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Integrating circular economy into STEM education: A promising pathway toward circular citizenship development

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The young generation is expected to address current development challenges. The main challenge of sustainable development is the problem of waste management and recycling. To promote long-term sustainability, it is crucial to equip youth with contemporary knowledge and skills and to change their daily habits. The Circular Economy (CE) has become a key concept in responding to unsustainable resource use and waste management globally. At the same time, Science, Technology, Engineering, and Math (STEM) education is an innovative teaching approach to promote learners' capacity for self-direction, problem-solving, collaboration, and management. This paper argues the role of STEM education in connecting science with society, the benefits of teaching CE in promoting sustainable consumption and production behaviors, and the potential integration of CE into STEM education through real-world context inquiry and real-world problem-solving. It also presents the case of Vietnam, where integration of STEM education and CE in secondary schools is crucial for a CE toward sustainable development. Questionnaire surveys with 873 secondary school teachers and semi-structured interviews with 54 were conducted during the integrated STEM professional trainings. The aims were to examine teachers' perspectives on the relevance of STEM education and CE to sustainable development and their behaviors toward integrating CE concepts into daily STEM teaching activities. The findings showed a high perception of STEM teachers on the relevance of CE with STEM teaching, the Vietnam context, its interestingness, and the importance of integrating CE into STEM education. Surveyed teachers have also voluntarily integrated development issues and CE principles into STEM teaching. Including CE in STEM education in secondary education offers a promising opportunity to foster more profound societal change toward sustainable development, which contributes to SDG4 — equitable and quality education for sustainable development and sustainable lifestyles and SDG 12.5 — reduce waste generation through prevention, reduction, recycling, and reuse.

KEYWORDS

real-world context, problem-based learning, development issues, CE principles, secondary education teachers, transdisciplinary, Vietnam

1. Introduction

Education for sustainable development (ESD) emerged from numerous international discourses addressing the key sustainability challenge. From Agenda 21 to Target 4.7 "by 2030, ensure all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development," education is a key mean for achieving sustainable development goals (SDGs) and needs of integrating sustainable development into educational systems (Leicht et al., 2018; Nguyen et al., 2020). The Global Action Programme (GAP), which has existed for a decade, aims to expand and improve ESD initiatives at all educational levels and across all subject areas. Inter-SDG collaboration with ESD is also gaining traction. All the Sustainable Development Goals (SDGs) require education because it equips individuals with the skills, values, and knowledge they need to advance themselves and society. All educational institutions, from preschool to higher education, play a role in preparing tomorrow's citizens to solve problems in the real world by understanding the connections between social, science, and technology (Nguyen et al., 2020). Secondary schools, on the other hand, are crucial in helping young people develop global competence. This multifaceted skill enables them to examine local, global, and intercultural issues, understand and appreciate various world views, interact respectfully with others, and take responsibility for sustainability and well-being (OECD, 2018). Schools are in a unique position to help students better comprehend their place in society and the globe, as well as develop their knowledge and skills for decision-making and actions (Hanvey, 1982). In order to teach sustainable development in schools, it is important to transform the learning environment and teaching approach. Thus, questions emerged in this context: which educational approach is more appropriate and significant in which schools can have an influence on society in two-fold outcomes: equip young people with social and scientific knowledge and skills and change their daily behaviors toward sustainable development? And how must learning and teaching environments and approaches be transformed to implement ESD? The integration of circular economy (CE) concepts into STEM (science, technology, engineering, and mathematics) teaching appears as a promising education approach in the preparation of the young generation with modern socio-scientific knowledge and skills as well as the right social behavior toward addressing the development challenges of our current and future society.

Apparently, STEM education has been extensively brought up within the worldwide landscape of educational development and reform policies in the last decades as it has been considered an innovative and multidisciplinary educational approach (Sanders, 2012; Bissaker, 2014). The approach emphasizes the focus of combining the four disciplines of science, technology, engineering, and mathematics to improve students' proficiency in math and science, but their knowledge also needs to be connected with technology and engineering (Cammaert et al., 2020). STEM instruction employs a "learner-centered" methodology to encourage students' ability for initiative, problem-solving, teamwork, and management (Stehle and Peters-Burton, 2019), and drive learners' innovation through designing and producing solutions to real-world problems (Margot and Kettler, 2019). Another essential feature is that it leverages real-world difficulties as entrance points for combining STEM disciplines (Nguyen et al., 2020). CE concept, on the other hand, has been seen as one among novel approaches to sustainable development drawn from longstanding economic and environmental paradigms which suggest the efficiency of resource use and the balance of benefits and externalities between economy, environment and society (Fitch-Roy et al., 2021). Thus, the CE is essentially a pathway to achieving SDGs. The connection between CE and SGD is shown in SDG 12 and its target 5 "By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse." Toward the transition process to a CE and sustainable society, CE-related educational approaches and tools have been outlined by a few scholars to teach the CE in higher education institutions for transition to a CE and sustainable society (Kirchherr and Piscicelli, 2019). The CE principles are built around decreasing the consumption of raw resources and reusing and recycling materials and energy.

However, there has been very little attention on the integration of CE and STEM teaching approaches in secondary schools. Although sustainability, or sustainable development courses, have been taught at the undergraduate and graduate levels in recent years as a growing academic topic (Karatzoglou, 2013; Sedlacek, 2013; Leal Filho et al., 2019). Especially the integration of CE and STEM teaching is designed based on a problem-driven and solution-oriented foundation to address complex anthropogenic challenges. Through literature review, this paper presents a perspective on how STEM education connects science with society, the benefits of teaching CE in promoting sustainable consumption and production behaviors, and the potential integration of CE into STEM education through real-world context inquiry and real-world problem-solving. The paper also presents the case of the Vietnam context, where integration of STEM education and CE in secondary schools is crucial for moving to a circular economy toward sustainable development. It examines the teachers' perspectives on the relevance of STEM education and CE to sustainable development and their perceptions and behaviors toward integrating CE into STEM education in secondary schools toward a CE for sustainable development. The goal is to highlight the necessity of transitioning to a more innovative, interdisciplinary, and real-world context-connected secondary education for a sustainable world.

2. Literature review

2.1. The role of integrated STEM in connecting science with society for sustainability

Today's global citizens are expected to use the scientific and technological knowledge they acquire in school to address real-world problems, including environmental degradation, unpredictable climate change, and resource depletion (Nguyen et al., 2020). STEM education connects challenging academic concepts to real-world applications through an interdisciplinary approach to the teaching and learning (Bybee, 2013). Through the integration of S-T-E-M, a STEM lesson can provide students with quality socio–scientific-technical knowledge, modern digital competencies (Barragán-Sánchez et al., 2020), and their application in addressing real-world problems. It also equips learners with soft skills and competencies crucial for the workforce (Wong et al., 2016). STEM education nurtures young people with innovation abilities – an important skill for adapting to local and global changes and shaping the world.

As a curriculum and instructional approach, integrated STEM education can be helpful in secondary schools at all levels (Margot and Kettler, 2019). The pedagogical principles of STEM education are (i) the combination of knowledge of multiple STEM disciplines, (ii) inquiry through representations, (iii) problem solving and reasoning, (iv) challenge-based learning, (v) design-based, and (iv) digital technologies learning approaches (Nguyen et al., 2020). Because the current local and global concerns cannot be resolved within a single field, the integration of various STEM disciplines aims to improve young people's capacity for learning about or solving problems in the real world. Young people are prepared with interdisciplinary expertise and, with the aid of technology, the ability to assess the complexity of real-world situations as well as to establish integrated solutions by studying comprehensive integrative knowledge of STEM fields.

All science disciplines can be taught and linked with sustainable development concepts thanks to the assistance of engineering, technology, and mathematics in STEM education. This will improve learners' comprehension and roles in the implementation and attainment of the SDGs. As the global job market today demands workers with the multidisciplinary expertise and abilities to address the problems of a complex, connected, and dynamic world, integrating multiple disciplines can prepare multidisciplinary expertise. This could facilitate the young generation's employment pathway.

In addition, real-world, context-based STEM instruction also piques students' interest in solving problems in the world and enables them to see how science is relevant to their everyday lives (George and Lubben, 2002). STEM principles pertinent to these problems can be examined and applied to explain everyday situations that learners are familiar with (Lubben et al., 1996). By tackling real-world problems, students in STEM programs learn about science, math and technology and hone their critical thinking, problem-solving, and cooperation abilities (Asghar et al., 2002). The problem-based learning approach is crucial to engage students in learning about science and developing their skills in solving real-world problems through collaborative learning. In order to make sense of new knowledge, resolve challenging problems, and come up with a solution, the problem-based learning approach encourages students to build on their prior knowledge and work collaboratively (Wyness and Dalton, 2018).

Science, technology, engineering, and math education also teaches students how to tackle problems in the actual world through design learning tasks. The design-based learning approach, which uses technology, mathematical reasoning, creative design, construction engineering, and scientific investigation to solve problems in the real world, is crucial in STEM education (Zheng et al., 2020). Students are encouraged to use the inquiry and reasoning processes to produce creative products or objects and solutions when learning using design-based methods (Gómez Puente et al., 2013). The fundamental qualities of a contemporary global citizen, including systems thinking, interpersonal competence, interdisciplinary knowledge, strategic action, and management skills, are provided to students through the design-based learning (Wiek et al., 2011). Design-based learning can aid in achieving the SDGs since it starts with describing an issue from a real-world setting and creating the best solutions for social challenges (Huang et al., 2020). The entire society must, however, work together to implement the SDGs. The aim of STEM education is to provide students with a wide range of skills and interdisciplinary knowledge; as a result, cooperative learning in STEM education is crucial to the growth, dissemination, and maintenance of education's place in society. Students can greatly contribute to the implementation of SDGs such as conservation, sustainable consumption and production, and social responsibility for the development, peace, and equity through their positive behavior in the collective responsibility (Pawlowski, 1996) for the sustainable development of their community and country.

2.2. Integration of circular economy principles in integrated STEM education and the promotion of sustainable consumption and production

The issue of waste management and recycling is currently the primary challenge facing sustainable development. Domestic residences and industrial settings both produce waste. In addition to consuming a significant quantity of raw materials and resources, industrial facilities, restaurants, hotels, stores, markets, and homes all generate significant amounts of solid and liquid waste. Consumption depletes natural resources and leads to waste generation, which increases environmental pollution. In response to unsustainable resource consumption and waste management worldwide, the CE has quickly emerged as a key idea. The closed-loop economy debates of the 1970s are where the CE notions originated, and they impacted waste management and resource use regulations (Fitch-Roy et al., 2021). The original CE concepts center upon integrated waste management (IWM) and Reducing, Reusing, and Recycling (Dockery et al., 1993). The CE is extendedly defined as "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively re-using, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro-level (products, companies, consumers), meso-level (eco-industrial parks) and macro-level (city, region, national and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017).

The CE, according to some scholars (e.g., Kirchherr and Piscicelli, 2019), is the novel pathway to sustainable development; thus, it must be part of school curricula and hence educational programs/policies for sustainable development. CE education is grounded on curriculum development and outcome-based learning approaches, which are mainly developed on constructivist teaching methods. For example, in EC education, some authors (e.g., Sanchez-Romaguera et al., 2016) suggested "the use of contextual, active, multidisciplinary, collaborative and cumulative approaches to learning," while others (e.g., Whalen et al., 2018) recommended experiential learning through the use of a game that supports holistic and transdisciplinary thinking for a CE. On the other hand, constructivist teaching methods such as problem-based learning approach, real-world context inquiry, design-based, and collaborative-based learning are crucial pedagogical approaches in STEM education. These instructional methods are used to integrate the four disciplines of S-T-E-M, connect science lessons to the real-world context, and apply engineering and technology to problem-solving and the production of solutions.

For this reason, STEM education offers an essential ground for integrating CE principles in designing school curricula and courses. By learning the CE through STEM education, students can make connections to real-life problems that make them more interested in learning and acting to solve problems in their daily lives. This will change students' behavior toward their environment. Through the integration of the CE principles into STEM education, students' internal representations of the real world and attitudes toward sustainable consumption can both be changed and ultimately triggers their innovation for sustainable development (Nguyen et al., 2020).

3. Vietnam case study

3.1. Vietnam context and ESD

Vietnam is a middle-income country with a population of approximately 98.168 million people in 2021. The population bomb and rapid economic growth have heavily pressured resource consumption and waste generation in Vietnam. In recent decades, the amount of raw materials produced from natural resources has increased, roughly proportionate to the nation's economic growth during the 1990s. Over the past three decades, Vietnam's per-capita material consumption has steadily increased, from less than 2 tons *per capita* in 1990 to more than 9 tons *per capita* in 2010 of domestic material consumption (Schandl et al., 2015). Consequently, waste generation in Vietnam has been increasing substantially. The annual average municipal solid waste generation in 2003 was 6,400,000 tons, but it increased almost three times in 2015, estimated to be around 30,368,000 tons annually in 2025 (MONRE).

The Vietnamese government has made many efforts to implement policies in sustainable environmental management and resource consumption. The development strategies of the Vietnamese government have highly focused on the "knowledge economy" and "green economy." Economic development, cultural and social development, environmental protection, and a proactive reaction to climate change are the main focuses of the most recent five-year socioeconomic development plan. The success of the nation's development plans, which include goals like raising workforce quality through increased science and technology capability and promoting economic restructuring with a new growth model, as well as raising productivity, efficiency, and competitiveness of the economy, has also credited been in part to STEM education and CE. The integration of STEM and CE has been made within a number of policies, such as "Sustainable Development Strategy for 2011–2020," promoting "sustainable and effective growth" that entails "social progress and equality" and "national resources and environment protection." The draft for the subsequent period 2020–2030 of the National Action Plan on Sustainable Production and Consumption up to 2020 has been made with a vision for 2030. These strategies' fundamental premise recognizes the crucial contribution of science and technology to creating the conditions and driving forces behind sustainable development. The use of cutting-edge, squeaky-clean, and environmentally friendly technologies in production is the goal of these initiatives.

Although the term 'CE" is not commonly used and addressed in legislation, the 3R CE principles have been adopted in resource efficiency and waste management practices in Vietnam, for example, the VAC model (Garden–Fishery–Husbandry) in sustainable farming, domestic waste composting, cement and concrete production from reusing fly ash and slag from thermal power plants, waste segregation, and treatment, etc. State and non-state actors have both worked to promote CE. Some CE programs have been supported by the private sector, such as "Zero Waste to Nature" by the Vietnam Chamber of Commerce and Industry in partnership with Unilever Vietnam, Coca-Cola Vietnam, and Dow Chemicals to increase student, community, local government, and private trash collector awareness of waste segregation, and a circular system of plastic waste management established by the public-private partnership between MONRE and these same private companies.

The promotion of the CE understanding and practices relies very much on education and awareness-raising as well as technology and innovation; thus, the role of education is crucial to the transition to a circular economy toward sustainable development in Vietnam. The Vietnamese government established the educational development policy for 2011–2020, concentrating on improving the teaching of law, foreign languages, life skills, and information technology, as well as intellectual and moral values. The national panorama of educational policies and changes has included STEM education heavily as well. The goal is to give students the knowledge, technical expertise in STEM subjects, and 21st-century abilities, including collaboration, critical thinking, and creativity. In the last 3 years, a STEM program has been implemented as part of the Second Secondary Education Sector Development Program II (SESDPII), which was started by the Ministry of Education and Training and funded by the Asian Development Bank. Its goal is to prepare the labor force and economy for Industry 4.0. Other STEM programs are developed through collaborations between governmental and non-governmental organizations, such as the STEM Alliance, a team of researchers, university professors, and private businesses dedicated to STEM education. The primary target audience for STEM Alliance's robotics and coding education programs is private secondary schools.

3.2. Vietnamese secondary education teachers' perceptions and behaviors toward the relevance of CE in STEM education

This study has examined STEM teachers' perceptions and behaviors toward integrating CE concepts into STEM teaching at secondary schools. Vietnam is an instrumental case representing a country that generates rapid economic growth from inefficient resource use and consequently encounters serious negative environmental impacts and waste management problems. The participants in the study were the trainees of integrated STEM training organized by the Vietnam Ministry of Education and Training under the Second Secondary Education Sector Development Program (SESDP II) in 2019, funded by the Asian Development Bank (ADB).

The study was conducted through three stages. Firstly, 635 teachers who participated in the four integrated STEM training sessions in the Highlands, Central, and Northern regions of Vietnam were requested to list down the main development challenges in

Vietnam that they wanted to address through their STEM teaching projects/topics. Open-ended questions were used to give respondents a chance to express freely their interests in teaching topics that could contribute to sustainable development. Secondly, 238 teachers who participated in the other three integrated STEM training sessions in the North, Center, and South of Vietnam were surveyed to gauge their understanding of the CE and attitudes toward it through a questionnaire. The first question focuses on CE knowledge regarding CE principles such as natural resource conservation, waste value enhancement, correct producer and consumer behavior, eco-product design, sustainable waste management, product life cycle enhancement, fossil fuel, and renewable energy use, the hierarchy of 3R (Reduce, Reuse, and Recycle). Correct answers received a score of "1," wrong answers a score of "−1," and "unsure" answers a score of "0" in terms of knowing the CE concepts. The second survey question was whether the respondents agreed on the relevance of CE to STEM teaching, to the local context, and the importance and interestingness of CE. Teachers' responses were graded on a Likert scale ranging from 1 to 5.

In addition, the questionnaire in the second stage was followed by 54 semi-structured interviews to examine teachers' perspectives on the CE further, and their relevant teaching experiences were gleaned *via* open-ended questions. Eighteen teachers, from each training location which made a total of 54, were approached randomly and asked for their voluntary participation in a short interview of 15 min during the break time. Lastly, 77 STEM teaching project proposals of teachers across the country submitted to the SESDP II were also examined. The analysis of these projects focused on the main teaching STEM topics, and pedagogical methods were proposed.

3.2.1. Top development issues indicated by secondary education teachers for teaching integrated STEM

Most of the development issues indicated by the 635 teachers in the first survey are relevant to CE (Figure 1). 82.8% of the 635 teachers who participated in the first survey said that to improve their students' environmental literacy, appreciation for environmental protection, and comprehension of the tools and procedures needed to monitor and analyze the environment; they preferred to incorporate the topic of environmental pollution into their STEM projects and classes. The creation of sustainable daily goods and objects, material recycling, and the promotion of renewable energy and water sources are other significant development concerns (69.7, 73.5, and 53.4%, respectively). These teachers found STEM education vital as it enhances the responsibilities and the significance of secondary schools in solving the nation's current development concerns, which helped achieve the SDGs.

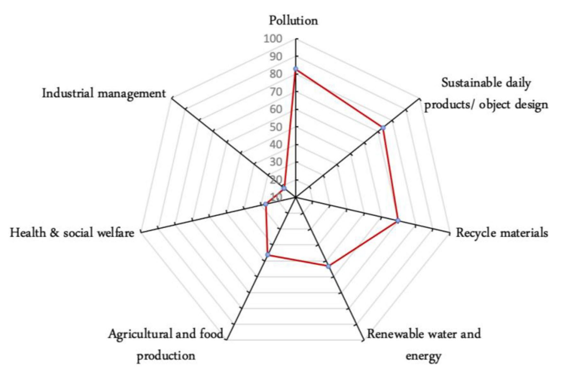

FIGURE 1
Top development issues to be used in the STEM lectures of the surveyed teachers. % Responses were counted based on the topics listed by the surveyed teachers. (*N* = 633).

3.2.2. The CE knowledge of the secondary education teacher

Many teachers who responded to the 2nd survey agreed that it is crucial to incorporate the idea of sustainable production and consumption into the curriculum to ensure that natural resources are used wisely; that less harm is done to the environment. Their understanding of the CE was evaluated by a series of questions on the CE's principles, to which they responded with "right" or "wrong" responses or "unsure" if they were unsure of the proper response. The average knowledge score was then determined by adding all the responses with incorrect answers given a value of −1, correct answers with a value of 1, and uncertain responses with a value of 0. The teachers' CE principles relevant knowledge of "natural resource conservation," "waste value enhancement," and "correct producer and consumer behavior" is exceptionally high, with ratings of 0.92, 0.9, and 0.9, respectively. "Eco-product design,' sustainable waste management," "product life cycle enhancement," and "fossil fuel and renewable energy use" were also highly known as relevant to the CE, which ranged from 0.82, 0.78, 0.76, and 0.74. However, the surveyed teachers did not know the hierarchy of 3R waste management actions (Reduce, Reuse, and Recycle). It was acknowledged in the literature that of the "3Rs," Reduce was the most important, followed by Reuse and Recycle, in the hierarchical structure for waste management; however, the study's teachers showed little knowledge of the subject (Figure 2). In further interviews, a few teachers also said they had never heard of "CE" or "sustainable production and consumption" terms.

3.2.3. Experiences of integration of CE concepts in STEM teaching of secondary education teachers

The analysis of 77 STEM teaching projects submitted by teachers who participated in integrated STEM training provided by SESDPII showed that many secondary education teachers have voluntarily integrated the CE concept into their STEM projects and lessons using several constructivist pedagogical methods to connect science with the real context problem (Figures 3, 4). 31.17% of projects focused on sustainable consumption and production, in which sustainable daily products and artifacts design (21%), waste management, and material recycling (10%). Sustainable water, food, and energy were also the 2nd theme that 29.87% of projects focused on. Pure scientific theory, inquiry, environment, climate, and health and education were less focused on the projects. Several constructivist pedagogical methods were used, including inquiry and experimental-based learning (24.68%), problem and collaborative-based learning (18.18%), and problem, inquiry-based learning (11.69%) and design-based learning (10.38%). For example, inquiry, experimental- and design-based learning approaches were applied to illustrate water pollution, and

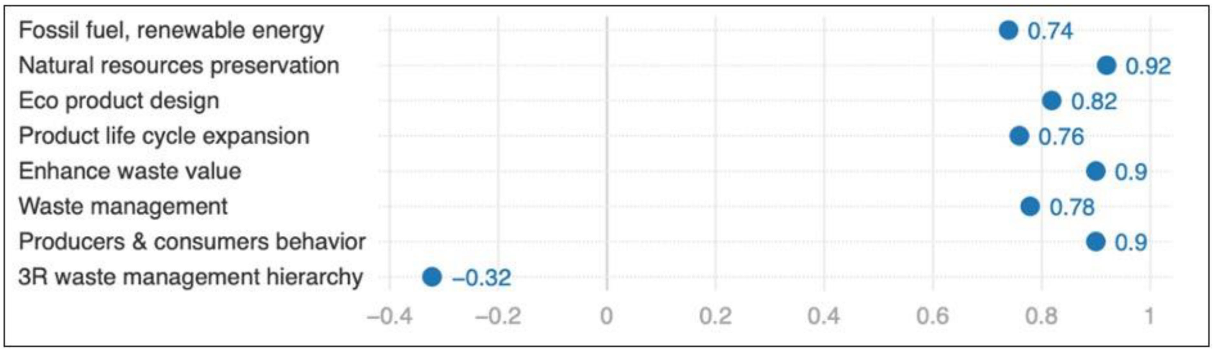

FIGURE 2
Teachers' CE knowledge. The average knowledge score ranges from −1 (low) to 1 (high) calculated by adding up all responses with wrong answers=−1, right answer=1, unsure=0. The value of 1 is considered a full understanding of the CE concepts. *N*=238.

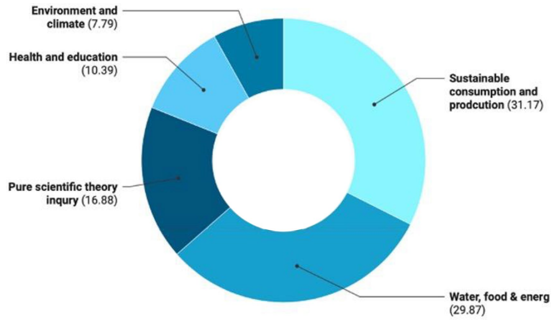

FIGURE 3
Themes of STEM teaching projects were developed by the surveyed teachers. The percentage is calculated using a total of 77 projects.

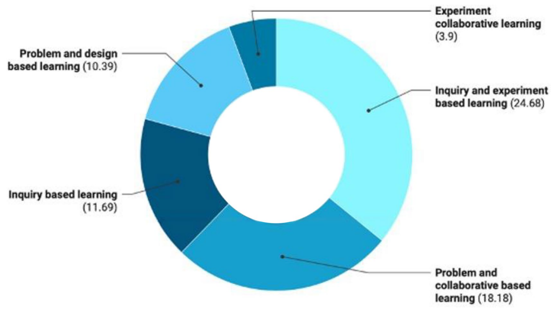

FIGURE 4
Constructivist pedagogical methods deployed in teaching STEM lessons. The percentage is calculated using a total of 77 projects.

design water filter or design-based learning was used to teach the designing a sprayer from recycled materials, or inquiry, experimental- and design-based learning for teaching and designing electricity circuit using bioenergy from fruits and vegetables. This real-world context-based inquiry would help students see the relevance of science to their daily lives, and the design-based learning approach is used to solve real-world problems. The collaborative-based learning approach would develop students' positive behavior in collective responsibility for the sustainable development of their society.

In addition, through the interviews, many teachers expressed their experiences in integrating the CE concepts, including collaborative skills through STEM education; students develop their positive behavior in collective responsibility for the sustainable development of their country in their science classes, as some Chemistry teachers shared *"Each unit of the Chemistry curriculum has a section labeled Application. There is information about CO2 gases and SO2 gases in the chapter on oxygen and sulfur. I made sure to include information about environmental concerns in these courses… I assigned the students the task of putting together a presentation on an environmental issue. They presented and engaged in a discussion."* Or *"I teach Chemistry so in my subject there are sections related to the environment, … for example, the polymer […] I showed students a video in which a flock of birds died when migrating because of plastic waste […] I let students explore the environment around them and feel and think about our impacts on the environment. If we use one nylon bag daily, what will happen 10, 15, and 45 years later?"*

Some other teachers revealed that they had included CE ideas in their STEM teachings, including manufacturing, pollution, waste segregation, material selection, recycling, and energy. For example, some biology teachers stated, *"I had a lesson in which I taught students to make products from different materials. Product ideas come from students, and they must explain why they chose those ideas. Concerning waste, I asked students to segregate."* Or *"I taught students to dispose of trash appropriately such as organic fruit skin, recyclable and non-recyclable trash," or "I taught students to] make new products from the trash. Students can make cards from the trash."* CE was taught in various ways, including lectures, presentations, debates, and field trips; as technology expressed, *"students had excursions to observe the waste station and the landfilling process."*

3.2.4. Teachers' attitudes toward integrating CE in integrated STEM teaching

Surveyed teachers had positive attitudes toward integrating CE into STEM education. They tended to agree that CE concepts are highly relevant to integrated STEM, to the Vietnamese context, and it was important and interesting in integration into STEM education. Kruskal–Wallis test shows that there is no difference in teachers' attitudes among the three groups of subject teachers. However, although more science teachers found the CE concepts relevant to

TABLE 1 Surveyed teachers' attitudes toward integrating CE in STEM teaching.

	Mean±SD				*H*-statistic	Value of *p*
	Overall	Math	Science	Technology		
Attitudes	4.11 ± 0.52	4.02 ± 0.59	4.29 ± 0.60	4.18 ± 0.55	3.15	0.207
Relevance to STEM	4.21 ± 0.59	4.25 ± 0.56	4.24 ± 0.56	4.16 ± 0.64	0.74	0.691
Relevance to context	4.00 ± 0.68	3.86 ± 0.73	4.06 ± 0.70	3.97 ± 0.61	2.403	0.301
Importance	4.18 ± 0.61	4.09 ± 0.63	4.25 ± 0.62	4.11 ± 0.58	4.212	0.122
Interestingness	4.06 ± 0.60	3.90 ± 0.58	4.13 ± 0.57	4.02 ± 0.65	4.391	0.111

Mean calculated from 5 Likert scale responses 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (N = 238).

STEM teaching, to the Vietnamese context, and important and interesting to teach in science classes, math, and technology, teachers also showed positive attitudes toward teaching the CE in integrated STEM (Table 1).

However, during the interviews, some barriers were expressed by the teachers that might constrain their voluntary of combining CE and STEM teaching. The knowledge of the CE principles and practices is the first barrier; as some teachers explained, "*these concepts of CE are very difficult*." Or "*The barrier is the interdisciplinary knowledge. We must learn knowledge of many subjects, and it takes time*." Or "*How can I connect these subjects? I still do not know how*." The lack of collaboration among teachers, the rigid school curriculum and textbook-based exam models, and the lack of managers' support in incorporating CE in STEM education are other barriers stated by the surveyed teachers. Low interest and capacity of students is also a problem in encouraging teachers to be innovative and creative in their daily teaching. This is because of past and current discipline or subject-centered conventional teaching approaches and lack of demonstration with real-world experiences. Inadequate facilities in disadvantaged regions also hammer the teachers' interest in teaching STEM by integrating CE concepts.

4. Discussion

The study showed integrated STEM method, which combines design-based learning and context-based real-world inquiry, helps change the old didactic triangle—teacher, student, content (Lubben et al., 1996) —that many secondary schools in Vietnam utilized to indoctrinate passive students and open opportunities for teachers to integrate the development issues and CE principles and practices in their everyday teaching in secondary education. Teachers in this study have already voluntarily integrated the CE principles into STEM teaching, which has created a great opportunity to promote the integration of CE into STEM education in secondary schools. Although there was a lack of familiarity with the CE principles and their link to taking a whole picture of a CE, certain CE concepts and principles were taught by surveyed teachers in isolation within the context of environmental education and STEM projects and lessons. Thanks to integrated STEM thinking and systems thinking, teachers created STEM modules and lessons geared at development concerns and CE principles with a sense of excitement, understanding the challenges through the eyes of someone who was confronting them. Students were given the opportunity to participate in science and technology, play agentive roles in reshaping their individual and communal futures, and contribute to long-term sustainability.

Teaching CE in integrated STEM using constructivist pedagogical methods encourages the "learning by doing" of students through real-life lessons (Kong, 2021). As they learn about "touch" and experiment with real-world problems as part of the learning process, it boosts students' motivation to address real-world challenges, the cornerstones of social change. This approach would have changed the way that many public and private schools in Vietnam taught, as they had previously depended on a teacher-centered, textbook-based method that precluded students from gaining from contextualized learning (Nguyen and Nguyen, 2008). The study showed that the secondary surveyed teachers were aware of the developmental challenges they face; thus, among the most common themes that teachers incorporated in their STEM modules or intended to teach in their STEM lectures were sustainable consumption and production and water–food-energy sustainability.

However, barriers to collaboration among disciplines since secondary education are characterized by discipline division and specializations, and inadequate general CE and subject-based knowledge of teachers could be the challenges of integrating the CE into STEM teaching. The disconnection between the school and the community, as well as other private and public sectors, could pose another obstacle to the integration of CE into STEM education. This could constrain the bridging of community-based knowledge and school-based knowledge (Bouillion and Gomez, 2001) and the provision of intellectual and meaningful science learning through practical experience of CE-related STEM teaching.

5. Conclusion

The study finding shows the high-level perception of secondary school teachers in Vietnam on the relevance of CE with STEM teaching, the Vietnam context, its interestingness, and the importance of integrating CE into STEM education. It also reports teachers' unconscious application of CE principles in their daily STEM teaching activities and their willingness to teach CE demonstrated through their STEM projects. As the key agents in advancing CE-related STEM education, teachers must get professional development that gives equal weight to improving their scientific and CE knowledge as well as training them on how to incorporate CE into STEM lectures, curriculum development, and pedagogical procedures. This study suggests that including CE in STEM education is part of a "breadth and depth" educational strategy. A "breadth and depth" educational strategy encourages teachers to cross disciplinary lines while sticking to their specialty. Although it prepares students for work in frontier disciplines, it is still essential for them to develop a thorough understanding of their primary field. This research illuminated that integrating CE in STEM education would aid students in developing their abilities and knowledge while also altering their behavior on contemporary real-world issues. The strategy promotes using a transdisciplinary approach and contextual scaffolding to link science with community and connects community knowledge with school-based knowledge. Therefore, Including CE in STEM education in secondary education offers a promising opportunity to foster more profound societal change toward sustainable development, which contributes to SDG4 — equitable and quality education for sustainable development and sustainable lifestyles and SDG 12.5 — reduce waste generation through prevention, reduction, recycling, and reuse.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

TN conceptualized, designed the research, analyzed the data, drafted and edited the manuscript. The author contributed to the article and approved the submitted version.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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