand and evaluate various possibilities, opportunities, and necessary things by linking physics concepts in social science and ethnoscience.
	Create a vision for the future in social science.
	Apply the precautionary principle to assess the consequences of an action.
	Handle risk and change in social science.
Critical thinking	Question norms, practices, and opinions by linking physics concepts with ethnoscience and social science.
	Reflect on one's values, perceptions, and actions by linking physics concepts with ethnoscience and social science.
	Take a position in the sustainability discourse by linking physics concepts with ethnoscience.

The questions are prepared based on ESD thinking skill indicators based on Table 1 with an ethnoscience and socioscience context related to understanding physics concepts. The preparation of questions with an ethnoscience context aims to integrate local culture, cultural practices, and the environment into the learning evaluation system. Meanwhile, the questions have a social-science context by connecting science, especially physics, with social issues, social norms, environmental habits, and problems in everyday life.

These questions have previously been tested for validity and reliability using the modern analysis Rasch model using an application Winstep. The item criteria, as shown in Table 2, are declared valid (fit) for the Rasch model by looking at the fulfillment of 2 of the following three values: 1) Outfit Mean Square value: $0.5 < MNSQ < 1.5$; 2) Z-Standard outfit value (ZSTD): $-2.0 < ZSTD < +2.0$; 3). Nilai Point Measure Correlation (Pt Mean Corr): $0.4 < Pt.\ Measure\ Corr < 0.85$ (Sumintono & Widhiarso, 2015). The questions met the valid requirements according to their suitability with the Rasch model and were reliable with a person reliability of 0.82, item reliability of 0.84, and Cronbach's alpha of 0.85, which means good. The difficulty level of the questions also varies from easy to difficult, with an item separation of 5.6, which means it can group respondents with various abilities.

Table 2. Criteria for Difficulty Level, Person/Item Reliability, and Cronbach's Alpha

Difficulty Level		Person/Item Reliability		Cronbach's Alpha	
b>SD	Very difficult	0.71-0.80	Enough	>0.8	Very good
0.0 <b≤SD	Difficult	0.81-0.90	Good	0.6-0.79	Good
-SD<b≤0.0	Easy	0.91-0.94	Very good	0.4-0.59	Enough
b≤-SD	Very easy	>0.94	Special	0.2-0.39	Low
				<0.2	Very Low

The data analysis technique used to describe each indicator of ESD competency of prospective physics teachers is percentage analysis. The percentage of ESD competency of prospective physics teachers is obtained using ESD competency assessment instruments with ethnoscience and social-science contexts calculated using the percentage formula (Sudijono, 2018) by adding up the achievement scores of prospective physics teachers, dividing by the maximum score, then multiplying by 100. The percentage data results are then interpreted based on the five criteria for ability levels using the guidelines in Table 3. Meanwhile, the Pearson correlation analysis technique was used to interpret the correlation coefficient value to determine the relationship between variables in this research.

Table 3. Percentage of ESD Competency of Pre-Service Physics Teachers

No	Percentage	Criteria
1	81%≤x≤100%	Very High
2	61%≤x≤80%	High
3	41%≤x≤60%	Moderate
4	21%≤x≤40%	Low
5	0≤x≤20%	Very Low

RESULTS AND DISCUSSION

The ESD (Education for Sustainable Development) competencies involve the cognitive and mental processes necessary to promote sustainable development. The education for sustainable development framework encompasses a holistic approach to fostering the knowledge, skills, and mindsets necessary to address sustainability's complex and interconnected challenges. These competencies include several key elements: Systems Thinking, Critical Thinking, and Anticipatory Thinking (Mochizuki & Fadeeva, 2010; Ichinose, 2019; Glavič, 2020; Ssossé et al., 2021; Yuan et al., 2022). Systems Thinking entails understanding the interconnectedness and complexity of systems, such as environmental, social, and economic systems, and recognizing how actions in one area can impact others (Flood, 2010; Cabrera & Cabrera, 2023). Critical thinking involves questioning assumptions, critically analyzing information, and evaluating arguments to make informed decisions that contribute to sustainable outcomes (Dwyer et al., 2014; Straková & Cimermanová, 2018; Turan et al., 2019). Anticipatory thinking focuses on long-term consequences and the sustainability of current actions and decisions rather than immediate benefits (Peter & Jarratt, 2015; Ojala, 2017). Statistical measures of the thinking skills of pre-service physics teachers are shown in Table 4.

Table 4. Statistical Measure of Pre-Service Physics Teachers' Thinking Skills

ESD Competency	Mean	Median	Mode	Standard Deviation	Minimum	Maximum	Count
Systems Thinking	55.12	56.25	56.25	18.11	12.50	93.75	83
Critical Thinking	41.87	37.50	50.00	15.30	12.50	87.50	83
Anticipatory	54.22	50.00	75.00	19.74	12.50	75.00	83

The mean score for Systems Thinking is 55.12, with the median and mode at 56.25. This result suggests that the central tendency of the data is around 56.25, with most participants scoring near this value. The standard deviation of 18.11 indicates a moderate spread of scores around the mean. The minimum score is 12.50, and the maximum is 93.75, showing a wide range of abilities in Systems Thinking among the participants.

For Critical Thinking, the mean score is 41.87, with a median of 37.50 and a mode of 50.00. This result indicates a slightly lower central tendency than Systems Thinking, with a broader difference between the mean, median, and mode, suggesting some variability in the scores. The standard deviation is 15.30, slightly lower than Systems Thinking, indicating a somewhat tighter clustering of scores around the mean. The range of scores, from 12.50 to 87.50, indicates a considerable variation in Critical Thinking skills among the participants.

Regarding Anticipatory Competence, the mean score is 54.22, with the median at 50.00 and the mode at 75. This result suggests that while the central tendency is slightly lower, there is a significant cluster of higher scores (75). The standard deviation is the highest among the three competencies at 19.74, indicating the most considerable response variability. The range of scores is from 12.50 to 75.00, showing a broad spread of abilities in anticipating future needs and conditions among the participants.

When compared, systems thinking and anticipatory competence have higher mean scores than critical thinking, suggesting that participants might feel more confident or skilled in these areas. Anticipatory competence shows the highest variability, implying that while some participants are experienced, others might struggle in this area. The distribution of scores shows that Systems Thinking is more consistently high across participants. At the same time, Critical Thinking has a lower and tighter distribution, indicating it might be an area for potential development.

The relatively lower performance in critical thinking becomes more significant when this competence is assessed through the lens of ethnoscientific and socio-scientific issues. In the context of ethnoscience, participants are exposed to topics such as the physics concepts embedded in traditional musical instruments (e.g., resonance, vibration, and sound waves in instruments like *serune kalee*, *gamelan*, or *taganing*) and traditional customs across the Indonesian archipelago, which are often linked to local wisdom regarding energy use and environmental management. The ability to question norms, practices, and opinions in such ethnically sensitive contexts poses a challenge, as it may involve critically evaluating long-held traditions and beliefs. Participants may hesitate to engage critically with ethnic heritage out of respect for ancestral practices and community values.

Furthermore, the ability to reflect on one's values, perceptions, and actions becomes especially demanding when participants confront deeply rooted ethical practices, such as traditional resource use or local explanations of natural phenomena. These reflections may evoke internal cognitive and emotional dissonance, requiring participants to reassess their personal beliefs concerning scientific reasoning and sustainability.

The third critical thinking indicator, taking a position in sustainability discourse, is also complex when applied to socio-scientific issues such as the tension between environmental preservation and local economic needs. For example, evaluating the traditional use of forest wood for musical instruments or ceremonial practices requires participants to weigh ethnic significance against ecological impact. Taking a stance in such multidimensional dilemmas necessitates informed judgment and the courage to assert a critical position, which not all participants may be prepared to do.

In contrast, systems thinking and anticipatory competence—although also contextualized through ethno-socio-scientific issues—are perceived as more accessible. Participants may more comfortably analyze systems or forecast potential outcomes without directly confronting ethnic identities or personal values. For instance, mapping the environmental impact of traditional practices or analyzing acoustic systems in local instruments can be approached from a technical or analytical perspective.

Figure 1 reveals a varied distribution of ESD competencies among pre-service physics teachers, indicating strengths and areas needing improvement.

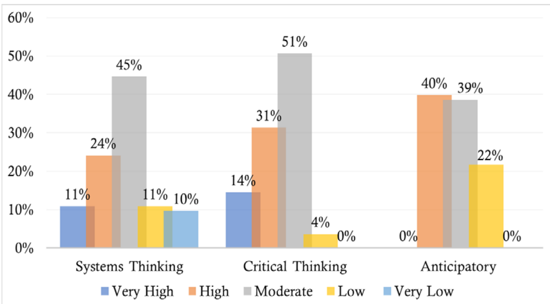

Figure 1. ESD Competency of Pre-Service Physics Teachers

In Systems Thinking, 35% of participants exhibit strong competencies (classified as "very high" and "high"), while a substantial proportion (21%) ranks within the "low" and "very low" categories. This distribution indicates that many pre-service Physics teachers may require additional support. Consequently, there is an evident need for targeted interventions to enhance these competencies comprehensively. Strengthening these skills will enable future Physics educators to deliver higher-quality education, as they will be better equipped to engage students effectively, facilitate the understanding of complex concepts, and promote a more profound comprehension of Physics (Dekker, 2016; Wenning & Vieyra, 2020; Iqbal et al., 2022). Critical thinking appears to be the strongest area, with 45% of participants categorized as very high or high and over half (51%) falling into the moderate category. The absence of participants in the very low category is promising, showing that all individuals possess at least foundational skills in critical analysis. However, with 4% still in the low category, there remains room for improvement, particularly in helping more participants advance from moderate to high levels of critical thinking.

On the other hand, anticipatory competence emerges as a significant area of concern. No participants are classified as very high, and 22% fall into the low category, which suggests challenges in the ability to foresee and plan for future scenarios. Although 40% are in the high category, the lack of participants in the very high range highlights a potential gap in anticipatory skills. The call for education that can contribute to a sustainable future has resulted in the "Education for Sustainable Development" campaign (Holfelder, 2019). This underscores the need for curriculum enhancements focused on future-oriented thinking and planning, which are crucial for effective education in sustainable development. Embedding ESSIs as thematic anchors within the curriculum allows learners to explore ethnically relevant issues—such as the future of forest resource use in traditional crafts—while considering environmental, social, and scientific dimensions. Approaches such as backcasting can further enhance this competence by enabling students to define a desirable future and work backward to identify necessary actions and decisions. Anticipatory competency, which involves the ability to understand and evaluate multiple possible, probable, and desirable, is essential for empowering students to engage with the interdisciplinary learning methodologies that address the complex economic, social, and environmental aspects of both the formal and informal curriculum (Bohnet et al., 2010; Khadri, 2022).

The proficiency of pre-service physics teachers in critical thinking is strong, but their abilities in systems thinking and anticipatory competencies are underdeveloped. This suggests a need for a more comprehensive approach to education, especially sustainability education. These skills are crucial for educators to recognize the broader implications of their teaching and anticipate future challenges (Levrini et al., 2021). Curriculum adjustments can enhance these competencies by integrating project-based learning and interdisciplinary approaches. Reflective practices in teacher education programs have also been shown to improve these skills. Prioritizing these competencies can produce educators capable of fostering a generation of learners prepared to tackle the complex challenges of the future (Satriawan et al., 2022; Scupelli, 2022).

Table 5 represents the ESD competencies of pre-service physics teachers, explicitly focusing on their thinking skills in a socio-scientific context across three key competencies: Systems Thinking, Critical Thinking, and Anticipatory thinking.

Table 5. Statistical Measure of Pre-Service Physics Teachers' Thinking Skills in Socio-Scientific Context

ESD Competency	Mean	Median	Mode	Standard Deviation	Minimum	Maximum	Count
Systems Thinking	53.31	50.00	50.00	16.57	0.00	87.50	83
Critical Thinking	68.07	50.00	50.00	25.40	0.00	100.00	83
Anticipatory Thinking	71.69	100.00	100.00	32.38	0.00	100.00	83

The mean score for Systems Thinking is 53.31, slightly above the midpoint. The median and mode are 50.00, indicating that most participants' scores cluster around this value. The standard deviation of 16.57 suggests that while there is some variability, most scores are close to the mean. The minimum score of 0.00 indicates that some participants struggle significantly with Systems Thinking within a socio-scientific context. In contrast, the maximum score of 87.50 shows that others have a stronger grasp of this competency.

Critical thinking has a higher mean score of 68.07, indicating that pre-service physics teachers perform better in this competency than in Systems Thinking. However, the median remains at 50.00, suggesting that while many participants perform well, there is a wide range of abilities. The standard deviation of 25.40 is higher than in Systems Thinking, indicating greater variability in Critical Thinking abilities among participants. The maximum score of 100.00 reflects that some participants have fully developed critical thinking skills, while the minimum of 0.00 shows that others may need considerable support.

Anticipatory Thinking has the highest mean score at 71.69, with the median and mode at 100.00. This data suggests that most participants are proficient in anticipating and planning for future scenarios within a socio-scientific context. However, the standard deviation of 32.38 is the highest among the three competencies, indicating a wide range of abilities. The fact that the minimum score is 0.00 again shows that some participants struggle with this competency. The data indicates that future physics teachers have different proficiency levels in three key competencies related to socio-scientific issues: Anticipatory Thinking, Critical Thinking, and Systems Thinking. Anticipatory Thinking appears to be the strongest competency, with many participants scoring at the maximum level. This finding suggests that many future teachers are well-prepared to think ahead and plan for future scenarios, which is crucial in socio-scientific contexts.

Critical thinking also shows strong results, with a higher mean score than Systems Thinking. However, the greater variability in scores suggests that while some participants excel, others may need additional support to develop their critical thinking abilities. This competency is vital for analyzing and evaluating complex socio-scientific issues, making it an area for potential focus in teacher training programs (Pithers & Soden, 2000; Liu et al., 2014; Shutaleva, 2023).

Although moderately strong, systems thinking shows the lowest mean and a narrower distribution around the median. This information indicates that most participants have a basic understanding of interconnected systems, but there is less variability in their proficiency. The lower minimum score suggests that some participants struggle to fully grasp the complexity of systems in socio-scientific contexts, highlighting a potential area for curriculum enhancement (Zohrabi, 2011; Prasetyono et al., 2021).

Pre-service physics teachers demonstrate strong skills in Anticipatory and Critical Thinking within the context of socio-scientific issues. This competency positions them well to anticipate and critically evaluate future trends and challenges in science education. Anticipatory Thinking allows these educators to envision possible scenarios, enabling them to develop forward-looking curricula that prepare students for the changing landscape of scientific and technological advancements (Sitta et al., 2023). On the other hand, Critical Thinking equips them with the analytical skills needed to assess complex information, fostering a classroom environment that promotes evidence-based reasoning and thoughtful discussions on socio-scientific issues (Liu et al., 2014).

Despite these strengths, there is a significant gap in their Systems Thinking skills—a skill increasingly recognized as crucial in addressing the multifaceted nature of socio-scientific issues. Systems Thinking enables educators to understand and demonstrate the interconnectedness of various scientific, social, and environmental factors, which is vital when dealing with climate change, public health, or sustainability topics (Carey et al., 2015; Lehtonen et al., 2018). Without a strong foundation in Systems Thinking, pre-service teachers may struggle to help students grasp the complexity and interconnectedness of real-world problems, leading to a fragmented understanding of science and its applications (Iacovidou et al., 2021; Cabrera et al., 2023).

International research emphasizes the importance of integrating Systems Thinking into teacher education programs. For instance, studies have shown that incorporating interdisciplinary approaches that blend physics with other disciplines, such as environmental science, economics, and ethics, can significantly enhance Systems Thinking skills (Lutzenhiser, 1994; Stock & Burton, 2011; Wagner et al., 2011; Sudarmin et al., 2020; Iacovidou et al., 2021). These competencies broaden their perspective and help them establish connections between different knowledge domains, which is essential for teaching complex socio-scientific issues.

Furthermore, project-based learning has been recognized as an effective teaching approach for developing Systems Thinking (Kokotsaki et al., 2016; Nagarajan & Overton, 2019; Elsawah et al., 2022). By participating in projects that require them to solve real-world problems, pre-service teachers learn to navigate the complexities of interconnected systems, considering the social, economic, and environmental impacts of scientific decisions. This hands-on experience is invaluable for preparing them to guide their future students through similarly complex issues.

The rapidly changing world these educators will teach further highlights the need to strengthen these competencies. As global challenges become more intricate and intertwined, thinking systemically and anticipating future developments will be crucial (Godet, 2000; Arnold & Wade, 2015). Teachers well-versed in Systems Thinking will be better equipped to help their students understand the broader implications of scientific knowledge, fostering a generation of learners who are prepared to tackle the complex socio-scientific challenges of the future (Dlouhá et al., 2019; Elsawah et al., 2022).

Continuous professional development and reflective practices are key to developing these competencies. International research suggests that engaging pre-service teachers in reflective exercises and critically evaluating their teaching practices and the outcomes of their instructional strategies can deepen their understanding of Systems Thinking (Liou, 2001; Sempowicz, 2012). This ongoing process of reflection and adaptation ensures that educators remain responsive to new challenges and developments in science education throughout their careers.

In conclusion, while pre-service physics teachers demonstrate commendable strengths in Anticipatory and Critical Thinking within the socio-scientific context, there is a clear and urgent need to enhance their Systems Thinking skills. Doing so will improve their ability to navigate and address complex socio-scientific issues and prepare them to meet the challenges of teaching science in a rapidly changing world, ultimately leading to more effective and impactful science education.

Figure 2 shows pre-service physics teachers' competencies in three areas—Systems Thinking, Critical Thinking, and Anticipatory Thinking—within a socio-scientific context.

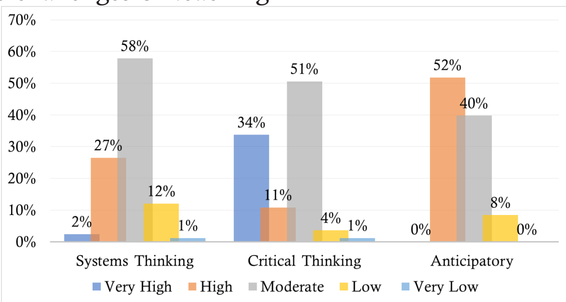

Figure 2. ESD Competency of Pre-Service Physics Teacher in Sosio-Scientific Context

Most participants (58%) fall into the moderate category, indicating a reasonable level of competency in systems thinking within a socio-scientific context. However, only 2% of the participants are in the very high category, and 27% are in the high category. This finding suggests that while some grasp systems thinking well, it is a small area overall. Additionally, 13% of participants are in the low or very low categories, indicating that some pre-service teachers struggle significantly with understanding and applying systems thinking in a socio-scientific context.

Critical thinking within a socio-scientific context emerges as a strong competency for pre-service physics teachers, with 34% of participants in the very high category and 11% in the high category. This finding suggests that nearly half of the participants excel in analyzing and evaluating complex socio-scientific issues. The majority (51%) are in the moderate category, indicating a solid foundation in critical thinking skills. Only 5% fall into the low or very low categories, highlighting that while there is some variability, most participants have developed critical thinking abilities.

Anticipatory thinking within a socio-scientific context shows a different pattern, with 52% of participants in the high category and 40% in the moderate category. This finding suggests that many pre-service physics teachers are competent in anticipating and planning for future scenarios within a socio-scientific context. However, no participants are in the very high category, indicating that while many are proficient, there needs to be more exceptional performance in this area. Additionally, 8% are in the low category, showing some variability in anticipatory thinking skills.

The data reveals that pre-service physics teachers demonstrate varying strengths across the three competencies within a socio-scientific context. Critical thinking is the most developed competency, with many participants exhibiting very high proficiency levels. This finding suggests that these future teachers are well-prepared to engage critically with complex issues, which is crucial for effective teaching in socio-scientific contexts. Critical thinking is fundamental for educators, as it underpins their ability to foster inquiry-based learning environments where students are encouraged to question, analyze, and synthesize information from multiple perspectives (Pithers & Soden, 2000; Liu et al., 2014; Sasson et al., 2018; Antonio & Prudente, 2023). This competency not only enhances students' understanding of scientific concepts but also equips them with the tools to navigate the broader societal implications of these concepts, such as ethical considerations and public policy debates.

Systems Thinking is less developed among the participants, with only a small percentage reaching a very high proficiency level. The majority are at a moderate level, suggesting that while these pre-service teachers recognize the interconnectedness of systems, they may need to fully grasp the complexity of these systems within socio-scientific contexts. The importance of Systems thinking in education, particularly in STEM fields, where understanding the intricate relationships between different system components is essential (York et al., 2019; Akiri et al., 2020; Danielson et al., 2022; Bielik et al., 2023). With a strong foundation in Systems Thinking, teachers may be able to convey the multifaceted nature of socio-scientific issues, such as climate change or public health, which require an understanding how scientific, social, and environmental systems interact. Participants in the low and very low categories further emphasize the need for targeted interventions, including incorporating more interdisciplinary approaches in teacher education programs, where pre-service teachers engage in problem-solving activities requiring them to consider multiple system levels and perspectives. Interdisciplinary problem-based learning (PBL) provides additional support by situating students in collaborative, real-world challenges that require integrating knowledge across science, culture, and ethics. Strategic planning tools such as futures wheels, stakeholder mapping, and SWOT analysis can also be introduced to support structured decision-making.

Anticipatory thinking shows a strong presence in the high category, with over half of the participants performing well in this area. However, the absence of participants in the very high category suggests that while many are competent, they may need to gain the ability to excel in foresight and planning for future scenarios. Anticipatory Thinking is a critical skill for educators, especially in the context of rapid technological advancements and global challenges that demand forward-thinking solutions. Anticipatory Thinking prepares teachers to guide students in considering the long-term consequences of scientific developments and societal choices (Rieckmann, 2012; Gardiner & Rieckmann, 2015; Fiel'ardh, 2024). This competency involves the ability to foresee potential future scenarios and the capacity to prepare students for uncertainty and change, fostering resilience and adaptability in the face of future challenges.

In conclusion, while pre-service physics teachers demonstrate solid strengths in Critical Thinking and a reasonable competency in Anticipatory Thinking, there is a clear and pressing need to bolster their Systems Thinking skills. Addressing this gap through targeted curriculum enhancements, such as project-based learning, interdisciplinary coursework, and professional development opportunities, will prepare these future educators to effectively navigate and teach in a world where socio-scientific issues are increasingly complex and interconnected (Liou, 2001; Zohrabi, 2011; Sasson et al., 2018). Furthermore, strengthening Anticipatory Thinking through exercises that encourage creative problem-solving and scenario planning can help pre-service teachers develop the foresight needed to address future challenges in science education (Hillmann et al., 2018; Tang et al., 2020; Wade & Piccinini, 2020). By fostering a more balanced development of these competencies, teacher education programs can ensure that pre-service teachers are fully equipped to engage their students in meaningful and comprehensive discussions on the challenges that lie ahead.

Table 6 represents the statistical measures of ESD competencies—Systems Thinking, Critical Thinking, and Anticipatory—among pre-service physics teachers in an ethno-scientific context.

Table 6. Statistical Measure of Pre-Service Physics Teachers' Thinking Skills in Ethno-Scientific Context

ESD Competency	Mean	Median	Mode	Standard Deviation	Minimum	Maximum	Count
Systems Thinking	56.93	62.50	62.50	30.57	0.00	100.00	83
Critical Thinking	15.66	0.00	0.00	20.55	0.00	75.00	83
Anticipatory	36.75	50.00	50.00	21.86	0.00	50.00	83

The results from Table 3 show that pre-service physics teachers have moderate skills in systems thinking within an ethno-scientific context, with an average score of approximately 56.93. The median and mode are both at 62.50. However, there is a wide range of scores, as indicated by the standard deviation of 30.57. The scores range from 0.00 to 100.00, demonstrating diverse competency levels.

Regarding critical thinking, most participants exhibit very low levels in an ethno-scientific context, with a notably low average score of approximately 15.66. The median and mode are both at 0.00. The standard deviation is 20.55, suggesting some variability, but the generally low scores indicate that critical thinking is a significant weakness among the participants.

Regarding anticipatory thinking, participants show moderate development with an average score of approximately 36.75. The median and mode are both at 50.00. The standard deviation is 21.86, suggesting moderate variability. The scores range from 0.00 to 50.00, and the maximum score is only 50.00, indicating that even the strongest participants still need to develop their anticipatory thinking skills in this context fully.

The proficiency levels of pre-service physics teachers in ESD competencies within an ethno-scientific context vary, with strengths and weaknesses in different areas. Systems Thinking is the strongest competency, with a moderate average score and higher median and mode. This finding suggests that many participants can understand and apply systems thinking, which is important for integrating scientific knowledge with ethnic contexts. However, the significant variability and low scores suggest a need to support and improve these skills among some participants.

On the other hand, Critical Thinking is the weakest competency, with most participants scoring extremely low. This finding is concerning as critical thinking is essential for analyzing and evaluating ethno-scientific issues, often requiring balancing scientific knowledge with ethnic considerations. The low median and mode at 0.00 suggest that many participants cannot engage critically in this context, highlighting a critical gap in their training.

Anticipatory thinking shows a moderate level of development but with limitations. While some participants can anticipate and plan for future scenarios within an ethno-scientific context, the relatively low average score and the ceiling effect (maximum score of 0.50) suggest these skills must be fully developed. Given the importance of foresight in addressing future challenges in science education, particularly in ethnically diverse contexts, enhancing anticipatory thinking should be a priority.

The results indicate that while pre-service physics teachers demonstrate some competency in Systems Thinking, there is a pressing need to improve their Critical and Anticipatory Thinking skills within an ethno-scientific context.

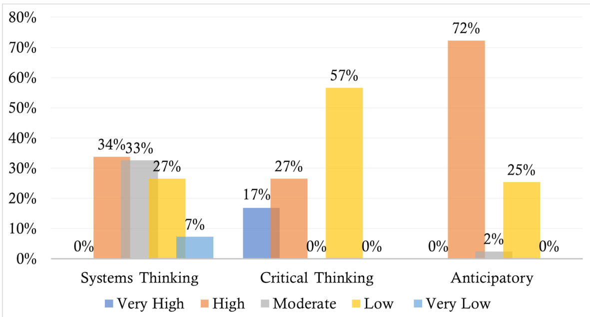

Figure 3. ESD Competency of Pre-Service Physics Teacher in Ethno-Scientific Context

Figure 3 shows the distribution of pre-service physics teachers' competencies in Systems Thinking, Critical Thinking, and Anticipatory Thinking within an ethno-scientific context.

In Systems Thinking, no participants reached a very high level. The highest concentration (34%) fell into the high category, while a similar proportion (33%) was in the moderate category, indicating that many participants reasonably understand systems thinking in an ethno-scientific context. However, 34% of participants (27% low, 7% very low) struggle with this competency, highlighting that a substantial group needs more skills to grasp and apply systems thinking effectively and fully.

Critical thinking shows a more polarized distribution, with 17% of participants reaching the very high level and 27% at the high level. However, a concerning 57% are in the low category, indicating that more than half of the participants struggle significantly with critical thinking in this context. The absence of participants in the moderate category further suggests that participants either perform well or poorly, with little middle ground. Anticipatory Thinking is the strongest area, with 72% of participants in the high category. However, no participants are in the very high category, indicating that while many are proficient, none have fully mastered anticipatory thinking. A quarter of participants (25%) are in the low category, which shows that some still struggle with this competency.

The research findings indicate that pre-service physics teachers display varying competency levels in Systems Thinking, Critical Thinking, and Anticipatory Thinking within an ethno-scientific context. Systems Thinking shows a moderate distribution, with a significant portion of participants performing at high and moderate levels. This finding suggests that many pre-service teachers have a foundational understanding of how different systems interact within ethnically specific scientific contexts. However, the fact that 34% of participants fall into the low and very low categories raises concerns. This gap highlights the need for additional support and targeted interventions to deepen their understanding of systems thinking, particularly how ethnic nuances influence scientific processes and knowledge systems.

Systems Thinking in ethnically diverse educational settings is important where teachers must navigate the complexities of integrating local knowledge systems with scientific principles (Mackinson, 2001; Rist & Dahdouh-Guebas, 2006; Failing et al., 2007; Raymond et al., 2010). With a strong grasp of Systems Thinking, teachers may be able to help students appreciate the interconnectedness of science and ethnicity, potentially leading to a cohesive understanding of both.

Critical thinking presents a more concerning scenario, as more than half of the participants are in the low proficiency category. This finding suggests that many pre-service teachers face challenges in critically engaging with and analyzing ethno-scientific issues. The stark disparity between those who excel and those who underperform underscores this group's significant gap in critical thinking skills. The absence of participants in the moderate category suggests a polarization in abilities, where some pre-service teachers demonstrate strong critical thinking skills while others struggle significantly.

Critical thinking is essential for teachers to effectively address and deconstruct ethno-scientific concepts, often requiring a nuanced understanding of ethnic context and scientific rigor. Critically evaluating ethno-scientific issues is crucial for fostering a learning environment where students are encouraged to question, analyze, and integrate diverse forms of knowledge (Jannah et al., 2022; Verawati et al., 2023; Adam et al., 2024; Kasi et al., 2024). The current data suggests an urgent need for curriculum reforms that prioritize the development of critical thinking skills, especially in terms of ethno-scientific content.

Anticipatory Thinking emerges as the strongest competency among the three, with most participants performing at a high level. This finding indicates that pre-service teachers are well-prepared to foresee and plan for future challenges in ethno-scientific content in physics education. However, the absence of very high performers and the fact that 25% of participants still need help with this competency suggests room for growth.

Anticipatory thinking is particularly important in ethnically diverse educational settings, where teachers must be able to anticipate and address potential conflicts between scientific knowledge and ethnic beliefs (McGinnis & Simmons, 1999; van Driel et al., 2001; Ertmer & Ottenbreit-Leftwich, 2010). Strengthening this competency could involve training pre-service teachers in scenario planning, foresight exercises, and ethnically responsive pedagogy, which would better equip them to anticipate and navigate the complex dynamics of ethno-scientific education.

Although Anticipatory Thinking has strengths, the data shows a need for focused interventions to improve pre-service physics teachers' Systems Thinking and Critical Thinking skills. It is crucial to bridge these gaps to equip educators with the necessary skills to address ethnically specific scientific challenges critically and systematically while also balancing ethnic relevance with scientific accuracy. This skill is essential to ensure that future educators are well-prepared to integrate scientific knowledge with ethnic sensitivity, leading to a more comprehensive approach to science education.

Table 7 shows the Pearson correlation coefficients between Systems Thinking, Critical Thinking, and Anticipatory Thinking among pre-service physics teachers. Each correlation is described as a moderate correlation, with significant p-values indicating the strength and significance of the relationships.

Table 7. Correlation between System Thinking, Critical Thinking, and Anticipatory Thinking of Pre-service Physics Teachers

Correlation	Pearson-Correlation	Sig. (2-tailed)	N	Description
Systems Thinking-Critical Thinking	.407**	0.00014	83	Moderate Correlation
Systems Thinking-Anticipatory	.459**	0.00001	83	Moderate Correlation
Critical Thinking-Anticipatory	.323**	0.002892	83	Moderate Correlation

The Pearson correlation coefficient of 0.407 indicates a moderate positive correlation between Systems Thinking and Critical Thinking. The p-value of 0.00014 suggests that this correlation is statistically significant. This means that as one competency increases, the other also tends to increase. The moderate correlation between these two suggests that pre-service teachers better understand and apply systems thinking and have stronger critical thinking skills. This significant relationship implies that fostering systems thinking could enhance critical thinking abilities concurrently.

The correlation between Systems Thinking and Anticipatory Thinking is slightly stronger, with a coefficient of 0.459, indicating a moderate positive relationship, where improvements in systems thinking are likely associated with improvements in anticipatory thinking. The p-value of 0.00001 confirms that this correlation is highly significant. The stronger correlation between systems thinking and anticipatory thinking emphasizes the importance of understanding interconnected systems for effective planning and preparing for future scenarios. Curriculum and training programs should emphasize the integration of these two competencies to prepare teachers for the dynamic nature of science education (Hays & Reinders, 2020).

The correlation coefficient of 0.323 between Critical Thinking and Anticipatory Thinking suggests a weaker, but still moderate, positive correlation. The p-value of 0.002892 indicates this relationship is statistically significant, though less strong than the other two correlations. While still moderate, the correlation here is the weakest among the three. This result indicates that while there is a relationship between critical thinking and the ability to anticipate future challenges, it is not as strong as the other pairings. This finding could suggest that while these competencies are related, they may develop more independently compared to how systems thinking does with the other two.

These findings suggest that these competencies are interrelated; improvements in one area could lead to enhancements in the others. The strongest correlation is between Systems Thinking and Anticipatory Thinking, highlighting the importance of understanding systems for effective future planning. While Critical Thinking correlates with the other two competencies, the relationship is slightly weaker, indicating that it may develop more independently. These findings emphasize the need for a holistic and integrated approach in teacher education programs to build these competencies concurrently, ensuring that future educators are well-equipped to address complex and ethnically specific scientific challenges.

CONCLUSION

Research results indicate that pre-service physics teachers exhibit varying competency levels in Systems Thinking, Critical Thinking, and Anticipatory Thinking within socio-scientific and ethno-scientific contexts. Anticipatory Thinking is the strongest, with many participants performing at a high level. Critical thinking is the weakest, with a significant number of participants struggling. Systems thinking shows moderate proficiency, but improvement is needed, particularly among those in the lower categories. Analyzing the Pearson correlation coefficients between Systems Thinking, Critical Thinking, and Anticipatory Thinking among pre-service physics teachers reveals moderate positive correlations across all three competencies. The success of Education for Sustainable Development (ESD) requires a holistic approach that fosters the development of all relevant competencies. Prioritizing critical thinking is essential, as it is a foundation for enhancing other competencies. Educational systems should focus on cultivating systems thinking and anticipatory thinking, as these are interconnected and mutually reinforcing in the transformation toward sustainability. Curriculum reforms should address gaps across all competencies, including continuous assessment and feedback. Incorporating ethno-socio-scientific contexts in training will enhance ethno-socio sensitivity, and ongoing professional development is essential to sustain these competencies throughout teachers' careers. However, a key limitation of this study lies in its population, which was restricted to pre-service physics teachers at a single university in Aceh Province, Indonesia. Consequently, the findings may not fully capture the diversity of educational practices, institutional characteristics, or ethnic perspectives in other regions. Future research should, therefore, include participants from multiple universities across different provinces to provide a more comprehensive and generalizable understanding of the development of these competencies in various educational and ethnic-socio contexts.

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