



## THE SUPPLEMENTARY LOW CARBON EDUCATION E-BOOK FOR ELEMENTARY SCHOOL STUDENTS TO ENHANCE SUSTAINABILITY LITERACY AND GLOBAL CHARACTER DIVERSITY

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### ABSTRACT

The development of e-books related to low-carbon education (LCE) has been used to enhance sustainability literacy and global character diversity (GCD) among elementary students. The research was conducted to identify the three themes of e-books available to students in phases A, B, and C. The three e-books have developed into a supplementary, ongoing curriculum. The e-books with flip mode and a high validity index have already been implemented and researched using a pre-experimental design in each phase. The e-books were designed as picture stories, equipped with various features to train students' sustainability literacy and GCD through invitations to think critically, to complete projects, and to express their thinking related to the context and environmental problems. The validity of the e-books was ensured through validation by 5 experts and 20 users, and the data were analyzed using simple statistics and CVI/CVR indexes. The sustainability literacy instrument used was developed and implemented together in the context of learning in Indonesia and Japan (Kitakyushu), with some modifications tailored to each phase. Students' GCD was monitored using a standard questionnaire based on GCD indicators. The research shows that all the e-books have high usability, as indicated by the CVI/CVR scores. The implementation results show, on average, an increase in students' sustainability literacy from moderate to high. The improvement in students' GCD was from the moderate to the high category. In addition, the books, attractively packaged with cartoon images, were easy to use with an Android app and very handy, which made the learning experience enjoyable for students.

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Keywords: Low Carbon Education; Global Character Diversity; Sustainability Literacy; e-book; elementary student

### INTRODUCTION

Education is a strategic step to foster low-carbon societal behaviour, which many experts are very concerned about (Neo et al., 2017; Zhang, 2017; Chen & Li, 2019). Low awareness of the world community about a low-carbon lifestyle is one of the factors driving global climate change in an increasingly dangerous direction.

This is the urgency why Low Carbon Education (LCE) should be introduced to students, from the age of elementary school (Phang et al., 2016) up to higher education (Beynaghi et al., 2016; Dai et al., 2018; Horan et al., 2019; Deshui et al., 2022; Li et al., 2024), so that the environment is free from carbon emissions. A person's understanding, skills, and awareness of the need for LCE to build a better environment for the welfare of humanity are the parameters of sustainability literacy. In the context of the elementary education

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curriculum in Indonesia, some subjects related to LCE are available, but very limited, shallow, and less likely to lead to the growth and development of awareness of low-carbon behaviour (Horan et al., 2019; Sofiyani et al., 2019; Amin et al., 2020; Permanasari et al., 2020; Obi & Ojo, 2026). LCE has been introduced through the environmental education subjects, including 3R (Reduce, Reuse, and Recycle), how to reduce CO<sub>2</sub> (Wong et al., 2017; Hudha et al., 2020), and in thematic learning to save water and electricity (Buchanan et al., 2016; Phang et al., 2016). Across studies, the lack of LCE response in curriculum policies generally results in low levels of student sustainability literacy (Nurramadhani et al., 2022; Aggarwal, 2023; Yadav, 2023). Therefore, LCE needs to continue to be echoed and disseminated to all interested parties, such as teachers, schools, communities, and researchers.

Low-carbon education is closely linked to efforts in achieving global goals, encapsulated in the Sustainable Development Goals (SDGs). Low-carbon education leads to a lifestyle oriented towards building a comfortable living environment for the future. Low-carbon education, at least, contributes to the achievement of global goals no. 4 (education for sustainable development, ESD), no. 6 (clean water and sanitation), no. 7 (affordable and clean energy), no. 11 (sustainable cities and communities), no. 12 (responsible consumption and production), no. 13 (climate action), no. 14 (live below water), and no. 15 (live on land).

The large contribution makes it essential to provide LCE as teaching material from early childhood education through university. Junting (2024), Du et al. (2023), and Zhu et al. (2026) also stated that, in the Chinese context, the status and challenges of low-carbon literacy among university students are now of greatest concern. The need to enhance students' awareness and behaviors towards a low-carbon lifestyle cannot be ignored. The importance of learning materials for LCE has also been highlighted by Zarate et al. (2024), Srkoc et al. (2022), and Jin & Liu (2025) through the development of programs and learning materials to enhance environmental awareness among high school students.

The conceptual awareness of building a comfortable environment is very closely related to the global character diversity (GCD). The Indonesian school curriculum also contains efforts to build this global character. Subjects of LCE have been introduced at the Phase A (Grades 1 and 2), Phase B (Grades 3 and 4), and Phase C (Grades 5 and 6) levels of Elementary educati-

on. Nevertheless, it has not been widely linked to sustainability literacy and is less related to efforts to build the character of global diversity. This weakness is one of the reasons students' sustainability literacy remains low (Wong et al., 2017; Nurramadhani et al., 2024). Xiang & Liu (2024) revealed that several factors and paths influenced students' low-carbon behaviour, including the low quality of education, the lack of LCE in the curriculum, and the limited material teaching of LCE.

The determining factor in the success of low-carbon education, beyond the curriculum, is the availability of supportive teaching materials. The results of interviews with elementary school teachers indicated that the school curriculum also includes efforts to build global character, but these efforts have not been widely integrated into LCE-related teaching materials. Ideally, for the best results, the LCE curriculum is aligned with global character education, making learning more meaningful. Generally, teachers struggle to find concrete examples of LCE cases, which makes learning less engaging. Teachers also found it difficult to find concrete examples of related material for practical purposes, and tend to follow a curriculum that still emphasizes memorization.

Based on the description, it can be concluded that to improve the quality of low-carbon education, it is necessary to provide an LCE curriculum to enrich the current curriculum, along with teaching materials that teachers and other users can use as guides for LCE. The materials should be packaged with concrete examples of the diversity of global characters. In line with efforts to integrate technology into today's learning, the provision of teaching materials in digital form has great development potential, one of which is e-books. The teaching materials also need to accommodate the cognitive abilities of elementary school students, who, on average, learn better through visualization. Therefore, non-text e-books are an option in this study.

Based on the description above, research has been conducted to solve the problems in LCE learning at the elementary school level with the research questions: (1) What are the needs of curriculum development and the need for LCE teaching materials? (2) How is the implementation of non-text curriculum and e-books in learning? (3) How can non-text e-books on LCE materials accommodate the improvement of the sustainability literacy of elementary school students? How does the global character of students change after learning with the non-text e-book?

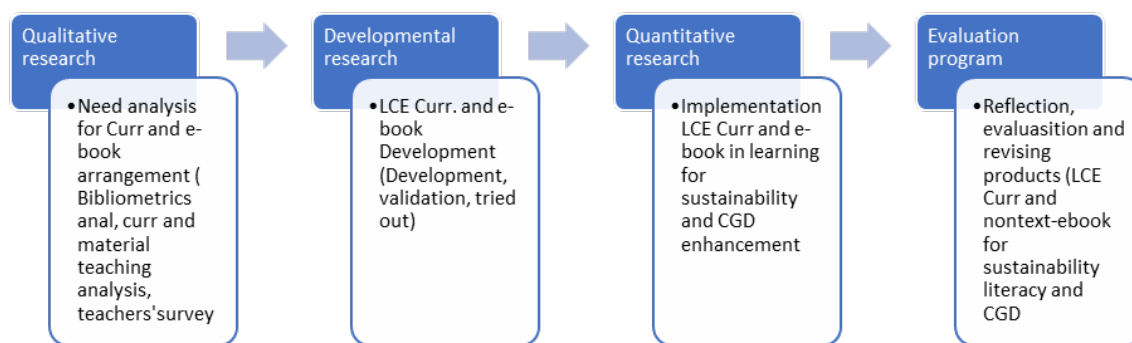
Through the research, it is expected that these supplemental books can be used by teachers and students in elementary school to enhance students' sustainability literacy and environmental awareness. Based on preliminary research, similar books have been developed for university-level use and for teachers in special-needs schools (Amin et al., 2019; Hudha et al., 2020).

## METHODS

Research has been conducted using a mixed-methods, sequential-exploratory design (Creswell & Clark, 2017). As shown in Figure 1, the first step of the research was a qualitative study that descriptively examined the needs of the LCE curriculum and teaching materials in elementary school. A literature review on bibliometric analysis was conducted alongside the survey, which was used to assess the sustainability literacy levels

of 110 elementary students purposively selected from three state elementary schools in Bogor city (2 Schools) and a suburban school (1 school). An in-depth interview with the 3 elementary teachers representing each phase was also conducted to gather information on the needs of the e-book content. A study of the school curriculum was also conducted to map the LCE materials that have not yet been incorporated.

The next step was developmental research, aimed at designing the LCE Curriculum as a complement to the LCE content in the ongoing curriculum. Furthermore, best practices for teaching materials have been compiled into a digital book for each phase. Along the way, focus group discussions (FGDs) involving relevant parties were conducted as a validation step to assess the feasibility of both the LCE curriculum manuscript and the digital books under development.



**Figure 1.** The Steps of Research on Using Sequential-Exploratory Design (Cresswell, 2017)

The FGD Session involved 20 participants, including 2 elementary school curriculum experts, 3 LCE experts, 10 users (elementary school teachers), 2 regional-level policyholders, and representatives of the elementary education association. The validation process for the three digital books developed as best practices involved 5 experts across various areas, including didactic-pedagogical, LCE, and IT. 20 experienced teachers also examined the books to ensure their eligibility. Some students were also involved in the books' trial to ensure they could be used easily.

In the third step, the quantitative research was conducted by implementing digital books at every level. Students' sustainability literacy was then measured before and after implementation. The global character of students after the learning was also measured. The implementation of learning was also observed and recorded to complete the quantitative data. In addition, interviews have been conducted with several elementary school teachers (members of the elementary teacher forum) from several schools in West Java,

Indonesia, regarding the implementation step. The evaluation program is the final step in the research stages and is carried out through an FGD. Discussion groups were held among the research team to revise the research products based on feedback and the results of product implementation throughout the learning.

The participants in the FGD for the LCE curriculum manuscript included 2 elementary school curriculum experts, 3 LCE Experts, 10 users (elementary teachers), 2 regional-level policyholders, and representatives of the elementary education association. The validation of the e-books involved 5 experts and 20 science teachers with more than 5 years' experience in teaching science at the elementary school for each e-book. During the learning implementation, each phase involved 20-30 students from Phase A (grade 2), Phase B (grade 4), and Phase C (grade 5). For the comparative study, the research was also conducted to develop an e-book for phase D (grade 7), involving 20 science teachers from secondary schools.



The density and connectivity of keywords suggest increasing scholarly attention to this topic, supporting the argument that LCE has emerged as a growing, relevant research field for addressing global environmental challenges. Integrating sustainability values and low-carbon behaviors into education from an early age is therefore considered essential to strengthen students' environmental awareness and character development (Phang et al., 2016), an aspect that has not been deeply explored in several existing studies. In addition, higher education institutions play a strategic role in promoting LCE through innovative and context-relevant learning approaches (Dai et al., 2018). Thus, from the results, it can be seen that the trend of research on low-carbon education continues to increase and can still be pursued in the future, focusing on environmental awareness, behavioral change, and knowledge in education at all educational levels, especially in the early stages.

The results of the bibliometric analysis are highly relevant to the need for developing material resources, such as e-books developed within a pedagogical framework. Much research on LCE focuses on low-carbon topics without considering pedagogical aspects. Some research on LCE has already been conducted, but its purpose is mostly to build environmental awareness rather than to focus on sustainability literacy. A similar bibliometric study was conducted by Ardoin et al. (2022), which identified 60 relevant studies through qualitative coding, revealing limited research on the development of environmental education for youth through learning innovations and tools to ensure competence, confidence, connection, character, and concern for the environment.

Research on the elementary education curriculum in Indonesia shows that several LCE concepts have emerged in the 2020 curriculum. However, the elaboration of the curriculum into learning materials remains insufficient and limited for use as a teaching guide. A survey of 200 elementary school teachers across various phases found that several LCE concepts have been incorporated into the curriculum. However, teachers feel the need for the elaboration of the content, especially to enhance sustainability literacy. They desperately need more in-depth content with concrete examples so that they can easily learn it to students. Moreover, teachers want the LCE material presented to be in accordance with students' cognitive development. It is similar to previous research that, to cultivate students' environmental awareness or sustainability literacy, it is ne-

cessary to include direct environmental activities and contextual content in learning (Saefudin et al., 2025).

Based on the results of the analysis of various literature and elementary school curriculum in Indonesia that are currently in force, and compiled with the expectations of elementary school teachers regarding the content of LCE, the LCE curriculum for elementary schools has been developed, which is packaged in themes according to the characteristics of the curriculum at the basic education level. The curriculum developed is complementary, especially for the development of teaching material. It should be noted that large-scale curriculum arrangements or revisions can only be made during a specific period, generally after 5 years of curriculum implementation. Considering that the LCE curriculum also needs to accommodate global character diversity, the curriculum is compiled based on four core competencies: sustainability knowledge, sustainability skills, sustainability-relevant values, and Global Character Diversity (GCD), as elaborated in Table 1.

The lack of LCE Content in the school curriculum in Indonesia is caused by many factors, including the excessive number of subjects, which means not all material is covered in depth. The lack of government attention to environmental issues over the past 20 years has also prevented LCE from becoming a main issue in the curriculum in both elementary and secondary schools.

Actually, since 2006, the Ministry of Education has begun paying attention to environmental issues through the *Adi-Wiyata* (Green School) Program. The program aims to create schools with environmental consciousness and culture. The program was first implemented in 10 schools in Java, the Bali Islands. However, it has faced stagnation due to several factors, including a lack of awareness and understanding from both the school and the community regarding the *Adi-Wiyata* Program, limited resources and funding, and the academic orientation of the school. In 2013 and 2025, the Ministry promulgated regulations on *Adi-Wiyata* School, but they remained at the administrative level and did not yet touch the curriculum content. This condition has also occurred in several developing countries over the last 10 years. The low level of commitment among policymakers and school staff, particularly principals, has been studied. Ntanos et al. (2022) reported that many principals still exhibit low levels of environmental and energy-saving behavior.

The increasingly alarming environmental issues worldwide have prompted the Indonesian government to once again prioritize environmental education. The United Nations, through UNESCO, is pushing worldwide to accelerate awareness of the environment through the concepts of the SDGs and ESD, offering new hope for education in Indonesia to reform its curriculum orientation towards ESD, where the concept of LCE is part of it. Although it has not yet been incorporated into the school curriculum, the government has at least shown significant attention to environmental issues and LCE, as reflected in the increasing number of LCE research projects funded by the Ministry of Education through research grants.

Based on the preliminary study and literature review, the research concludes that an additional curriculum for elementary school should

be developed to strengthen the science curriculum by integrating all related aspects, such as lifestyle, character, and the environment. This aligns with the research by Xu & Dai (2025), which suggests that integrating natural science education into the framework of green and low-carbon education enhances students' sustainability literacy. Moreover, Mammadova & Rustamov (2023) stated that, aligned with sustainability literacy, integration must not only occur between science education and social issues but also address the importance of economic values.

By systematic research, the core competency and learning outcome (CCLO) of LCE in elementary school is developed as elaborated in Table 1. As stated in the previous section, LCE is closely related to enhancing global character diversity, so the CCLO of global character was also included.

**Table 1.** Core Competency and Learning Outcome (CCLO) of Low Carbon Education in Elementary Student Curriculum

No	Core Competency	Learning Outcome
1	Sustainability knowledge	<ol style="list-style-type: none"> <li>1. Understanding basic ecological principles</li> <li>2. Approaching problems and situations from a systems perspective;</li> <li>3. Thinking critically, solving problems creatively, and applying knowledge to new situations;</li> <li>4. Assessing the impact of the use of technology and human actions;</li> <li>5. Evaluating the long-term consequences of decisions.</li> </ol>
2	Sustainability skills	Using tools, objects, and working procedures with a sustainability-based Realizing thoughts into practical and effective actions based on knowledge to create ecological designs
3	Sustainability-relevant values	Feeling care, empathy, and respect for others and living things. Appreciating and judging the work of others from different perspectives based on different backgrounds, motivations, and intentions. Committing to fairness and inclusivity, towards achieving sustainability Demonstrating a spirit of passion for sustainability Having respect for/appreciate nature and all living things Feeling connected to nature and inviting others to feel the same way.
4	Global Character Diversity (GCD)	Knowing and appreciating culture, namely appreciating ethnic and religious diversity; Being able to interact between cultures, namely interacting with peers with different backgrounds and avoiding discrimination of ethnicity, religion, and social status; Performing a sense of responsibility in diversity and applying an attitude of tolerance

Sustainability literacy is universal so that all core competency dimensions can be applied to all students at every phase—likewise, learning outcomes. What distinguishes one phase from another is the depth and complexity of the material and the assessment developed. The integrative nature of the low-carbon education curriculum is evident in its ability to accommodate efforts to

build character across global diversity (Amin et al., 2019; Chen et al., 2022).

Based on the core competencies and learning outcome that has been discussed previously, then low-carbon education materials are arranged and packaged in the form of themes, which are arranged in stages ranging from simple themes to more complex themes, according to the hierarchy

of phases A, B, and C. Materials for each phase are presented in four themes, each of which is adjusted to the gradation of the needs of each phase, with a gradation of the level of complexity of the material. The three big themes were arranged to cover subthemes in each phase, namely “*I do not want to live with the mountain of garbage*” (Phase

*A*), “*I wonder how to handle the garbage*” (Phase *B*), and “*healthy living without waste*” (Phase *C*).

These three main themes are broken down into smaller themes that can be taught during the learning periods. The small themes, descriptions, and time loads of each theme at each phase are shown in Table 2.

**Table 2.** Material Teaching and Learning Load of LCE in Elementary school

Phase	Theme	Description	Learning load
A	Topic 1: Let's manage the waste for a healthier	The subject provides students with an opportunity to discuss how to manage waste.	8x 35 minutes
	Topic 2: My garbage, my responsibility	The subject is packed to build awareness and responsibility to act on how to manage and minimize waste based on students 'understanding.	
	Topic 3: Paper and my school	The subject aims to make students know and understand how to make paper, what it is for, and how much paper waste is produced at school (by observation)	
	Topic 4: I can recycle paper	Understanding and practising the way to recycle paper waste	
B	Topic 5: Why should you use glass bottles?	Understanding and practising how and why we have to use glass bottles for a green environment	8 x 35 minutes
	Topic 6: Which plastic is safe for food?	Understanding and practising plastics classification for food	
	Topic 7: How to choose a can that is safe for food?	Understanding and practising identifying the safe can for food.	
	Topic 8: How to sort organic waste?	Understanding and practising how to sort domestic waste (waste bank)	
C	Topic 9: Healthy living for a brighter future	Habituation to hand washing and how to urinate and defecate in a place for better sanitation	8 x 35 minutes
	Topic 10: Towards a greener future	Knowledge and practice of how to recycle cooking oil waste for a better life	
	Theme 11: I can recycle plastic waste	Knowledge and practice of how to make an Eco brick into a table in the school garden	
	Theme 12: Let's make fertilizer from food waste	Knowledge and practice of how to make fertilizer from organic/food waste	

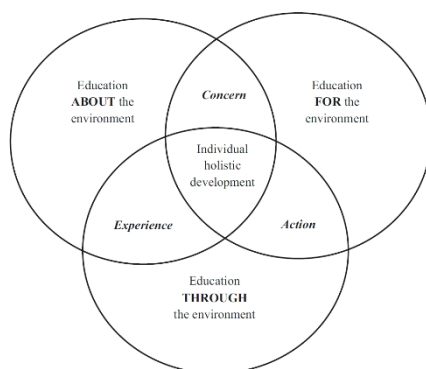
Based on responses from teachers and validation results from material and pedagogical experts, the learning materials outlined in Table 2 are very suitable for application in elementary schools. This is supported by some viewpoints from researchers regarding the material teaching for LCE: Junting (2024) argues for the need for lifestyle material as a material in LCE. Moreo-

ver, Ferguson (2022) argued that climate change should be included in the LCE Curriculum. Mochizuki & Bryan (2015) also recommended climate change as one of the topics for LCE teaching materials, given that the world is now beginning to feel the impacts of global warming. The importance of material on climate change was also emphasized by Rap & Bodas (2024),

who stated that climate action empowerment should be part of the young-adult education curriculum. In fact, the current curriculum has already addressed this climate change issue, so this additional LCE curriculum is no longer needed.

Students can learn from their immediate environment and practice learning outcomes through real-world practice. This will enhance understanding and awareness of the importance of managing the environment themselves. Moreover, through certain activities, students will enjoy the class, leading to meaningful learning.

This aligns with Phang et al. (2016) and Nazir & Pedretti (2016), who state that education arises from the environment, encouraging students to explore their personal responses to their relationships with it and to environmental issues. Similar to Neal & Palmer, the education with the three key points: about, through, and for the environment (Figure 3), will lead to concern, experience, and finally make students willing to take action towards the environment. This is what building the holistic individual development (Amin et al., 2019).



**Figure 3.** Framework of Low Carbon Education with the Environmental Context (Amin et al., 2019)

After developing the LCE-GCD Curriculum and its teaching material, the non-textbook digital material was then developed. Digital books were mostly designed as picture books, with brief explanations accompanying the illustrations. Interesting images with colorful performances pique students' interest in learning about them. A visually appealing book will increase students' motivation to study it and can improve their learning outcomes (Gheraout et al., 2018; Wang, 2020). The book also contains invitations to build awareness of low-carbon behaviour. In addition,

the book was packed with student activities and invitations to take real actions, for example: let's clean the school yard, let's count how much plastic bottle waste is in our school yard, let's make plastic waste valuable, and others. The presentation of each theme ended with a reflection in the form of case studies for students to solve and invitations to engage in various forms of low-carbon behaviour. In accordance with the number of themes designed in the curriculum, the digital book has been composed for the 3 themes represented by the three phases A, B, and C (Table 3).

**Table 3.** The Validation Result of The Three E-Books of LCE Produced for Elementary school Students

School Phase	e-Book Theme	Link Availability	Validity Index (CVI/CVR)	Category
A (grade 1-2)	<i>Ayo kelola sampah agar bumi makin sehat</i> (Let's manage the waste for our earth to be healthier)	<a href="https://heyzine.com/flip-book/3bb5921c72.html">https://heyzine.com/flip-book/3bb5921c72.html</a>	0.92/0.90	HV/Acceptable
B (grade 3-4)	<i>Hidup sehat untuk masa depan lebih cerah</i> (Healthy living for a brighter future)	<a href="https://heyzine.com/flip-book/86307ac41e.html">https://heyzine.com/flip-book/86307ac41e.html</a>	0.95/0.97	HV/Acceptable
C (grade 5-6)	<i>Menuju masa depan lebih hijau</i> (Towards a greener future)	<a href="https://heyzine.com/flip-book/d4438edf63.html">https://heyzine.com/flip-book/d4438edf63.html</a>	0.96/0.97	HV/Acceptable

HV = High validation

The LCE curriculum has been implemented using validated e-book media (Figures 4 and 5). Learning was conducted in Grade 2 (Phase A), Grade 4 (Phase B), and Grade 5 (Phase C) at the elementary school in Bogor, West Java, Indonesia, with 23 students per class. Learning began with an introduction to the material, teaching, and how to use the e-books. The use of e-books is guided directly by the class teacher step by step. In the initial step, the teacher showed a case related to the subject using a video (Mounting the garbage and its dangers; the stomach pain caused by dirty food; waste and its problems). In the next step, teachers lead students in proposing problems about the video they had seen. Students were then asked to read the e-book individually to solve the problem. Students then asked them to do the projects recommended by the e-book. Students in groups are given the freedom to choose a project that suits their interests. After completing the project, each group presented its product, accompanied by an explanation prepared in the journal.



**Figure 4.** Learning LCE of Elementary Student Phase C Using Non-Text Digital Book: “Towards a Greener Future”



**Figure 5.** Student Finished the Recycle Waste Project and The Products

Completing the project and exhibition session is an important step in implementing the LCE curriculum. The step makes students proud of the projects they have created and proud to be part of the effort to improve the quality of the environment. This is similar to Wong et al. (2017), who organized an exhibition to showcase green activities for raising low-carbon awareness.

Based on observations, students mostly engage in effective learning activities (Figures 4 and 5). Using a computer to study is indeed rather rare, so from the beginning, they are already excited about learning. E-books packed with

interesting pictures and not too many narratives make them even more engaging, so they are all absorbed in learning. Occasionally, they discuss something with their closest friends. It could foster problem-solving skills that may help students address environmental concerns with a systematic, analytical approach (Li et al., 2025). A thorough examination of environmental issues requires collaboration and knowledge exchange through discussion to identify the appropriate answer and improve environmental awareness and literacy (Hanifha et al., 2023; Wibowo et al., 2024). A good learning environment leads to student performance, as depicted in the journal.

After studying the e-book, students compiled a group journal in which they abstracted, reflected, and responded to the e-book’s performance. Students’ ability to abstract texts/narratives is, on average, very satisfactory. In line with Hudha et al. (2020, 2022), they are very happy to read e-books because of the many pictures, interesting and colorful, that attract them. In the case of the learning in Phase C, they created an abstract that explained how plastic waste is impacted and how to manage it. They also became understanding of why it is recommended to use glass bottles instead of plastic bottles. They are now to choose the better approach for distinguishing the type of plastic to be used for food and beverages based on the packaging’s characteristics (Hudha et al., 2021). They began to realize that garbage should not be thrown into the sea, and they wanted to make the school environment cleaner and greener. One group offers an interesting summary. They showed the sustainability in some various statemen as follows: 1) We know how much plastic waste has been used by people; 2) Actually, using plastic is still okay as long as you do not overdo it; 3) The more plastic is used, the more we contribute to environmental problems; 4) We are now better off bringing food and drinks to school to reduce plastic waste.

Based on the narrative journal, students demonstrate the ability to reflect on themselves and their learning environment. Revealed from the journal several interesting statements as a form of their reflection, including: 1) Pollution mitigation awareness: use glass bottles, bring empty bottles to school (there are Refills), bring food using plastic containers that are not disposable; do not litter; 2) Our school sometimes still has a lot of garbage scattered around, I should not add to the garbage at school; 3) Garbage at school must be reduced in many ways. Must be practiced; 4) We can choose safe plastic, just found out, it turns out there are many types of plastic. We have to

choose plastic so that it is safe for health. 5) I will now use bottles that are safe and no longer waste. I do not want to use drinks in plastic packaging. 6) This book made me know the types of plastic that are safe for health.

Interestingly, two groups argued in a funny, somewhat unexpected way. Their statements showed they were still unsure about using glass bottles. They stated that: 1) Glass bottles are good but heavy. I will bring the safe plastic bottles that can be refilled from home; 2) I am still confused about how to live without plastic because I already use a lot of it.

The narrative shows us that students' sustainability literacy has begun to develop through learning LCE using the e-book media. This outcome, induced by interactive media, plays a crucial role in the development of sustainability literacy, which includes the knowledge, skills, and understanding of sustainability among elementary school students. (Phang et al., 2016; Campbell et al., 2021; Hudha et al., 2021, 2022; Warliyah et al., 2023).

Students' sustainability literacy before and after learning strengthened the argumentation. It was shown that students' sustainability literacy increased significantly before and after learning about a greener future. The detail increase is shown in the following Table 4.

The table shows that basically, students have shown sustainability literacy. Nevertheless, LCE learning has significantly contributed to improving sustainability literacy, with an average moderate increase. It should be noted that learning is implemented in schools with strong environmental insight principles and policies. Based on interviews with teachers, it was also revealed that the school's parenting program had been running well, including the introduction of insights into school- and home-environmental factors. Thus, it can be understood that at the beginning of learning, students' sustainability literacy has begun to rise. The overall scores for Sustainability Literacy and Global Character of students in phases A, B, and C are presented in Table 4.

**Table 4.** The Enhancement of Sustainability Literacy and Global Character of Elementary Students

Grade/Phase	Sustainability Literacy-Score	N-gain	Global Character- Score	N-gain
2(A)	90.2 ± 3.5	0.67 (Fair)	89.0 ± 3.4	0,68 (Fair)
4(B)	92.7 ± 4.2	0.63 (Fair)	92,1 ± 4.2	0.72 (High)
5(C)	87.3 ± 4.7	0.65 (Fair)	88.7 ± 5.7	0.75 (High)

In the Indonesian curriculum 2020, the global character has become the new paradigm in educational goals. Indicators of global character include responsibility, discipline, affection, environmental consciousness, frugality, caring, and respect. The table shows that students' sustainability literacy score is closely related to the global character. This can be understood because the three dimensions of sustainability literacy comprise sustainability knowledge, sustainability skills, and sustainability-relevant values (Adam et al., 2021; Havita et al., 2021). The indicators of sustainability relevant value dimensions include feeling, concern, empathy, and respect for other people and living beings; appreciating and evaluating other people's work; feeling connected to nature and encouraging others to share that feeling; and caring for each other and the environment.

By the deep analysis, it was revealed that some students in phase A could not answer questions nos. 4, 9, 10, and 14. Question No. 4 asks for an explanation of how often students use usable items. The interview results showed that students felt confused by the question. He was trap-

ped in the thought that the question was about whether he was buying and using second-hand goods. Question No. 9 was not answered by student Number 10 because he never did it (reminding others to throw garbage in its place, this is a kind of honesty). Student Number 16 did not answer question No. 14 because he had never done it (carrying a shopping bag), so he did not know it was part of the lifestyle.

Overall, the questions on sustainability literacy and global character reveal similarities between them. Based on the elementary school curriculum about global character, there are five global character indicators that teachers should concerned about are (1) performing awareness of environmental conservation; (2) Responsible for yourself; (3) performing cooperation/mutual cooperation; (4) Demonstrate the ability to communicate between cultures; and (5) Knowing and appreciating the nation's culture. The question for these indicators can be closely related to the LCE material. For example, for indicators of knowing and appreciating the nation's culture (Figure 6a) and performing cooperation/mutual cooperation (Figure 6b).

- A.

  - ✓ In ancient times, food wrappers were made from banana, teak, or taro tree leaves. If asked to choose, would you choose leaves or plastic for the wrapping? Why?
  - ✓ In an area in Bogor, there is a custom of people to use bamboo bongs/baskets as a substitute for plastic bags in holiday ceremonies. Do you think that habit is good for environmental conservation?

B

  - ✓ Do you agree that there is community service at school or around the house? Why?

**Figure 6.** a. Sample Questions of Knowing and Appreciating the Nation's Culture Indicators; b. Sample Questions of Performing Cooperation/Mutual Cooperation

Based on the above rationale, educating for global character in learning through the LCE framework is also highly relevant to the development of global character diversity. This is also accommodated in the e-book developed. The results showed that students' Global Character Diversity was excellent, with an average of 90.20 (max score=100). There is consistency between the results of students' interviews, which show low improvement in sustainability literacy, and the GC. It also reveals that students' confusion, perceptions, and honesty contribute to their low GC. This confusion may be caused by instruments that students do not understand. Décamps et al. (2017) and Gericke et al. (2019) stated that sustainability awareness instruments must be thoroughly validated to avoid raising doubts among students. Further interviews suggest that the three students already have an awareness of low-carbon living. Their confusion in interpreting the questions' statements caused them to hesitate to answer. Surprisingly, these three students have a high level of honesty that deserves appreciation.

Regarding global character, the research results show that students' CG improvement in

phase A remains in the moderate category, while students in other phases have shown quite good results. Learning that trains global character can be done not only in science subjects but also integrated with other subjects in various contexts. This aligns with Tohri et al. (2022), who discovered that global character is significantly increased by learning about local culture. Deng & Wang (2023) demonstrated that integrating local culture and background into educational materials enhances the significance and engagement of the learning experience for students. This method fosters the maintenance of cultural identity and strengthens students' ties to their community.

The implementation of e-book media has also been carried out more extensively across all phases, including the different elementary schools, each with 25 students. The same implementation has also been conducted in Phase D (Grade 7) using the same theme e-book as in Grade 5, but with different depth and project difficulty levels (Figure 7). The enhancement of sustainability literacy in every dimension across every phase is elaborated in Table 5.

**Table 5.** The Average Score of Sustainability Literacy in Three Sustainability Dimensions of Students in Elementary and Secondary School (Before and After Class)

Sustainability Dimension	Elementary school Phase A (av.)		Elementary school Phase B (av.)		Elementary school Phase C (av.)		Sec. School Phase D (av.)	
	before	after	before	after	before	after	before	after
	Sustainability knowledge	2.75	3.2	2.97	3.45	2.80	3.30	2.90
	N-gain= 0.36		N-gain= 0.47		N-gain= 0.42		N-gain= 0.55	
Sustainability skills	2.50	3.30	2.78	3.51	2.91	3.60	2.70	3.60
	N-gain= 0.53		N-gain= 0.59		N-gain= 0.63		N-gain= 0.69	
sustainability-relevant values	2.79	3.15	3.00	3.60	2.75	3.50	2.76	3.60
	N-gain= 0.30		N-gain= 0.60		N-gain= 0.60		N-gain= 0.66	
Over all	2.64	3.22	2.92	3.52	2.82	3.47	2.79	3.56
	N-gain= 0.43		N-gain= 0.56		N-gain= 0.55		N-gain= 0.63	

Notes: max score = 4; N-gain > 0.60 means high effective; number of students on each level = 25

The overall sustainability literacy score in each phase is categorized as fair, with an average N-gain below 0.60. The high category is attributed to secondary students, reaching a value of 0.63. The research indicates that improvements in upper-level student literacy are superior to those of lower-level students, particularly in the dimension of sustainability-related values. The growth in a student's age results in enhanced maturity in thought and action, as well as an improved sense of care and responsibility.

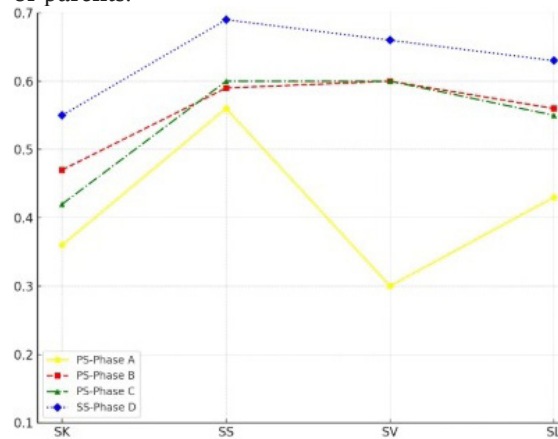
The implementation revealed that, despite the uniformity of the materials and projects provided to students for converting plastic waste into valuable products, the practical outcomes varied significantly. Figure 7 shows that the products developed by the student groups in phase D were more complex and had greater commercial potential than the simpler goods from phase C. The level of students' cognitive maturity at each stage corresponded with their educational experiences, thought processes, and personal development.



**Figure 7.** Realizing Thoughts into Practical and Effective Actions Based on Knowledge to Create Ecological Designs of Phase C (Left) and D (Right)

Figure 8 shows the profile of sustainability literacy across all dimensions for elementary and secondary students. The lowest level of sustainability literacy is in phase A (grade 2), and the dimension that needs to be addressed is the lowest level of sustainability-relevant value. The research results offer great hope that the developed e-book media can help students improve their sustainability literacy and global character.

Nevertheless, the weaknesses are evident in the measurement results for phase A students, particularly in the sustainability-relevant values dimension. This can be understood by considering that students' thinking abilities at phase A are still at a concrete, simple level. Their ability to consider values based only on understanding is still in a low category. At this level, they still apply values based on examples given by teachers or parents.



**Figure 8.** Trend of Sustainability Literacy of Elementary and Secondary Students

Mahat et al. (2020) stated that building a low-carbon society among children and teenagers in Malaysia is very important. Their research showed that environmental literacy and low-carbon practices are key to students' sustainability literacy, and that these will increase when learning accommodates students' needs, such as innovative learning, high-quality media, and effective tools. Arga et al. (2025) also found that the good e-book included interactive features such as quizzes and project-based activities, which fostered active learning and responsible consumption behaviors, thereby contributing to enhancing food literacy.

Despite some challenges, such as students' difficulty accessing digital learning materials and the obstacles to learning outside class hours, students reported positive responses after using an e-book. The following list in Table 6 is a selection of students' responses from Phases A and C, derived from short, random interviews.

**Table 6.** Students 'Responses After Learning from the e-Book of LCE

Phase	Students' Responses
Student phase A	Now I always throw trash in its place.....(SV) My teacher says that littering makes the environment dirty..... (SK) I now like to keep the candy wrappers in my pocket until I find the trash can..... (SS) I wash my hands with soap after collecting trash in the yard (SV)
Student phase C	I understand the importance of conserving energy, such as electricity and water, to protect the environment..... (SV and SK) My way of sorting waste: food scraps and vegetable scraps go in one place. Plastic waste and plastic bottles are in another place. I put glass shards in a separate plastic bag ..... (SS and SK) An experience of mine using second-hand items: I used plastic bags to hold vegetables and store trash. (SS) I made a pencil case from an old can yesterday..... (SS)

The overall results of the study show that low-carbon education, which is actualized in a non-text e-book, has positive implications for improving both sustainability literacy and global students' character. The developed teaching materials (e-book) have accommodated learning needs to develop sustainability literacy, with features that encourage students to think, argue, and create. LCE materials must be crafted to engage students in the learning process, fostering critical thinking, creativity, and problem-solving abilities. This can be accomplished through interactive, participatory pedagogical approaches (Pramesti et al., 2022).

As is known, education in elementary school is the foundation for building character. If this is done continuously, our hopes for sustainability can be realized. In line with the findings above, several studies show that low-carbon education-based learning increases sustainability literacy, which ultimately leads to global sustainability (Décamps et al., 2017; Kusumaningrum & Yanti, 2021).

The research also revealed the importance of a guidebook for implementing LCE learning, enabling teachers to implement the curriculum more easily. Ren et al. (2024) emphasized the importance of teacher guides, stating that teachers in both elementary and higher education still need guidance for implementing LCE, including guidelines to motivate and direct the practice of low-carbon behavior.

Compared to the research conducted by Hudha et al. (2022) and Amin et al. (2020), the e-book developed through this study contributes to improving sustainability literacy more effectively. This is mostly due to differences in the book's intended level. The book by Amin et al. (2020) is dedicated to prospective elementary school teachers. Given the book's relatively high level of complexity, its use does not have a significant impact on students' sustainability literacy. Meanwhile, implementing the LCE e-book for stu-

dents with special needs indeed poses a significant challenge, given students' limitations. Nevertheless, the advantage of the e-books developed is the inclusion of cartoon images/illustrations, which are currently favored by students of this age, making them easier to comprehend.

If all of LCE's efforts are realized, the goal of education for sustainable development will also be achieved, and it can be a major contributor to achieving the Sustainable Development Goals (SDGs). Above all, character building must be the foundation and carried out at the lowest level of the education curriculum (Kinzer, 2021; Lee & Manfredi, 2021; Chen et al., 2022;).

Based on the results of the research above, there is no doubt that the research products had a positive impact on the government's efforts to improve sustainability literacy and environmental awareness among students. Considering that the e-books are intended for elementary students, it is hoped that the impact will foster a nurturing effect on the educational process at higher levels. This research product also constitutes a significant contribution to the previous work of other researchers.

## CONCLUSION

The current Indonesian Elementary school curriculum has accommodated the principles of low-carbon education in a limited context. In addition, the curriculum has not adequately addressed the learning needs of low-carbon education and has not met teachers' expectations. Through the research, an LCE supplement curriculum for elementary education has been developed that accommodates the development of global character (GCD) and sustainability literacy. The validated LCE curriculum comprises 4 core competencies and 16 learning outcomes, organized into 12 the-

mes, 4 per learning phase. The implementation of the LCE curriculum has been completed, with LCE digital non-textbooks available across three phases of learning: A, B, and C. The results of the implementation (in phases B and C) show a significant increase in sustainability literacy in both phases and build character in global diversity, with a very satisfactory average among students. A further implication is that e-books can be used and distributed in elementary education. Given their attractive, easy-to-use, and handy nature, e-books can also be used by various external parties, such as learning centers or extracurricular institutions, as teaching materials.

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