Encouraging Primary Students' Environmental Awareness by Using STEM Inquiry-based Learning

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Abstract: The Circular Economy (CE) has emerged as an essential idea in the worldwide response to unsustainable resource consumption and waste management, and educators have incorporated this scenario into the theme in classroom. At the same time, STEM (Science, Technology, Engineering, and Mathematics) education is an essential approach for educating students with the necessary skills for a competitive workforce in the twenty-first century. Several academics are currently attempting to integrate inquiry-based learning, which is one such technique whose efficacy is higher in science-based education. Furthermore, technological integration has been used in scientific courses. This research examined the implementation of combining inquiry-based learning with STEM education using ICT technology in citizen science activities to promote the circular economy for fourth-grade students in a university-based demonstration school located in the northeastern part of Thailand. The results of this study include aspects of students' conceptual understanding about types of plastic and their awareness of the environment. We found that students had a significantly increased conceptual understanding regarding types of plastic. Moreover, the students expressed positive attitude towards plastic waste management awareness. These findings support the notion that ICT technology could assist students in better understanding science concepts and attitudes, especially when integrated with a STEM inquiry-based learning method in the citizen science activity.

Keywords: STEM, Technology, Circular economy, Citizen inquiry

1. Introduction

In recent years, the discipline of science, technology, engineering, and mathematics (STEM) has experienced an important rise in popularity and importance as an academic study and research area. STEM education has become a significant focal point of national importance in several countries worldwide. Several educators have adopted an integrated approach to STEM (science, technology, engineering, and mathematics) education to promote essential skills among students, such as creativity, problem-solving, and teamwork. This strategy aims to cultivate a highly skilled workforce that can effectively compete in the 2 1st century (Freeman, Marginson, & Tytler, 2019). Moreover, STEM education could improve students' motivation, interests, and persistence in learning, fostering their development as self-directed learners (Abouhashem et al., 2021; Syed Abdullah, & Md Khambari, 2022). Additionally, students' effective domain toward STEM educational work is important for successful STEM education implementation in a sustainability context (Sellami et al., 2023). Consequently, to promote a nation's sustainable economic and social well-being, education must increasingly prepare students for STEM-related disciplines of study and future careers (Mohr-Schroeder et al., 2020).

Citizen Inquiry is an innovative approach to informal science education that attempts to facilitate the involvement of citizens in online scientific investigations (Aristeidou, Scanlon,

& Sharples, 2013). This approach integrates aspects from both Citizen Science and Inquiry-based Learning, including practices such as sharing information and evaluation by others (Citizen Science), as well as experimentation, exploration, critical analysis, and reflection (Inquiry-based Learning). In order to enhance environmental awareness among students may be achieved through formal and informal educational approaches. As informal learning, citizen Inquiry arises as the learning method, motivated by people's personal interests in science and its basic rationale. Environmental awareness can be developed by the adoption of attitudes and actions that are focused on conserving the environment, while the obtaining of knowledge is essential for effectively managing the environment (Meinhold & Malkus, 2005). As the importance of knowledge about managing the environment, Nizaar et al. (2020) found that by teaching students to process garbage using the 3R principle, it is possible to reduce excessive household waste production.

During the emerging technologies era, mobile technology, one of the technologies that contribute to citizen inquiry, is implemented to enhance students' effective domain in different subjects and levels. For example, Plastic Island Game (Adita & Srisawasdi, 2022), Weather-it platform (Aristeidou et al., 2015), 360-degree Virtual Learning Environment (Chaipidech & Srisawasdi, 2023), and the Sense-it app (Sharples et al., 2017). Consequently, this research investigates the effect of integrating STEM learning into guided inquiry with ICT technology on the conceptual understanding and awareness of students. The outcome might have implications for teaching and learning with technology in the citizen science activity.

2. Literature Review

2.1 The Role of Integrated STEM with Circular Economy

Nowadays, education is a fundamental requirement for attaining Sustainable Development Goals (SDGs) as it provides individuals with essential skills, values, and knowledge necessary for personal and societal progress. To effectively incorporate sustainable development into educational institutions, it is important to begin an extensive redesign of the learning environment and instructional methodologies. In addition, the topic of waste management and recycling is presently the most important challenge in the advancement of sustainable development. The circular economy (CE) has become an essential concept in response to waste management and recycling. Moreover, citizens of the world are expected to use the scientific and technological knowledge they obtain in school to resolve real-world issues, such as environmental degradation, unpredictable climate change, and resource depletion (Nguyen et al., 2020). STEM education is a one of learning that could facilitates the integration of complex academic concepts with practical applications by employing an interdisciplinary approach to instruction and learning (Bybee, 2013). Consequently, several educators endeavor to integrate instructional methods and learning strategies. As integrate STEM education with the circular economy, Nguyen (2023) demonstrated the integration of Circular Economy principles into Science, Technology, Engineering, and Mathematics (STEM) education to promote sustainable development and reduce waste generation. This paper shows that the incorporation of CE into STEM education is part of a "breadth and depth" educational strategy that encourages teachers to cross disciplinary lines while maintaining their expertise in the field.

2.2 Citizen Inquiry Integrating with Technologies

Citizen science is a rapidly expanding field of study and practice that generates new knowledge and understanding through the participation of citizens in scientific research. It is becoming increasingly essential for educators to consider the field's potential to promote educational and learning possibilities as it develops. Citizen science has been recognized as having enormous potential in the field of scientific education and learning for some time (Bonney et al., 2009). As for the potential of citizen science, numerous researchers challenge integrating of citizen science into mainstream education systems, especially inquiry learning.

Citizen inquiry is one of innovative method that incorporates components from citizen science and inquiry-based Learning, including sharing of information and review by others (Citizen Science) and experimentation, discovery, critique, and reflection (Inquiry-based Learning). The purpose of citizen inquiry is to enable students or anyone to engage citizens in online scientific investigation (Aristeidou et al., 2013). For example, Aristeidou et al. (2013) explore the creation and evolution of an online community called Weather-it enabling people to create and maintain their weather investigations to which others can contribute. The result showed that the sustained engagement and evolution of a citizen inquiry community will require active engagement of a person. The study also found that feeling a part of the community increases the likelihood of remaining active, but there are concerns about the members who did not feel like a part of the community, even though they had many contributions. Additionally, Herodotou (2014) used technology that is the nQuire Missions framework is a web-based platform that provides the development and administration of personal inquiry missions by young people and a sensor-based mobile application that facilitates the collection of data on mobile phones to support citizen inquiry. Moreover, Chaipidech and Srisawasdi (2023) developed and implemented a 360-degree virtual learning environment to support out-of-class inquiry activity for preservice teachers into the citizen inquiry activity. The study found that the learners had positive perceptions and self-reflection regarding their learning experiences using the 360-degree virtual learning environment. Furthermore, using simulation and serious games as learning tools for the circular economy concept, the teaching approaches could effectively promote active student learning (Torre et al., 2021).

2.3 Mobile Technology Facilitates Science Learning

Mobile technologies, such as smartphones and tablet computers, have been used in educational settings increasingly over the past ten years in attempts to enhance educational quality and the learning process. Mobile devices, also known as m-devices, have been recognized as a new educational instrument that has the ability to support teaching and learning techniques that take use of the context of each student. As such, Chaipidech and Srisawasdi (2018) used integrating mobile technology with personalized flipped open inquiry-based approach that is a simulation and hands-on laboratory via mobile for secondary school students. This result showed that a personalized flipped open inquiry-based approach using mobile technology is effective in enhancing students' conceptual understanding and intrinsic motivation towards learning science. In addition, Thumtathong, Premthaisong and Srisawasdi (2019) examines the effectiveness of teaching English with science using Content and Language Integrated Learning (CLIL) approach and mobile-assisted inquiry pedagogy on students' learning motivations and perceptions. They participated with interactive video from Lifesaver application to learn a choking situation. After that, students used iStyle science note to collect data and Nearpod application to discuss their idea via smartphone about respiratory system concepts in science classroom. Moreover, many researchers integrated STEM modules with various technology, such as computer-based board games, online game. This study demonstrated that connecting classrooms with online interclass tournaments could be possible to implement in schools. Besides, integrating the sustainability concept into Virtual Reality (VR) system-aided STEAM education could enhance the learning satisfaction and outcomes of students and to arouse their learning motivation (Hsiao & Su, 2021).

3. An Example of STEM integrated Technology-enhanced Inquiry learning

STEM discipline integrated technology-enhance guided-inquiry science learning is a pedagogical approach aimed at enhancing students' learning in science within the context of circular economy. This research integrated the four disciplines of science, technology, engineering, and mathematics (STEM) in one class, unit, or lesson, based on STEM principles and situated within an actual context or real-world scenario, serves to enhance student learning (Kelly & Knowles, 2016). Moreover, this approach involves engaging students in processes of scientific inquiry, which enable them to actively work with the scientific method and foster their oriented guided inquiry-based learning, Buck, Bretz, and Towns (2000) describes six steps; the first step is Problem or Question; the teacher will start the session by presenting a problem scenario related to the management of plastic waste, specifically focusing on the amount of plastic waste that has become to the plastic trash mountain. Second is Theory or Background; students will be provided an interactive 360-degree video to learn about plastic varieties in the area of university. The third step is Procedures or Design related to the phenomenon, using "Plastic collector" on the Appsheet, students will be required to collect data by taking photos regarding plastic debris in daily life. In addition, students must select the types and locations of plastic. Fourth is Result analysis; students will be tasked with analyzing data from the "Plastic collector" using Google Sheet to transform the quantity of each type of plastic into a graph. The fifth step is Result Communication; students utilized the Padlet platform to share information and discuss the quantity of plastic. Finally, the conclusion of the session, the teacher will conclude the lesson on plastic types. Figure 1 illustrates the pedagogy that was developed.

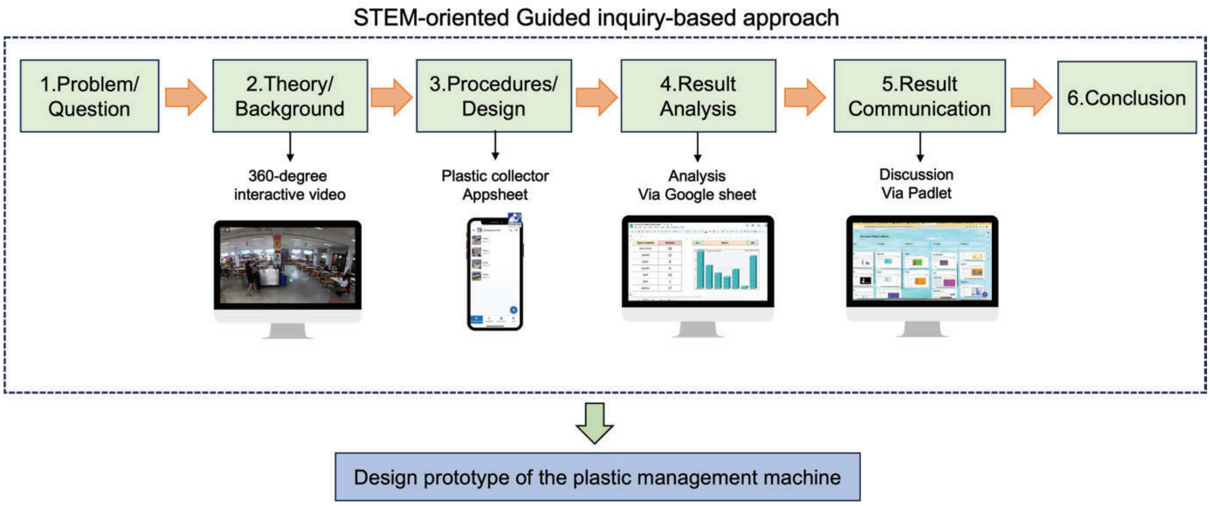

Figure 1. A STEM inquiry-based Learning with ICT Technology.

Furthermore, the teacher will provide a case study of the procedure for managing plastic waste, which complies with the principles of the 3R approach: reduce, reuse, and recycle. Finally, students will be tasked with the responsibility of designing a prototype for the plastic management machine. Therefore, this study comprises the four disciplines of science, technology, engineering, and mathematics (STEM). The scientific aspect focuses on the various types of plastic, including Polyethylene (PE) and Polypropylene (PP). The technological component involves the 360-degree interactive video, as well as the utilization of platforms such as the application of plastic collectors, Padlet, and other relevant tools. The mathematical dimension includes the analysis of plastic data, while the engineering aspect relates to the design of a prototype for the management of plastic.

4. Methodology

4.1 Study Participants

The participants of this experiment included 25 fourth-grade students from primary school at a university-based demonstration school located in the northeastern part of Thailand. They were enrolled in a basic education science course and were invited to participate in this study. Participants were between 9 and 10 years old. All of them had adequate fundamental computer and information and communication technology skills, but none had ever used a computer for science instruction before.

4.2 Research Instruments and Data Analysis

The research instruments comprised two instruments. For the first instrument, a conceptual pre-test and post-test for measuring students' learning achievement of the STEM learning activity about types of plastic. The conceptual pre-test was designed to determine whether students had a foundational understanding of all types of plastic. It consisted of ten multiple-choice questions, and one point was given for each correct response, resulting in a total of 10 points. The purpose of the conceptual post-test was to evaluate students' understanding of the main characteristics of various plastic varieties. The pre-test and post-test were both created and evaluated by three experienced science instructors. The second instrument also included a post-awareness interviewing to measuring students' environmental awareness after completing the learning activity. The post-awareness interviewing was adapted from Ozden (2008). An interview protocol has been developed for this study regarding the attitudes toward environmental problems to investigate students' awareness after interacting with a STEM inquiry-based learning with ICT technology.

For the activity, students were given 15 minutes to fill out the conceptual understanding test toward types of plastic concepts. Afterward, over a period of 3 days (a total of 200 min), the students learned about the types of plastic (i.e., Polyethylene Terephthalate, Polyvinyl Chloride, High-Density Polyethylene) in STEM lessons. After completing the instruments, they were explored to interact with the assigned of the technology-integrated STEM inquiry-based learning in the citizen science activity. After finishing the learning process, students were administered by the same conceptual test again for 15 minutes to determine their conceptual understanding. Moreover, students were asked to complete post-interviewing to determine students' awareness of the environment. Figure 2 shows students working on the assignment using various technologies.

Figure 2. An illustration of students' interaction with ICT technology integrated STEM inquiry-based learning about types of plastic concepts.

Following the completion of the learning activities, all students participated in a post-test to determine their conceptual understanding. Additionally, they were asked to complete an interviewing to measure their awareness of plastic-related issues. The duration of the interviewing was around 15-20 minutes. Furthermore, researchers focused their attention on the study of the data obtained from the post-interviewing. The statistical data for evaluating students' conceptual knowledge were analyzed using IBM SPSS Statistics 23.

4.3 Learning Material

According to previous studies, several researchers have developed a 360-degree virtual tour as an educational tool (Chaipidech & Srisawasdi, 2023; Rupp et al., 2019; Abidin, Suryani, & Sariyatun, 2020; Garcia, Nadelson, & Yeh, 2023). Nevertheless, using 360-degree virtual tours when combined with STEM inquiry-based learning was not employed. As a result, the present study demonstrated the use of 360-degree learning media within the context of STEM education in a science inquiry-based learning module focused on understanding various concepts related to varieties of plastic.

The 360-degree learning media on types of plastic was designed with three components in each location. In the first section, information about varieties of plastic will be displayed, including the names of objects, the type of plastic, the characteristics of plastic, and examples of items made from this type of plastic. After interacting with the second section, the information section, students were given multiple plastic-related questions that create by using "H5P" to assess their understanding. After the user selects an answer, the system will display the correct response and respond in real-time. Students can select the running man icon to navigate to another location and study additional plastic varieties in the last section. The 360-degree media is shown in Figure 3.

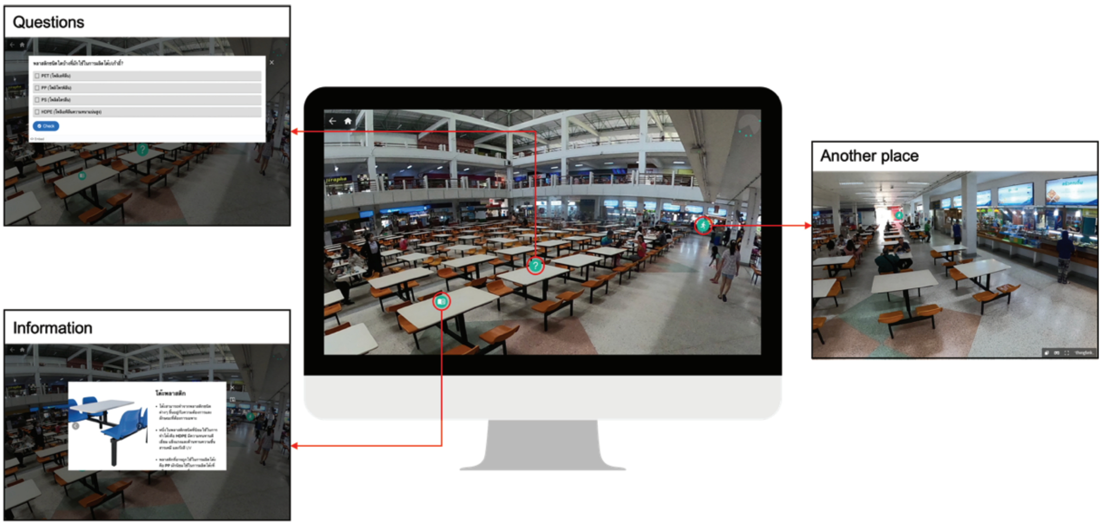

Figure 3. Illustrates a 360-degree virtual tour for learning about types of plastic.

According to the citizen inquiry activity, the learner is given the essential inquiry, "What types of plastic are most commonly found in our city?". In order to enhance students' awareness and knowledge of plastic types, we provided the "Plastic Collector" Appsheet platform for collecting plastic waste in everyday life, shown in Figure 4.

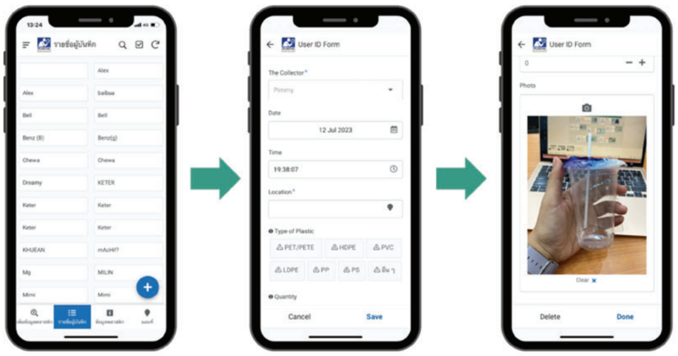

Figure 4. Illustrate of "Plastic Collector" on Google Appsheet to collect plastic around the city.

As part of this activity's citizen science component, students collected objects produced from plastic by taking at least three daily photographs. After taking photographs, students will choose the types of plastics related to the picture. Then, they have to choose the location of plastics. The advantage of the Appsheet's "Plastic Collector" is that students can share all information about plastic at their location, and others are able to view their information. In addition, students will be aware of the amount of each form of plastic in the city. Based on the aforementioned, this research presented various technologies to support STEM inquiry-based learning in the context of the circular economy. Additionally, in an effort to promote citizen science, students were given the opportunity to participate in citizen science by using their own devices on the Plastic collector application.

5. Result and Discussion

5.1 Types of Plastic Conceptual

The Wilcoxon signed rank test findings indicate a significant statistical difference ($Z = -4.073$, $p = .000$) between the pre-test and post-test scores following the implementation of STEM-integrated technology-based inquiry learning. In addition, the average score of the pre-test understanding was 3.84, with a standard deviation of 1.864. Table 1 displays the mean score of post-test conceptual comprehension, which was found to be 6.28 with a standard deviation of 1.542.

Table 1. *Statistical Results on Wilcoxon Signed-Rank Test for The Students' Conceptual Understanding Of Types of Plastic*

Time		N	Sum of Ranks	Z	P value
Pre-test	Negative rank	1[a]	5.50	-4.073[b]	.000*
Post-test	Positive rank	22[b]	270.50		
	Equal	2[c]			
	Total	25			

*p<0.05

As shown in Table 1.1, the conceptual understanding of students who learn with a STEM-integrated inquiry-based approach performs better after learning. This evidence demonstrated that integrating a STEM inquiry-based learning approach with various technologies could have greater effects on fostering students' scientific understanding of plastic types in the context of a circular economy. Similar to the prior research that using technology with STEM education, Lindner et al. (2022) found technology study that involved the creation of an augmented reality (AR) app, as well as a worksheet and lesson plan, to incorporate hyperspectral remote sensing data into STEM education. The findings revealed that when students interacted with this strategy, their understanding increased. Similar research was found when using mobile learning the STEM education, the implementation of STEM practical kit using free mobile apps could improve students' understanding on the topic of sound (Chu, et al., 2023).

5.2 Student's Awareness

As mentioned in the section on methodology, we conduct research by qualitatively analyzing data collected through semi-structured interviews. In this part, we present a sample of the collected data based on the recordings of interviews conducted with thirteen students participating in STEM inquiry-based learning within the context of the circular economy. The quotations in this section are organized in accordance with the five dimensions of the survey (Ozden, 2008). Cronbach alpha determined that the internal consistency of the scale was 0.88.

5.2.1 Awareness of environmental problems-AEI

In this dimension, awareness of environmental problems focuses on students' awareness of environmental challenges and their understanding of the impact of these issues on everyday life. Students commented in respect of the problem of environmental. Student 01 mentioned that “If there is an issue with plastic garbage near the school, it may harm us”. In the meantime, student 04 told that: “It is dependent on whether people care about the environment. If people do not care for the environment, it can lead to issues in the future”. Moreover, student 09 said that: “It takes a long time for plastic trash to break down. The more people use it, the worse it is for the earth”.

Based on the aforementioned comments, it is evident children possess a heightened awareness about environmental concerns. Furthermore, it is important for students to understand the implications of these challenges on their daily lives.

5.2.2 Awareness of individual responsibility-AIR

In this part, awareness of individual responsibility focus on awareness of individual environmental responsibilities among students. In this part, the awareness of individual responsibility focuses on students' awareness of their individual environmental responsibilities. All students have indicated that the collective responsibility for the preservation of the environment extends beyond the authority of the government or industrial entities. Student 08 told that: “Every country should work to solve environmental problems, not just one. This is because the effects of environmental problems may not only affect the country in issue, but also the countries around it”. Additionally, student 10 told that: “If we don't take care of the environment, our hometown will be full of trash, which will cause problems”. Furthermore, student 13 said that: “People use a lot of plastic every day, which means that there is a lot more trash. We are the ones who should use less”.

From the mentioned quotations, students’ awareness of their environmental responsibilities is emphasized in their awareness of individual responsibility. In addition, they presented ideas for environmental management.

5.2.3 General attitudes towards environmental solution-GAES

In this dimension, the general attitudes towards environmental solutions focus on the perspectives of students on potential solutions to environmental issues. The opinions of students about possible solutions to environmental concerns were discussed. Student 08 said that: “People's lack of care for conservation may result in an around the world trash overflow”. Moreover, student 04 told that: “Someone does not throw trash into the garbage container, that it might be a problem of plastic waste issue. So, we should start doing it by ourselves”. In addition, student 09 said that: “We can start by doing simple things, like making toys or other helpful things out of plastic trash instead of just throwing it away.”

The students' quotation highlighted their views on potential solutions for addressing environmental challenges. From the perspective of students, it is the method through which they can initiate initiatives inside their own environment and individually.

5.2.4 General attitudes towards environmental problems-GAEP

For this part, general attitudes towards environmental problems focus on students' perspectives on the impact of environmental concerns on daily life. Students expressed their opinions about the influence of environmental issues. Student 07 told that: “If you throw the trash into the water, fish and other marine animals might eat it or get caught in it, which could kill them.” Student 01 told that: “People shouldn't destroy nature because making too much trash is bad for us. For example, different pollutants that are released and breathed in can hurt our health”. Student 13 concludes and points out: “There is a lot of plastic in the world as several companies produce many types of plastic. Factories also make a lot of other kinds of hazardous waste.”

In these quotations, students emphasize the factors that have an adverse impact on the environment and the country's inhabitants. Meanwhile, students continue to be oblivious to how technology can be environmentally damaging.

6. Conclusion and Limitation

This study examined the impact of a technology-integrated pedagogy of STEM learning in the citizen science activity through inquiry on fourth-grade students, and the findings revealed that students improved their conceptual understanding of different types of plastic and developed a positive attitude toward the environment after participating in the citizen inquiry activity. Consequently, it implied that the possibility of promoting primary students' integration of various technologies into STEM inquiry-based learning in a circular economy framework might be an effective strategy to increase their environmental awareness. However, the number of participants in this study was limited, as they were chosen from a science class at a university-based demonstration school located in the northeastern part of Thailand. This limits the generalizability of the findings for students in primary schools in Thailand. Furthermore, in order for this strategy to be worth future study, the control and experimental groups of participants must be improved in order to compare treatment in each approach. Nevertheless, this study provides evidence of a positive starting point for designing ICT technology-integrated STEM inquiry-based learning of citizen science activity in primary students.

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