Low Carbon Virtual Lab (LCVL) on electricity to empower sustainability literacy of junior high school students

Salsabila Kholifahtun Nisa', Muhammad Nur Hudha*, Nurma Yunita Indriyanti, Riezky Maya Probosari, Lina Mahardiani, Kadek Dwi Hendratma Gunawan

Department of Science Education, Sebelas Maret University, Surakarta, Indonesia
*Corresponding author, email: hudha.mn@staff.uns.ac.id

Article History
Received: 1 December 2024
Revised: 24 December 2024
Accepted: 27 December 2024

Keywords
Virtual lab
Low Carbon
Electrical Energy

Abstract
Electricity is a conceptual and complicated physics subject, hence technological integration is required to help understanding. Using the ADDIE development research approach, this study will investigate how the design, practicality, and characteristics of Low Carbon Virtual Lab (LCVL) media might empower students' sustainability literacy. The LCVL was built using low carbon education values and sustainability literacy indicators to test student abilities through quizzes and discussion topics. The feasibility of LCVL was rated as very good. Material experts scored 96.59%, media experts scored 86.98%, and language experts scored 95.60% (very feasible). The teacher and student response test to LCVL also yielded an overall average, with student responses of 91% and instructor responses of 82.41%. LCVL possesses the following characteristics: (1) an interactive digital simulation media, (2) packed in the form of a website link, (3) user-friendly, (4) utilized to empower students' sustainability literacy, and (5) the concept of electrical material supplied is combined with low carbon education. Thus, LCVL is appropriate for use in the learning process to improve students' sustainability literacy.

Nisa', S. K., Hudha, M. N., Indriyanti, N. Y., Probosari, R. M., Mahardiani, L., & Gunawan, K. D. H. (2025). using sentence case. *Momentum: Physics Education Journal*, *9*(1), 163-172. https://doi.org/10.21067/mpej.v9i1.11178

1. Introduction

Both college students and elementary and secondary school students continue to have poor levels of awareness regarding sustainable literacy (Chen & Li, 2019). Sustainability literacy knowledge and abilities among high school students were found to be quite low (A. A. Putri et al., 2023). This shows that there is awareness of sustainability issues in students but they do not have sufficient knowledge to apply it to real actions (A. A. Putri et al., 2023). The low level of sustainability literacy of students, which is currently one of the indicators of educational success, is influenced by various factors, one of which is the lack of integration of low carbon education in the curriculum and learning process. The lack of understanding and application of low carbon concepts in education hinders the formation of environmental awareness and attitudes among students, which ultimately has an impact on sustainable development and climate change mitigation efforts in the future (Warliyah et al., 2023).

A low carbon society can be realized through the education system, beginning with families and schools (Amin, Permanasari, Setiabudi, et al., 2020). This is known as low carbon education, or LCE. Environmental education plays a crucial role in helping parents at home and instructors at school mold children into environmentally conscious individuals from a young age (Masruroh, 2018). However, low carbon behavior in the community and school environment is still a special concern (Bai & Liu, 2013) so it needs to be improved. This behavior has an important role in reducing carbon emissions and improving the quality of the surrounding environment (Chen & Li, 2019), so that knowledge and behavior about low carbon become important dimensions of the definition of other awareness (Warliyah et al., 2023).

Indonesia is one of the countries that wastes electricity because its people think that natural resources in Indonesia are abundant and cheap (Masykuroh & Fatmilatun, 2022). Fossil fuels, such as coal and petroleum, continue to be the main source of energy for Indonesia (Bahij et al., 2020). According to 80% of data worldwide, fossil fuels are the primary source of energy (Mardani et al., 2019). The environment will be threatened by excessive energy use since it will deplete fossil fuels

doi: 10.21067/mpej.v9i1.11178

ISSN: 2548-9135

and raise CO2 emissions (Amin, Permanasari, Setiabudi, et al., 2020). Generally speaking, a lot of women and kids are reported to consume electricity wastefully. Overuse of electricity is common among children (Masykuroh & Fatmilatun, 2022).

Students' lack of awareness of energy conservation is demonstrated by their poor conduct in using low carbon principles (Amin, Permanasari, Setiabudi, et al., 2020). There are a number of student habits and behaviors that waste electrical energy. For example, 55% of students leave electrical devices like fans, televisions, and cellphone chargers plugged into outlets, 39.6% of students leave room lights on even when they are not in use, and 49% of students leave the air conditioner or AC running all day (Amin, Permanasari, Setiabudi, et al., 2020). Thus, LCE can be developed through an educational environment for sustainable development (ESD) to raise awareness of environmental quality in electrical energy saving behavior (Warliyah et al., 2023). Through everyday actions, LCE seeks to raise student understanding and behavior in managing and addressing environmental issues while lowering energy use and pollutant emissions (Hudha et al., 2020).

Since neither teachers nor students are familiar with the concept, LCE is still seldom ever used in Indonesian curricula (Hudha et al., 2022a). In Indonesia, the LCE program is incorporated into green schools, also known as environmental learning institutions. However, textbooks still only address a small portion of the content and material related to low-carbon issues (Hudha et al., 2021). Because the material presented in science classes has direct touch with the environment and nature, it can truly teach students about the environment and help them develop an ecologically conscious character (Amin, Permanasari, & Hamidah, 2020). In order to further increase the force of science education in forming and empowering students about environmental care and sustainability, it is hoped that LCE content be incorporated into science education (Amin, Permanasari, & Hamidah, 2020). This demonstrates the necessity of a low-carbon learning strategy to enhance students' sustainability literacy, particularly when it comes to the use of electrical energy (Warliyah et al., 2023).

Technology has a significant role in education in this digital age, especially LCE (Hudha et al., 2020). Technology can be used to implement low carbon in science education (Lv & Qin, 2016). Additionally, a lot of practical or experimental activities in the lab are part of science education (Aljuhani et al., 2018). Because they can give students practical experience in training, implementing, and introducing scientific steps, practicums are one of the most crucial teaching strategies in science education (Sukenti, 2022). One strategy for fostering environmental literacy is through hands-on activities (Angreani et al., 2022). Using a virtual laboratory to supplement or replace a physical laboratory is one of the ways that technology can be used as a learning tool nowadays, particularly for practicums (Hadi et al., 2022). A computer-based learning tool called a "virtual laboratory" includes simulations of tasks that might not be apparent in real-world settings (Muhajarah & Sulthon, 2020). The goal of using virtual labs in education is to create and conduct interactive, synchronous experiments on scientific ideas (Almaatouq et al., 2021).

Learning using virtual labs can also improve students' conceptual understanding, scientific problem-solving skills, and creative thinking (Angreani et al., 2022). One benefit of virtual lab learning materials is that they allow for practical exercises to be completed without consuming large amounts of energy or physical resources, which is consistent with the low carbon philosophy (Lv & Qin, 2016). By enhancing students' sustainability literacy, the creation of virtual lab materials that include low carbon content for electrical energy conservation is a calculated move in integrating science education. This virtual lab learning tool enhances students' comprehension of the low carbon idea by letting them experience with different energy usage designs and their effects on carbon emissions in the electrical energy conservation content.

Previous research related to the LCE concept has been studied through the development of low-carbon e-book learning media that is oriented towards efforts to build environmental literacy and the 21st century leading to sustainability literacy (Warliyah et al., 2023). To help science instructors become more environmentally literate, low-carbon teaching resources are also being developed (Amin, Permanasari, & Hamidah, 2020). The creation of web-based application media that employs the Universal Design Learning (UDL) principle to assist students in low carbon learning (Hudha et al., 2022), interactive educational games on climate change content that can enhance students' sustainability literacy (Haerani & Suhartini, 2023), and low carbon poly (locapoly) games learning media based on science edutainment about carbon footprints that demonstrate a very feasible category (Nabila et al., 2022). However, there hasn't been much investigation into the creation of virtual lab medium with minimal carbon content up to this point. Even so, this virtual lab gives students the chance to experiment or run simulations with the idea of low-carbon electricity. Reducing carbon emissions and promoting energy sustainability are also the primary learning objectives of the low carbon virtual lab. Furthermore, studies on sustainability literacy are crucial for the subject of education, particularly in scientific domains like electricity. The majority of research on sustainability literacy is presented in a broader or international context.

Given the low level of sustainability knowledge among students, the significance of the low carbon idea, and the effectiveness of virtual labs as learning tools for electricity-related content, low carbon virtual lab learning materials must be created. The creation of this low carbon virtual lab (LCVL) electricity is intended to raise students' knowledge and comprehension of sustainability and equip them with energy-saving techniques so they can support sustainable development worldwide with a generation that cares about the environment. The purpose of this study is to ascertain how LCVL media's features, design, and viability might enhance students' sustainability literacy.

2. Method

The ADDIE development model, which consists of multiple stages—analysis, design, development, implementation, and evaluation—is the foundation for the research and development process (Branch, 2009). A low carbon virtual lab (LCVL) with electrical components is the end product that needs to be created. Figure 1 presents the phases of the LCVL development research in this study in a systematic manner. Analyzing students' issues and requirements for learning media was the first step in this study. Additionally, the study of the challenges that have been conducted serves as the foundation for media design. In order to build LCVL media, this design starts with the creation of a material and media concept. Prior to implementation, the outcomes of this development will be verified by material, media, and language specialists to ascertain the viability of LCVL media through the distribution of media validation evaluation questionnaires. In order to determine how teachers and students react to the designed LCVL, implementation is done by testing their answers using questionnaires. The final step is to assess the outcomes of the development that has been completed.

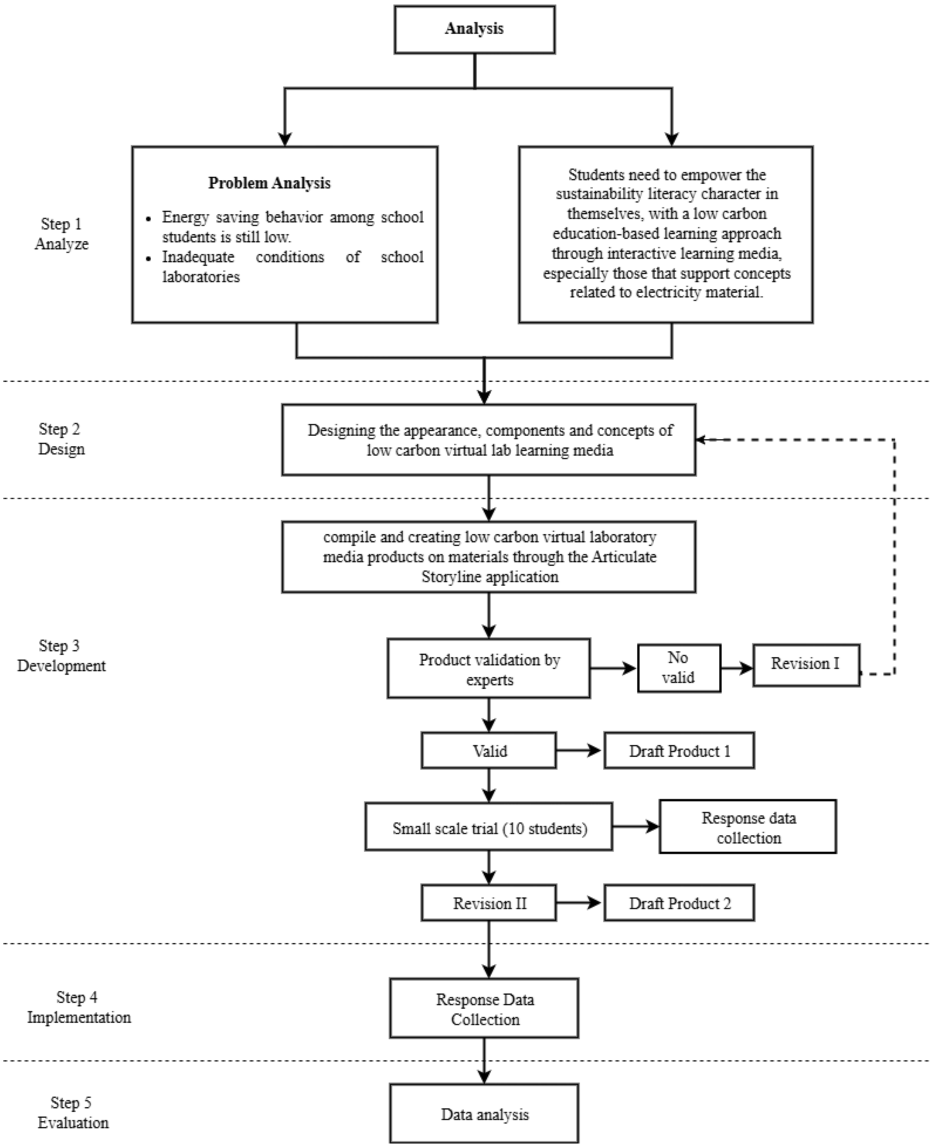

Figure 1. LCVL Development Stages Based on the ADDIE Model

3. Results and Discussion

Low carbon virtual lab (LCVL) electricity was developed as a consequence of the research and development to enhance students' sustainability knowledge. The ADDIE model, which comprises the phases of Analysis, Design, Development, Implementation, and Evaluation, was used to carry out the research's phases. Analyzing students' issues and requirements for learning media and sustainability awareness is the first step. This investigation revealed issues pertaining to students' ignorance of energy-saving practices in daily living. Furthermore, students still lack an awareness of how excessive electrical energy use affects the environment. As a result, learning materials that incorporate low carbon education must be created (Hudha et al., 2022b). Low carbon development and sustainable development can be realized through education that incorporates low carbon education (Nurramadhani et al., 2022).

The analysis of the required learning media must also be taken into consideration while designing the product. Science education frequently involves hands-on activities (Darwis & Hardiansyah, 2021). For instance, practical exercises are required to demonstrate a notion, theory, or law in the abstract field of electricity (Octafianus et al., 2022). As a result, virtual laboratory media were chosen as a substitute or supplement to actual laboratories (Hadi et al., 2022). The outcomes of the design strategy serve as the foundation for the creation of LCVL media. The development of a material concept is the first step in product design. To make media creation easier, a flowchart and storyboard concept are compiled to create the media design plan. To make the navigation structure of the virtual laboratory media easier to understand, a flowchart or flow diagram is created based on the order of steps in a procedure. The scenario design for the virtual laboratory media in development is called a storyboard. The supplied flowchart serves as the basis for the storyboard.

Figure 1Figure 1displays the outcomes of the creation of low carbon virtual lab (LCVL) electrical media. The user interaction system in a virtual laboratory for learning about low carbon-based power is depicted in the LCVL flowchart results. The process begins by entering an identity before accessing the main menu. Additionally, there are a number of options in the main menu, including Quiz, Content, Experiments, Profile, Introduction, and Instruction. Learning objectives and expected outcomes are included in the Introduction section, and instructions for using the virtual lab are provided in the Instruction section. Details about the system developer are displayed in the profile. Users can access educational resources in the Content section, which are separated into three primary categories: energy saving, dynamic electricity, and static electricity. Every category has relevant resources to aid in understanding the idea.

Students can then perform virtual experiments in the Experiments section, such as ESP-based static electricity experiments, Electrical Circuits experiments that teach them the distinctions between series and parallel circuits, and Energy Saving experiments that teach them to identify different kinds of lamps and measure power consumption in order to understand energy efficiency. A case study, lab instructions, data table completion, and a discussion of the findings are all included in each experiment. Following learning and experimentation, students can take a quiz including multiple-choice questions, answer selection, discussion, and scoring to gauge their comprehension. By highlighting the significance of energy efficiency in daily life, this flowchart demonstrates how electricity materials, low-carbon projects, and evaluations may be integrated to enhance students' sustainability literacy.

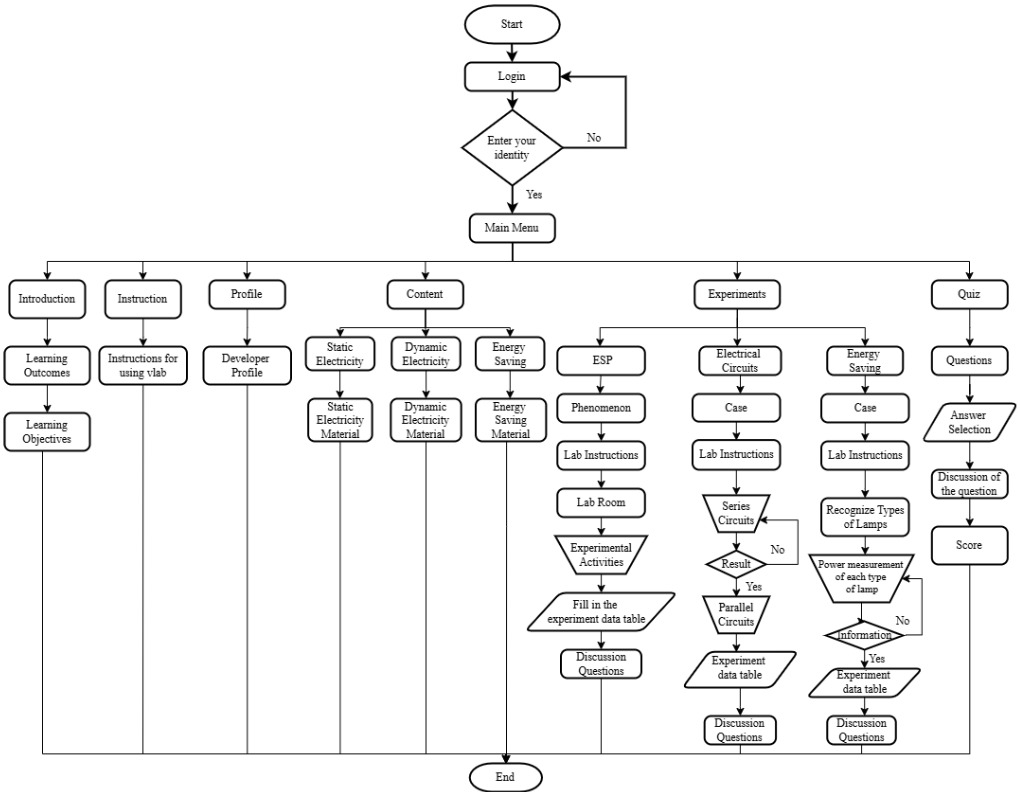

Figure 2. Design Development Flowchart

The low carbon virtual lab (LCVL) concept was developed by creating a matrix that connects practicums to measures of empowered sustainability knowledge. Figure 3 shows the LCVL matrix design to enhance sustainability literacy. Each practicum activity incorporates low carbon content that supports the goals of students' sustainability literacy indicators, as determined by the matrix design. This ensures that students not only comprehend the concept but can also implement it in accordance with sustainable values (Warliyah et al., 2023). The outcomes of this LCVL design include learning objectives that are intended to help students grasp the notion of electricity by establishing values related to the low carbon philosophy. Additionally, situations or phenomena pertaining to low carbon issues will be presented, and practical activities will be used to examine or address them. Additionally, LCVL has assessment tools in the form of quizzes, project-based questions, and discussion questions that gauge students' comprehension of energy efficiency, their ability to calculate energy use, and their ability to identify actions that will reduce carbon emissions through energy-saving behavior. At the conclusion of each practical activity, a Google Form is listed together with the assessment instrument in LCVL media (Rohaenah, 2022). Figure 4 displays the outcomes of the electrostatic precipitator (ESP) experiment's production of LCVL media.

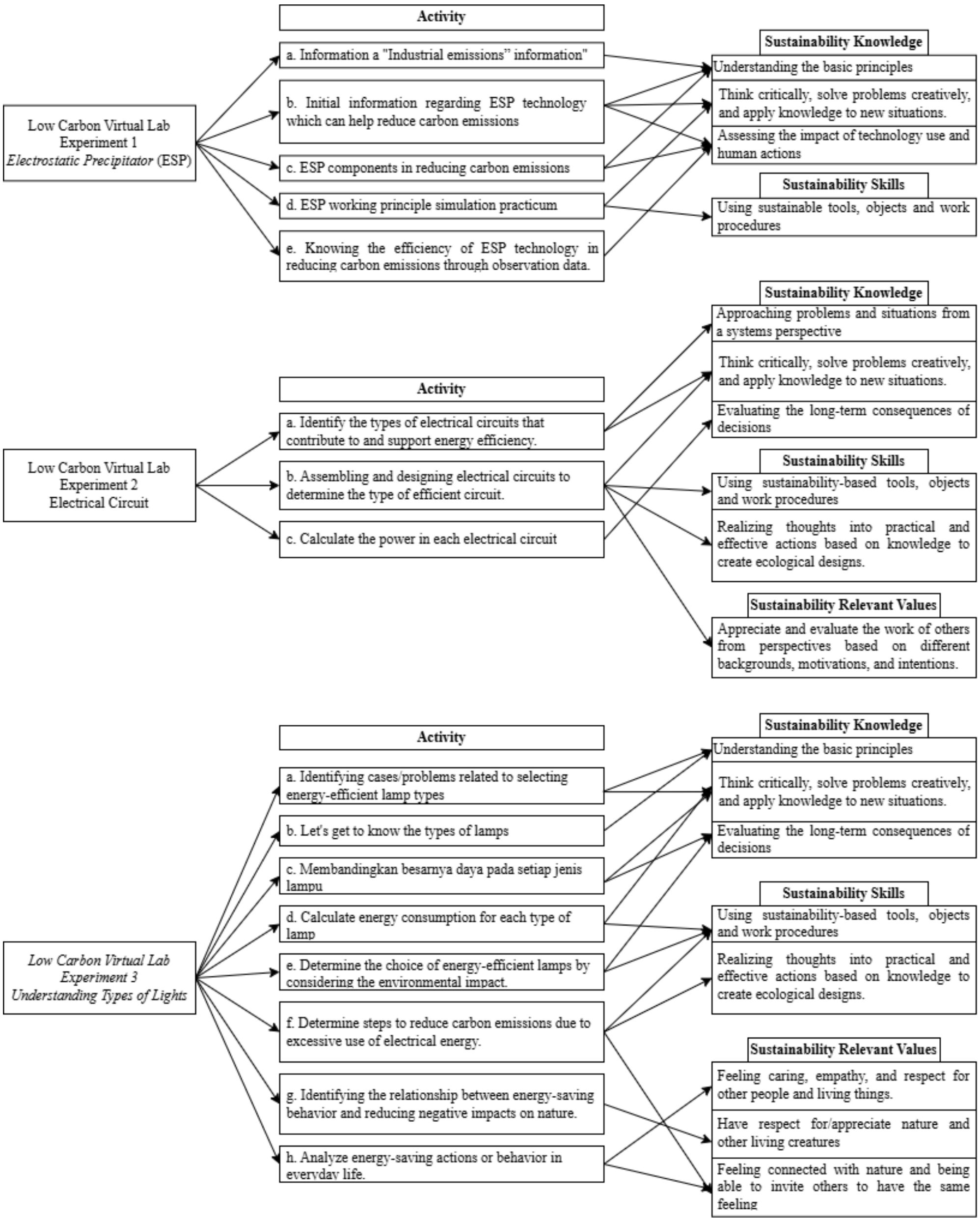

Figure 3. LCVL Concept to Empower Students' Sustainability Literacy

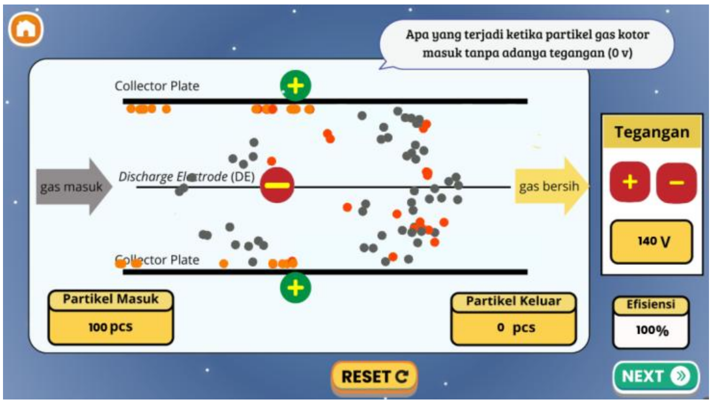

Figure 4. Results of LCVL media development in electrostatic precipitator (ESP) experiments

The low carbon virtual lab (LCVL) design outputs will be turned into a medium, which will subsequently be verified by a number of validators, including media specialists, language experts, and material experts. To ascertain the viability and features of the media being developed, validation of this LCVL media was conducted. With modifications and input based on expert suggestions, the evaluation of language experts received a value of 95.60% (very valid), the validation of material experts on LCVL yielded a value of 96.59% (very valid), and the evaluation of media experts yielded a value of 86.98% (very valid). Based on the results of the feasibility of the LCVL media, it shows a very valid criterion. Additionally, the feedback from teachers and students following the use of this LCVL media were extremely positive. Ninety-one percent of the student responses fell into the "very good" category. In the meantime, 82.41% of the instructor answers fell into the "very good" category. According to the responses, LCVL helps students comprehend the different reasons and effects of excessive electrical energy use on the environment. It also encourages students to evaluate how human behavior and environmentally friendly technology affect environmental safety. Additionally, it encourages students to use and select energy-saving devices and to make an effort to save electrical energy in order to lower carbon emissions. The findings of the students' responses are consistent with research that claims that the creation of low-carbon learning materials aims to teach students about low-carbon concepts that have been shown to have positive effects and can help them become more sustainability literate (Warliyah et al., 2023).

The characteristics of the low carbon virtual lab (LCVL) media were determined by the results of expert validation feasibility and responses from teachers and students. These responses showed that the interactive nature of the LCVL media facilitates active student participation in the learning process, making it easier for students to learn electricity-related material. In order to promote a grasp of abstract concepts in electrical material, interactive and visual learning materials can produce engaging and successful learning experiences (Diraya et al., 2021). The low carbon content of the practical exercises offered enables the use of LCVL media in the educational process to support students' sustainability literacy, which can help them develop an environmentally conscious mindset, use energy-efficient devices wisely, and become more conscious of the effects of electrical energy use. This is consistent with studies on the creation of instructional materials that incorporate LCE, which have been shown to assist both educators and learners during the learning process and can raise students' sustainability literacy (Warliyah et al., 2023).

Furthermore, the media is user-friendly, with a simple, clear design and navigation controls that can be used quickly and easily. The low carbon virtual lab (LCVL) also includes instructions or user guides to make it easier to use. Materials, worksheets (task sheets), interactive tools (Muhajarah & Sulthon, 2020), simulations or experiments, and animations (Haryoko & Hendra, 2014) are all key components of virtual laboratory media development. LCVL media is a digital simulation that duplicates physical experiments, allowing students to conduct virtual experiments that are similar to those performed in a physical laboratory. Computer simulation programs can be utilized as learning tools to improve students' conceptual knowledge of a subject (Rizaldi et al., 2020). This LCVL allows for experimental operations while minimizing expenditures and reducing the danger of physical mishaps. This is consistent with the statement that virtual lab media can reduce the cost of the tools and materials required, and students can make mistakes without fear of loss, allowing them to learn from failed experiments and repeat them without risk or additional costs (Kurniawan et al., 2020). As a result, practical activities conducted in virtual labs can help to decrease unnecessary energy and physical resource usage (Lv & Qin, 2016).

The low carbon virtual lab (LCVL) uses language and writing that is simple to grasp and communicate. The creation of learning media using simple language might increase students' enthusiasm for learning by attracting their attention to the content being studied (Kotimah, 2024). Students can easily read and understand the font type and size chosen. The type and size of the font are critical because they influence students' comfort in learning and understanding the material offered (Hanidian et al., 2022). Thus, the visual aspect, particularly the font choices, facilitates information delivery and allows pupils to focus on the material offered (Permata et al., 2024). Based on the assessment results, it is clear that LCVL is simple to use, that students may use it as an autonomous learning medium, that it facilitates learning, and that features and menus on the media are simply accessible. Virtual lab media immerses students in a virtual setting, allowing them to actively participate through interactive simulations similar to real-world experiences (Bayu et al., 2023). The ease of use and quickness of reaction in learning media enable students to learn autonomously, enhancing the learning experience and allowing students to better master the practical subject (Putri & Fajri, 2024).

The creation of low carbon virtual lab (LCVL) media uses an interactive design layout and clear and appealing graphics and animations to pique students' interest in learning. This is reinforced by the statement that the usage of interactive learning media accompanied by animation can engage and delight students in learning, hence increasing their interest in learning (Diraya et al., 2021). Furthermore, students' answers to the electrical energy material offered in the LCVL media are clear and easy to comprehend, and they include engaging experimental tasks. Simulations in experimental activities, for example, can assist students understand the notion of the content more easily by combining text and visualizations to generate stronger student representations (Mayer & Fiorella, 2021). LCVL media also helps pupils understand electricity-related content. The usefulness of digital media in autonomous learning demonstrates that technology can help students understand concepts and learn independently (Wati, 2021).

4. Conclusion

As technology advances, virtual labs in education are gaining popularity. This research study presents a conceptual design for a Low Carbon Virtual Lab (LCVL) platform for scientific learning. LCVL integrates low-carbon educational ideals into electricity practicums and assesses student abilities through quizzes or discussion questions based on sustainability literacy indicators. Validators, material experts, media experts, and language experts all rated LCVL's feasibility as excellent. Material experts provided a grade of 96.59% (very feasible), media experts gave 86.98% (very feasible), and language experts offered 95.60% (very feasible). The test of instructor and student responses to the LCVL also produced extremely good results. The average overall assessment of student responses was 91%, while teacher responses received an 82.41% rating. LCVL has the following characteristics: (1) an interactive digital simulation media, (2) packed in the form of a website link, (3) user-friendly, (4) utilized to empower students' sustainability literacy, and (5) the concept of energy given is combined with low carbon education. Thus, this LCVL is appropriate for usage in the learning process in order to empower students' sustainability literacy.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

Funding

No funding support was received.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Aljuhani, K., Sonbul, M., Althabiti, M., & Meccawy, M. (2018). Creating a Virtual Science Lab (VSL): the adoption of virtual labs in Saudi schools. *Smart Learning Environments*, *5*(1). https://doi.org/10.1186/s40561-018-0067-9

Almaatouq, A., Becker, J., Houghton, J. P., Paton, N., Watts, D. J., & Whiting, M. E. (2021). Empirica: a virtual lab for high-throughput macro-level experiments. *Behavior Research Methods*, *53*(5), 2158–2171. https://doi.org/10.3758/s13428-020-01535-9

Amin, M. S., Permanasari, A., & Hamidah, I. (2020). Integrasi Low Carbon Education Dalam Kurikulum Pendidikan Calon Guru IPA di Indonesia sebagai Upaya Revitalisasi Peran Pendidikan IPA dalam Merespons Tantangan Ekologis di Masa Depan. *Jurnal IPA & Pembelajaran IPA*, *4*(2), 231–243. https://doi.org/10.24815/jipi.v4i2.17965

Amin, M. S., Permanasari, A., Setiabudi, A., & Hamidah, I. (2020). Level Literasi Low Carbon Siswa Sekolah Dasar dalam Aktivitas Kehidupan Sehari-Hari. *Titian Ilmu: Jurnal Ilmiah Multi Sciences*, *12*(2), 49–57. https://doi.org/10.30599/jti.v12i2.653

Angreani, A., Saefudin, S., & Solihat, R. (2022). Virtual laboratory based online learning: Improving environmental literacy in high school students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *8*(1), 10–21. https://doi.org/10.22219/jpbi.v8i1.18120

Bahij, A. Al, Nadiroh, N., Sihadi, S., & Astar, M. I. (2020). Pengaruh Pengetahuan Dan Sikap Hemat Energi Terhadap Perilaku Hemat Energi. *Edusains*, *12*(2), 259–265. https://doi.org/10.15408/es.v12i2.13063

Bai, Y., & Liu, Y. (2013). An exploration of residents' low-carbon awareness and behavior in Tianjin, China. *Energy Policy*, *61*, 1261–1270. https://doi.org/10.1016/j.enpol.2013.06.014

Bayu, W., Aziezah, N., & Wicaksono, A. (2023). Pengembangan Model Laboratorium Jaringan Virtual Menggunakan GNS3 Di SMKS Bhinneka Karya 5 Boyolali. *NUSANTARA Jurnal Pengabdian Kepada Masyarakat*, *3*(2), 72–80. https://doi.org/10.55606/nusantara.v3i2.1118

Branch, R. M. (2009). *Instructional Design: the Addie Approach*. Spinger.

Chen, W., & Li, J. (2019). Who are the low-carbon activists? Analysis of the influence mechanism and group characteristics of low-carbon behavior in Tianjin, China. *Science of the Total Environment*, *683*, 729–736. https://doi.org/10.1016/j.scitotenv.2019.05.307

Darwis, R., & Hardiansyah, M. R. (2021). Pengaruh Penerapan Laboratorium Virtual Phet Terhadap Motivasi Belajar Ipa Siswa Pada Materi Gerak Lurus. *ORBITA: Jurnal Pendidikan Dan Ilmu Fisika*, *7*(2), 271. https://doi.org/10.31764/orbita.v7i2.5514

Diraya, I., Budiyono, A., & Triastutik, M. (2021). Kontribusi Virtual Lab Phet Simulation untuk Membantu Praktikum Fisika Dasar. *Phenomenon : Jurnal Pendidikan MIPA*, *11*(1), 45–56. https://doi.org/10.21580/phen.2021.11.1.7367

Hadi, A., Masruhim, M. A., & Hartati, Y. (2022). Development of Android-Based Virtual Laboratory to Improve Critical Thinking Ability on Reaction Rate Materials. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *5*(3), 21449–21459.

Haerani, R. P. R., & Suhartini, E. (2023). Analisis Kebutuhan Pengembangan Game Edukasi Online untuk Meningkatkan Sustainability Literacy pada Tema Perubahan Ikimm. *Jurnal Ilmiah Pendidikan Dasar*, *9*(1), 1792–1803.

Hanidian, O., Mulyani, M., & Cahyani, D. D. (2022). Pengembangan Media Video Animasi Berbasis Pendidikan Karakter dalam Pembelajaran Ketrampilan Menulis Puisi pada Siswa Kelas VIII SMP. *Repetisi: Riset Pendidikan Bahasa Dan Sastra Indonesia*, *5*(1), 28–36.

Haryoko, S., & Hendra, J. (2014). *Laboratorium Virtual (Konsep dan Desain)*. Edukasi Mitra Grafika.

Hudha, M. N., Hamidah, I., Permanasari, A., & Abdullah, A. G. (2021). How low-carbon issues are addressed in primary school textbooks. *Jurnal Pendidikan IPA Indonesia*, *10*(2), 260–269. https://doi.org/10.15294/jpii.v10i2.26628

Hudha, M. N., Hamidah, I., Permanasari, A., & Abdullah, A. G. (2022a). E-Low Carbon Media Awareness for Elementary School in Indonesia Using User Experience Questionnaire. *Journal of Engineering Science and Technology*, *17*, 67–74.

Hudha, M. N., Hamidah, I., Permanasari, A., & Abdullah, A. G. (2022b). Web-Based Low Carbon on Universal Design for Learning: a Conceptual Design. *Journal of Engineering Science and Technology*, *17*, 56–64.

Hudha, M. N., Hamidah, I., Permanasari, A., Abdullah, A. G., Rachman, I., & Matsumoto, T. (2020). Low carbon education: A review and bibliometric analysis. *European Journal of Educational Research*, *9*(1), 319–329. https://doi.org/10.12973/eu-jer.9.1.319

Kotimah, E. K. (2024). Efektivitas Media Pembelajaran Audio Visual Berupa Video Animasi Berbasis Powtoon Dalam Pembelajaran IPA. *Jurnal Pelita Ilmu Pendidikan*, *2*(1), 1–18. https://doi.org/10.69688/jpip.v2i1.55

Kurniawan, R. A., Rifa'i, M. R., & Fajar, D. M. (2020). Analisis Kemenarikan Media Pembelajaran Phet Berbasis Virtual Lab pada Materi Listrik Statis Selama Perkuliahan Daring Ditinjau dari Perspektif Mahasiswa. *VEKTOR: Jurnal Pendidikan IPA*, *1*(1), 19–28. https://doi.org/10.35719/vektor.v1i1.6

Lv, J., & Qin, S. (2016). On Low-Carbon Technology. *Low Carbon Economy*, *07*(03), 107–115. https://doi.org/10.4236/lce.2016.73010

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N., & Khoshnoudi, M. (2019). Carbon dioxide (CO2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Science of the Total Environment*, *649*, 31–49. https://doi.org/10.1016/j.scitotenv.2018.08.229

Masruroh, M. (2018). Membentuk Karakter Peduli Lingkungan Dengan Pendidikan. *Jurnal Geografi Gea*, *18*(2), 130. https://doi.org/10.17509/gea.v18i2.13461

Masykuroh, K., & Fatmilatun, D. (2022). Pengembangan Media Pembelajaran Video Animasi Hemat Energi Listrik Pada Anak Usia Dini. *Jurnal Pendidikan Anak Usia Dini Undiksha*, *10*(1), 144–152. https://doi.org/10.23887/paud.v10i1.48720

Mayer, R. E., & Fiorella, L. (2021). The Cambridge Handbook of Multimedia Learning. *The Cambridge Handbook of Multimedia Learning*, *February 2022*. https://doi.org/10.1017/9781108894333

Muhajarah, K., & Sulthon, M. (2020). Pengembangan Laboratorium Virtual sebagai Media Pembelajaran: Peluang dan Tantangan. *Justek : Jurnal Sains Dan Teknologi*, *3*(2), 77. https://doi.org/10.31764/justek.v3i2.3553

Nabila, S. A., Leksono, S. M., & Resti, V. D. A. (2022). Pengembangan Media Pembelajaran Low Carbon Poly Berbasis Science Edutainment Pada Tema Jejak Si Karbon. *PENDIPA Journal of Science Education*, *6*(3), 651–657. https://doi.org/10.33369/pendipa.6.3.651-657

Nurramadhani, A., Riandi, R., Permanasari, A., & Suwarma, R. (2022). Low Carbon Education: Student'S Understanding, Applications in Daily Life, and Science Learning. *Journal of Engineering Science and Technology*, *17*, 101–109.

Octafianus, P., Astuti, I. A. D., & Dasmo. (2022). Pengembangan E-Modul Praktikum Virtual Phet Simulation Berbasis Android Pada Materi Listrik Dinamis. *Prosiding Seminar Nasional Sains*, *3*(1), 108–116.

Permata, I., Cibro, P. S., & Tanjung, E. F. (2024). Penerapan Strategi Active Learning Berbasis Teknologi Informasi pada Mata Pelajaran PAI di Pondok Pesantren Darurahmah Sepadan Aceh. *EDUKASIA: Jurnal Pendidikan Dan Pembelajaran*, *5*, 1627–1636. https://jurnaledukasia.org

Putri, A. A., Hidayat, T., & Supriatno, B. (2023). Senior High School Students Perception on Sustainability Literacy in Biology Learning. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5737–5744. https://doi.org/10.29303/jppipa.v9i7.3705

Putri, N. K., & Fajri, R. B. (2024). Rancang Bangun Virtual Lab pada Materi Pembelajaran Kenaikan Titik Didih Larutan pada Praktikum Kimia I. *Jurnal Vokasi Informatika (JAVIT)*, *4*(2), 87–96. https://doi.org/https://doi.org/10.24036/javit.v4i2.175

Rizaldi, D. R., Jufri, A. W., & Jamaluddin, J. (2020). PhET: SIMULASI INTERAKTIF DALAM PROSES PEMBELAJARAN FISIKA. *Jurnal Ilmiah Profesi Pendidikan*, *5*(1), 10–14. https://doi.org/10.29303/jipp.v5i1.103

Rohaenah, R. (2022). Upaya Meningkatkan Prestasi Belajar IPA Materi Perpindahan Energi Panas dan Listrik Melalui Pembelajaran Jarak Jauh (PJJ) Dengan Menggunakan Media Whatssapp dan Google Form Sebagai Mobile Learning Pada Siswa Kelas VI Semester II SD Negeri Tambaksari 02. *Jurnal Insan Cendekia*, *3*(1), 1–20. https://doi.org/10.54012/jurnalinsancendekia.v3i1.55

Sukenti, E. (2022). Pengembangan Laboratorium Virtual Untuk Meningkatkan Penguasaan Konsep Pada Materi Sistem Sirkulasi. *Pedagonal: Jurnal Ilmiah Pendidikan*, *05*(April), 01–06. http://journal.unpak.ac.id/index.php/pedagonal

Warliyah, H., Permanasari, A., Rachman, I., & Matsumoto, T. (2023). Low Carbon e-Book on Climate Change with Education for Sustainable Development Framework for Sustainability Literacy of 7th Grader. *Jurnal IPA & Pembelajaran IPA*, *7*(4), 317–334. https://doi.org/10.24815/jipi.v7i4.33663

Wati, A. (2021). Penggunaan Media Virtual Laboratory Untuk Meningkatkan Penguasaan Konsep Materi Dan Kemandirian Siswa Melakukan Praktikum. *Jurnal Guru Dikmen Dan Diksus*, *4*(2), 256–270. https://doi.org/10.47239/jgdd.v4i2.373