



Phenomenon-Based Learning on Rare Earth Mining: Impacts on Students' Attitudes toward Sustainability, Environmental Awareness, and Environmental Education

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Abstract

Global calls for educational development align with UNESCO's framework for sustainable development, which emphasizes a balance between human progress and environmental preservation. Many transboundary environmental phenomena remain outside the public's awareness yet profoundly affect local contexts. Therefore, this study aimed to investigate attitudes toward sustainability, environmental awareness, and environmental education awareness among 529 high school students following participation in an online phenomenon-based learning activity titled "How Rare Earth Mining in Neighboring Countries Affects Our Local Communities." Employing a one-group posttest-only design, data were collected using a 5-point Likert-scale survey covering three variables and an open-ended question to explore what students had learned from the online activity. The results showed that all three variables were at a high level, and multiple regression analysis revealed that environmental awareness and environmental education awareness significantly predicted attitudes toward sustainability, explaining 56.5% of the variance ($R^2 = .565$). Among the predictors, environmental awareness ($\beta = .483$, $p < .001$) had the strongest influence. Through phenomenon-based learning focused on rare earth mining, students recognized the relevance of chemistry knowledge in understanding rare earth elements, related processes, and their environmental impacts. The findings suggest that pedagogy can draw on real-world phenomena as case materials to stimulate students' thinking and enhance environmental awareness, thereby fostering more positive attitudes toward sustainability.

Keywords: *Environmental awareness, Environmental education awareness, Rare earth mining, Regression, Attitudes toward sustainability*

Introduction

People have shared and taught each other environmental knowledge for a very long time, such as how to fish, how to navigate, how to survive in nature, or how to grow crops [1]. However, recent research clearly confirms that many human activities are harming the environment. For example, human-induced climate change contributes to global warming and also leads to direct impacts such as heavy rainfall, droughts, and storms, which create significant costs for society and the environment [2]. These impacts also relate to biodiversity loss and ecosystem disruption, not only in big cities but also in urban areas in general [3]. Some human actions are easy to see and understand, like vehicle emissions or forest burning, where black smoke released to the atmosphere supports heat retention and increases global temperature. In contrast, other actions are less visible, harder to understand, and often perceived as far from daily life, such as rare earth mining.

Rare earth mining is a process that starts from exploration, mining, crushing, and separation, and then continues to chemical processing to obtain purified rare earth elements. Rare earth elements, such as Neodymium (Nd), Lanthanum (La), Cerium (Ce), or Dysprosium (Dy), are a group of chemically similar elements that are essential for modern technological applications. Since Mendeleev introduced the systematic arrangement of elements in the periodic table to enhance meaning and facilitate learning, the classification of elements has provided a fundamental framework for chemistry teaching and learning for more than 150 years [4]. Even so, at the basic education level in many countries, the periodic table is often presented as abstract and detached from students' everyday lives. As a result, learning about chemical elements is frequently based on memorization with limited direct experience. Some elements are rarely known or recognized by students, even though they are important components of technologies and devices used in daily life, like rare earth elements.



Historically, the first rare earth element identified and discovered was cerium (Ce). Despite the strategic and industrial importance of rare earth elements, their origin, classification, and geochemical background are rarely discussed in depth in compulsory education curricula in many countries. In a similar way, the seventeen rare earth elements are not included in the basic education curriculum in Thailand. Learning about chemical elements mainly focuses on an overview of the periodic table and electron arrangements in principal and subshell energy levels, with emphasis mostly on representative elements. Therefore, rare earth elements are rarely encountered or recognized by students. This omission can restrict students' understanding of the completeness of the periodic system and its contemporary relevance. For this reason, this study uses rare earth mining and its environmental impacts as a key phenomenon to support environmental education and environmental awareness, which may contribute to attitudes toward sustainability.

This study integrates a real-world phenomenon into an online learning environment through phenomenon-based learning (PhBL), an approach originating in Finland [5]. PhBL conceptualizes learners, teachers, and knowledge as interconnected within contextual settings and is theoretically grounded in constructivism, pragmatism, and phenomenology [6]. At the policy level, it aligns with transversal competencies and twenty-first century skills, while methodologically it draws from problem-based learning, inquiry-based learning, and related approaches [6]. A key objective of PhBL is to connect learning content with students' local environments and lived experiences to strengthen student agency [7]. Although it holds strong didactic potential, PhBL is not a universal or easily transferable method but rather a reflective lens on contemporary education [5]. Within this framework, sustainability education, also referred to as education for sustainable development (ESD), aims to cultivate values and motivation for sustainable action at personal, community, and global levels [8]. The concept of sustainable development emerged prominently in the late 1980s in response to urgent environmental and social challenges, emphasizing an ongoing process rather than a fixed outcome [1], [9]. Following the 1997 Tressaloniki Declaration, UNESCO formally advanced ESD, highlighting the integration of environmental, social, cultural, economic, and political dimensions [1], [10]. Building on these perspectives, the study assesses students' environmental education awareness, environmental awareness, and attitudes toward sustainability after learning through Phenomenon-Based Learning on Rare Earth Mining.

Contemporary research indicates that Environmental Education Awareness (EEA) is positively associated with Attitudes toward Sustainability (AS), as it develops sustainability-oriented knowledge and values at both individual and societal levels. Empirical evidence shows that EEA directly fosters positive sustainability attitudes and related behaviors [11,12], and students engaged in environmental education generally demonstrate high levels of pro-sustainability attitudes, although knowledge does not always translate linearly into behavior [13]. In addition, recent studies confirm a statistically significant positive relationship between Environmental Awareness (EA) and attitudes toward sustainability. Environmental awareness has been shown to correlate with and predict sustainable thinking and consciousness [14,15], and it also influences sustainability-related attitudes and behavioral intentions through cognitive and motivational pathways [16]. Overall, the literature suggests that both EEA and EA function as key determinants of sustainability-oriented attitudes, with EA often acting as a cognitive foundation for broader sustainability perspectives.

Based on the literature, this research also seeks to determine whether EEA and EA can predict AS. The study collected data through both quantitative methods to analyze relationships and predictive power, and qualitative methods to understand students' perceptions, explanations, and meanings developed through the learning experience.

Research Objectives

1. To determine the level of environmental education awareness, environmental awareness, and attitudes toward sustainability among students after learning through Phenomenon-Based Learning on Rare Earth Mining.
2. To examine whether environmental education awareness and environmental awareness can be used to predict students' attitudes toward sustainability.

Methodology

This study employed a one-group post-test only design. Data were collected during the orientation program, a compulsory activity for all students in the Science, Mathematics, Technology, and Environment program (SMTE) across the Lower Northern school network. The orientation was conducted for Grade 10 students from 19 network schools in the Lower North (one SMTE classroom



per school, approximately 30 students per classroom). In total, there were 570 Grade 10 SMTE students across the 19 schools. The orientation took three hours in an online format based on phenomenon-based learning and using rare earth mining as a phenomenon.

Data Collection and Analysis

Following the three-hour online lecture on *Phenomenon-Based Learning in Rare Earth Mining*, students were asked to complete a survey. The questionnaire was divided into four sections. **Part I** explained the purpose of the questionnaire and obtained informed consent from the respondents. Students could choose either “consent” or “do not consent” to participate. If a student selected “do not consent,” the subsequent sections of the questionnaire were not displayed. **Part II** collected demographic information, including age and gender. **Part III** applied items from [17], which adjusted the original version of the instrument measuring attitudes and behaviors related to sustainability developed by [18,19]. This section included 21 items rated on a 5-point Likert scale, covering three constructs: attitudes toward sustainability (10 items), environmental awareness (4 items), and environmental education awareness (7 items). These self-assessment items ranged from 1 = strongly disagree to 5 = strongly agree. Before implementation, the original versions of each construct were translated into Thai and validated through face validity by an English language expert and two authors. The translations were revised with minor wording adjustments that did not alter the core meaning. Additionally, double-negative statements were simplified for clarity, and the word ‘environment’ in item 17 was replaced with ‘rare earth.’ All survey items were mandatory to prevent missing responses. **Part IV** consisted of one open-ended question: “*How has today’s orientation activity influenced changes in yourself regarding environmental conservation and sustainable development?*”

Data from part II were analyzed using descriptive statistics to understand students' demographics. In part III, the data were analyzed for construct validity using confirmatory factor analysis and for internal reliability with the coefficient H for each dimension (Table 1). Then, multiple regression was conducted to examine the predictive power of environmental awareness and environmental education awareness on students' attitudes towards sustainability. All quantitative data were analyzed using Jamovi 2.3.28. Responses in part IV, the qualitative data, were analyzed through inductive interpretation. By carefully reading each response and re-reading, codes emerged. The frequency of each code was counted. Related codes were grouped to identify overarching themes.

Table 1. Standard estimate and coefficient H

Statements	Standard estimate
Attitudes toward sustainability (H= 0.89)	
1. Increasing opportunities for people to live longer and healthier lives promotes sustainable development.	0.683
2. Protecting the environment is essential for sustainable development.	0.658
3. Economic development is necessary for sustainable development.	0.654
4. Sustainable development requires reducing all types of waste.	0.608
5. Human actions affect the atmosphere and the Earth’s climate system.	0.529
6. Biodiversity conservation, meaning the preservation of the number and variety of living organisms, is essential for sustainable development.	0.736
7. Sustainable development requires respect for human rights.	0.646
8. Sustainable development depends on the use of renewable resources.	0.654
9. Sustainable development involves reflecting on the meaning of quality of life.	0.696
10. Being a good citizen is necessary for sustainable development.	0.659
Environmental awareness (H=0.74)	
11. I believe I can contribute to environmental conservation through my behavior.	0.577
12. Everyone has a responsibility to protect the environment.	0.505
13. Each person has a responsibility to integrate knowledge of science, mathematics, and technology with environmental issues.	0.710
14. Environmental issues should receive greater attention at the national level.	0.716
Environmental education awareness (H=0.87)	






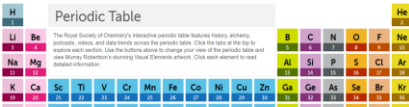
15. Integrating environmental issues into education is important.	0.650
16. School activities related to the environment (e.g., Environment Day, field trips, exhibitions) are very important.	0.635
17. If I knew more about Rare Earth, I would apply environmental considerations in daily life.	0.659
18. All students should be required to take environmental courses.	0.649
19. Learning in school influences my attitudes toward the environment.	0.743
20. Learning in school influences my knowledge of the environment.	0.773
21. Learning in school influences my behavior toward environmental conservation.	0.749

CFI=0.912, TLI=0.901, RMSEA = 0.0658

Phenomenon-Based Online Learning on Rare Earth Mining

In this study, Phenomenon-Based Learning (PhBL) begins by introducing a real-world phenomenon and then uses driving questions to spark students' thinking and guide their learning process. These questions are prepared in advance and serve to guide the planned sequence of online learning activities. This method aims to help students go beyond strict subject boundaries by linking different disciplines through the phenomenon itself and the key questions that emerge from it. Table 2 presents the phenomenon and the driving questions.

Table 2. Sequence for presenting the phenomenon and posing critical questions

Phenomenon	Evidence
<p>Thailand National Broadcast: Thailand local news reported a situation in northern Thailand where infected fish were found and died in large numbers in the <i>Kok River</i>, which flows from a neighboring country. This incident significantly affected local fisheries and agricultural livelihoods, as fish caught for sale and consumption was perceived as unsafe. Local people became reluctant to consume fish, and those who relied on fishing for their livelihood avoided catching and selling fish due to concerns about potential health risks to the public.</p>	 <p>Fig. 1. Infected fish found in the <i>Kok River</i>. [20]</p>
<p>Driving Questions: According to the news, what happened, and how did it affect living organisms and people in the local area? How did this serious situation impact the local economy and the livelihoods of community members?</p>	
<p>Thailand National Broadcast: Statistical data from the Thailand Pollution Control Department on arsenic (As) detection in the <i>Kok River</i> were presented. Water samples were collected and measured four times at three different locations. Results indicated that As concentrations exceeded the standard limits, which negatively affected fish survival. In addition, water quality monitoring processes were implemented to prevent contaminant levels from exceeding the standards required for tap water production.</p>	 <p>Fig. 2. Arsenic levels exceeding the standard in three sampled areas [20]</p>
<p>Driving Questions: Why was a large amount of arsenic detected in the <i>Kok River</i>, which flows from a neighboring country? What activities may have led to this contamination?</p>	
<p>Thailand National Broadcast from Global Witness: Myanmar is an important global source of rare earth mining. Hundreds of mining sites have been found across <i>Kachin State</i>, Myanmar. Three major mining areas located in <i>Shan State</i>, near the Thai border, are the sources of the <i>Kok River</i> and <i>Sai River</i>. All 17 rare earth elements are essential materials in the high-technology supply chain.</p>	 <p>Fig. 3. Rare earth mining in neighboring countries. [21]</p>
<p>Driving questions: According to the news, which rare earth elements have students heard of, and where are these elements located in the periodic table? For what purposes do major powers use rare earth elements?</p>	
<p>Present the periodic table to help students activate and connect their prior knowledge of the periodic table and element properties, and pose the question: Where are rare earth elements located on the periodic table?</p>	



<p>Driving question: What are the key properties of rare earth elements, and what types of industries are they used in? [Due to their unique properties, rare earth elements are used in the production of wind turbines, electronic components, circuit boards, electric vehicle batteries, and so on.]</p>	<p>Fig. 4. Periodic Table [22]</p>
<p>According to a report by DW, Thailand accounts for 2.9% of the global production process, while a neighboring country—supported by investment from major powers—accounts for 9.4% of rare earth mining production.</p>	
<p>Driving question: While the development, control, and export of rare earth minerals are crucial for driving economic growth, the mining process also contributes to environmental degradation and global warming. This issue is close to home and cannot be overlooked. For students in the SMTE program, what are your views on this situation?</p>	<p>Fig. 5. Global Distribution of Rare Earths Production [23]</p>

Results

The level of environmental education awareness, environmental awareness, and attitudes toward sustainability among students after learning through Phenomenon-Based Learning on Rare Earth Mining.

Result showed that total respondents of 529 out of 570 (respond rate 92.81%). Among this comprised of 207 male (39%) and 322 female (61%) with average age of 15.22 years. Based on the criteria of interpretation (A mean score of 4.51 or higher indicates the highest level; 3.51–4.50 indicates a high level; 2.51–3.50 indicates a moderate level; 1.51–2.50 indicates a low level; and less than 1.50 indicates the lowest level.), the students hold their attitudes toward sustainability (M 4.235, SD 0.469), environmental awareness (M 4.439, SD 0.807) as well as environmental education awareness (M 4.315, SD 0.632) at the high level.

Environmental education awareness and environmental awareness can be used to predict students' attitudes toward sustainability.

A multiple linear regression analysis was conducted to examine whether environmental awareness (EA) and environment education awareness (EEA) predict attitudes toward sustainability (AS) (all variables were measured using 1–5 Likert scales; $N = 529$). The model showed a strong association ($R = .752$) and explained 56.5% of the variance in AS ($R^2 = .565$, Adjusted $R^2 = .564$), with $RMSE = .309$ (i.e., the standard error of the estimate). Both predictors were statistically significant. EA positively predicted AS ($b = 0.386$, $SE = 0.0317$, $t = 12.18$, $p < .001$, $\beta = .483$, 95% CI [0.406, 0.561]), and EEA also positively predicted AS ($b = 0.247$, $SE = 0.0295$, $t = 8.36$, $p < .001$, $\beta = .332$, 95% CI [0.254, 0.410]). Overall, EA showed a stronger standardized effect than EEA ($\beta = .483$ vs. $\beta = .332$).

What students learned from online phenomenon- based learning activity

Students' responses to the open-ended question were analysed using thematic analysis. Codes were partly predetermined from theory and partly derived from the data. The frequency of each theme was counted, as shown in Table 3.

Table 3. Thematic analysis of what students have learned

Theme	Description/Code [Frequency]	Example
Environmental awareness	Students demonstrated environmental awareness, reflected in students' recognition of environmental problems, perceived importance of natural resources, understanding of environmental impacts, and appreciation of nature's value.	"It made me see the importance of the environment and natural resources." [S-271]
	[EA: 240]: Perceived problem/awareness/positive or negative impacts/ value	"...aware of global environmental impacts, and everyone must help protect the environment." [S-298]
Environmental conservation awareness	Demonstrated intention to conserve the environment, care for nature, protect the planet, and improve environmental condition.	"It made me want to protect the environment." [S-441].
	[ECA: 210]: Conserve/care for/protect/improve	"It made me realize how important the environment is, and everyone should help protect it." [S-394].
Gain New Knowledge	Direct learning outcomes, reflected in gaining new knowledge, deeper understanding, and learning previously unknown information.	"It gave me knowledge about environment..." [S-249]
	[GK: 170]: gaining new knowledge/	"I gained more knowledge about the environment and can be applied in



	information/more understand about environment	<i>daily life.</i> [S-263]
Environmental responsibility	Demonstrated clearly environmental behavioral intentions, including reducing plastic use, waste separation, saving electricity and water, planting trees, and using resources efficiently.	<i>"I will help plant trees."</i> [S-43] <i>"Today's activity made me want to use fewer plastic bags and start separating my trash to help the environment."</i> [S-223]
	[ER: 120]: Action/ reducing plastic use/ waste separation/using resources efficiently	
Changing agent	Evidence of personal agency, reflected in intentions to change one's own behavior, start with oneself, encourage others, and shift personal mindsets.	<i>"I'll share what I learned with others using simple words..."</i> [S-210] <i>"I will improve environment starting from myself"</i> [S-226]
	[EG: 95] change behavior, telling other people to change behavior, change mindset	
Sustainability	Emphasis on sustainability, including sustainable development, consideration for future generations, and the balance between economic growth and environmental protection.	<i>"It made me realize the goal of the SMTE class, to develop the country in a sustainable way without harming the environment."</i> [S-248] <i>"...the importance of protecting the environment and managing in a sustainable way."</i> [S-511]
	[SD:45]: sustainability, sustainable development, balance between economic and environment	
Gain New Knowledge about Rare Earth	Explicit expressions of increased knowledge about rare earth elements, rare minerals and mining	<i>"I learned more about rare earth."</i> [S-444, S-448, S-553] <i>"...part of environmental damage comes from consuming and producing rare earth...I want to help protect the Earth."</i> [S-484].
	[GKR: 8] rare earth elements, rare earth minerals, rear earth mining	
General Positive Feeling	Response positive emotion in general, such as feeling very good, enjoying the activity, and liking.	<i>"I feel proud to study in this class, and it has changed my way of thinking."</i> [S-8]
	[EF:35] good, very good, great, enjoy, like today activity	

Note: EA – Environmental awareness; ECA – Environmental conservation awareness; SD – Sustainability development; ER – Environmental responsibility; GK – Gain new knowledge; GKR – Gain new knowledge about rare earth; EG – Environmental Agency; EF General positive feeling

The open-ended analysis revealed that environmental awareness was the most prominent theme, reflecting students' recognition of environmental problems, the importance of natural resources, and global environmental impacts. The second major theme was environmental conservation awareness, indicating intentions to protect and improve the environment. Additional themes, environmental responsibility, change agent, and sustainability, suggested emerging behavioral intentions such as reducing plastic use, sorting waste, and conserving energy. Students also reported gaining new knowledge, particularly about rare earth and its environmental impacts, though this theme appeared less frequently. Overall, responses reflected increased awareness, knowledge acquisition, pro-environmental intentions, and general positive feelings toward the learning activity.

Discussion and Implication

This study aimed to explore students' affective dimensions related to sustainable development and the environment and environmental awareness among freshman students in the SMTE program. Phenomenon-based online learning was implemented during the orientation, and data collection was monitored. The orientation aimed to encourage Grade 10 students in the SMTE program to recognize the importance of their curriculum, raise their awareness of environmental conservation, and see the value of environmental education through integrating science, mathematics, and technology disciplines. Results showed that students' attitudes toward sustainability (AS), environmental awareness (EA), and environmental education awareness (EEA) were at a high level. Regression analysis indicated that both EA and EEA significantly predicted AS, with EA showing a strong effect than EEA. Thematic analysis confirmed students' environmental awareness and environmental conservation awareness, as well as their gain of new knowledge about environment and rare earth mining. Moreover, some students reflected intentions to conserve the environment and change their behaviors. Previous research showing that environmental education awareness can shape students' sustainable values and attitudes [24,25] and influence their environmental behaviors [26]. The implications can be discussed in two points. Firstly, a curriculum is a strong guideline for developing effective citizen who not only understand environmental issues but also take action. Human have learned about the environment for many years, but expected outcomes should be clearly stated in the



curriculum. Students should be expected to act and change their behaviors to protect the environment and reduce causes of environmental harm. Particularly in the science curriculum, disciplinary learning should be linked with these expected actions. Secondly, pedagogy is crucial for raising students' environmental awareness. Students' environmental education (EE) accounts for 46% of the variance in teaching practices [25,27], especially when teaching abstract concepts. In chemistry, learning about elements mainly focuses on an overview of the periodic table and electron arrangements in principal and subshell energy levels, with primary emphasis on representative elements. Rare earth elements, therefore, are rarely encountered or recognized by students. This omission restricts students' understanding of the periodic system's completeness and contemporary relevance. Several abstract content can be made more real in the classroom. However, pedagogy can adopt real-world phenomena as cases to provoke students thinking and raise environmental awareness, with the expectation that learning may support behavioral change through students' value and sense of responsibility as citizens.

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