

Integrating Project-Based Green Education Learning in Environmental Chemistry Courses

An Innovative Strategy to Foster 21st-Century Skills and Digital Literacy of Pre-Service Chemistry Teachers

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ARTICLE INFO

ABSTRACT

Article history

Received 17 November 2025

Revised 26 February 2026

Accepted 29 March 2026

The digital era requires pre-service teachers to possess digital literacy that is integrated with environmental awareness values. A crucial issue that emerges is the limited ability of pre-service chemistry teachers to combine critical thinking, creativity, collaboration, and communication with digital technology skills to address environmental problems innovatively. Previous studies have demonstrated the effectiveness of Project-Based Learning (PjBL) in enhancing 21st-century skills; however, a research gap remains in integrating green education values with strengthened digital literacy within the context of environmental chemistry learning. This study aimed to analyze the effectiveness of integrating YouTube-based PjBL with a Green Education approach in improving 21st-century skills and digital literacy among pre-service chemistry teachers. This research employed a mixed-methods sequential explanatory design, beginning with quantitative data collection through pretest-posttest, followed by qualitative data obtained through interviews, observations, and document analysis. The test instruments measured 21st-century skills and digital literacy, while video project quality was evaluated using a rubric, with two raters. The results show a significant increase in 21st-century skills with an N-

gain of 0.71 (high category), and an increase in digital literacy with an N-gain of 0.64 (medium category) across all dimensions, particularly in digital communication and collaboration. Video project assessments indicated good quality with an average score of 85.24. Qualitative data reinforced the quantitative findings, revealing that YouTube-based PjBL fosters meaningful learning, enhances creativity, technological competence, and environmental awareness. This study implies that digital PjBL has the potential for broader implementation in chemistry education to strengthen 21st-century competencies.

Keywords

21st-Century Skills
Digital Literacy
Green Education
Pre-Service
Project-Based Learning

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Introduction

The rapid development of digital technology and the transformation of education toward the era of Education 5.0 have created new challenges for higher education, particularly in the preparation of pre-service chemistry teachers. A crucial issue that emerges is the limited ability of pre-service teachers to integrate essential 21st-century competencies, which are highly needed in today's digital era [1]–[3]. These competencies include critical thinking, creativity, collaboration, and communication, along with digital literacy skills oriented toward the creative, ethical, and reflective use of technology [4],[5]. Digital literacy has now become a fundamental competency that educators must possess to adapt to technology-based learning and respond to the needs of global society [6],[7].

Furthermore, global challenges related to environmental crises and sustainability demand the reinforcement of green education values within science curricula. In the context of chemistry education, the Environmental Chemistry course offers substantial potential for nurturing both ecological awareness and digital skills, as it examines the relationship between chemical concepts and environmental issues such as pollution, acid rain, global warming, contamination, waste management, and ecosystem preservation. However, learning in this course tends to remain theoretical and lacks emphasis on contextual learning experiences. Addressing these challenges requires the development of digital literacy in scientific contexts by connecting scientific knowledge with digital applications that demand active student engagement [8],[9]. These conditions highlight a research gap regarding the implementation of learning models capable of simultaneously integrating conceptual knowledge, ecological awareness, and digital competence.

In facing 21st-century challenges, educational innovation plays a key role in creating dynamic, adaptive, and learner-centered teaching and learning processes for the digital era. Educational innovation is not only about teaching methods but also about shaping learning environments that encourage creativity, collaboration, and critical thinking [10]. In line with this, the concept of Green Education becomes a relevant approach to addressing sustainable education challenges. Green Education emphasizes the balance between technological advancement and ecological responsibility [11]–[13]. This approach not only fosters scientific knowledge but also develops environmentally conscious teacher candidates committed to sustainable development. Integrating green values into Environmental Chemistry learning has the potential to shape future teachers who are ethical, creative, and reflective regarding the ecological impacts of scientific and technological innovations. Therefore, a strategic learning model is needed to support these learning demands [14].

From a pedagogical perspective, Project-Based Learning (PjBL) has been shown to effectively develop higher-order thinking skills, collaboration, and creativity through project activities that require real-world problem-solving [15],[16]. Previous studies [13],[17],[18] have demonstrated that PjBL enhances learning outcomes, critical thinking, and scientific attitudes compared to conventional models. However, research integrating PjBL with a Green Education approach to strengthen digital literacy and 21st-century skills among pre-service chemistry teachers remains limited. The implementation of Project-Based Green Education Learning can be strengthened through the use of digital technologies. Technology integration allows students to develop digital literacy, improve scientific communication, and disseminate environmentally themed project results more creatively and widely.

The use of digital media in learning, such as YouTube, within the PjBL framework also shows great potential as an innovative platform. This platform enables students to express scientific understanding through engaging educational videos while simultaneously enhancing digital literacy, scientific communication, and learning motivation [19]–[21]. This combination of learning strategies encourages students to be active, creative, and reflective in project-based learning that is relevant to academic contexts. YouTube promotes skills in searching, selecting, sharing, and creating educational content [22]. In the context of Green Education, YouTube functions not only as a digital learning medium but also as an ecological campaign tool that promotes environmental awareness and social participation through the dissemination of evidence-based scientific content. This learning approach is expected to cultivate a generation of educators who are adaptive, environmentally responsible, and competitive in the era of sustainable digital education.

Based on the above discussion, this study is crucial because it responds to the urgent need for a learning model that not only enhances 21st-century competencies and digital

literacy but also builds ecological awareness and social responsibility among pre-service chemistry teachers amid digital transformation and global environmental crises. The integration of Project-Based Learning and Green Education is expected to provide authentic, meaningful, and contextually relevant learning experiences aligned with sustainability challenges. Moreover, this model has the potential to serve as a pedagogical solution aligned with the demands of Education 5.0 education that is human-centered, technology-oriented, and ecologically conscious. Thus, this study contributes not only to the development of innovative chemistry learning but also enriches the scientific literature on integrating green values and digital literacy in higher education. To achieve these goals, this research seeks to address two core questions: How can the implementation of Project-Based Green Education Learning enhance 21st-century skills and digital literacy of pre-service chemistry teachers in the Environmental Chemistry course? How do students perceive and experience the integration of Green Education values in project-based learning supported by digital technologies? This study is expected to provide contributions to chemistry education innovation in higher education and serve as a model of integration between pedagogical, ecological, and digital approaches in preparing future teachers who are adaptive to the era of Education 5.0.

Material and Methods

This study employed a mixed-methods approach using a sequential explanatory design, which integrates quantitative and qualitative methods in a sequential manner. The first phase involved collecting and analyzing quantitative data, followed by qualitative data to provide a deeper understanding of the effectiveness of integrating YouTube-based PjBL and Green Education in enhancing the digital literacy of pre-service chemistry teachers. The research subjects consisted of 14 chemistry education students enrolled in the Environmental Chemistry course at Musamus University, South Papua. The study was conducted over eight weeks and consisted of four stages: (1) exploration and review of scientific sources, (2) collaboration and elaboration of information, (3) production and publication of YouTube-based scientific videos, and (4) in-depth interviews to explore students' perceptions of their learning experiences, as well as YouTube video content analysis used as supporting data to capture public responses to the students' project outcomes.

The research instruments consisted of both quantitative and qualitative tools. The quantitative instruments included a 21st-Century Skills Test (pretest–posttest) measuring critical thinking, creativity, collaboration, and communication. Additionally, a Digital Literacy Questionnaire using a 1–5 Likert scale was administered. The Project Assessment Rubric evaluated video products based on scientific content quality, creativity and innovation, communication, collaboration, Green Education aspects (sustainability, environmental

solutions, ecological education), and digital literacy components (video editing software use, content originality, digital presentation quality, and effective use of the YouTube platform). The qualitative instruments included semi-structured interview guidelines, group process observation sheets, and project documentation.

Quantitative data were analyzed using descriptive and inferential statistics (N-gain) to determine the significance of improvement before and after the intervention. Qualitative data were analyzed using thematic analysis through coding, categorization, and interpretation of thematic meanings to understand students' learning experiences. The findings from both data sets were then integrated in the final interpretation stage to provide a comprehensive understanding of the effectiveness and student perceptions regarding the implementation of Project-Based Green Education Learning.

Results and Discussions

The YouTube-based Project-Based Green Education Learning model was implemented in the Environmental Chemistry course. The following presents the quantitative and qualitative results of the 21st-century skills and digital literacy of pre-service chemistry teachers.

A. Quantitative Analysis Results

1. Improvement in 21st-Century Skills

The pretest–posttest data from 14 students show significant improvement across all indicators of 21st-century skills after participating in the Project-Based Green Education Learning activities.

Table 1. Results of Pretest and Posttest on 21st-Century Skills

21st-Century Skills Component	Pretest Mean	Posttest Mean	N-gain	Category
Critical Thinking	55	88	0.73	High
Creativity	60	85	0.63	Medium
Collaboration	65	94	0.83	High
Communication	62	87	0.66	Medium
Average	60.50	88.50	0.71	High

The greatest improvement occurred in collaboration (N-gain = 0.83), indicating that the Project-Based Green Education Learning model is highly effective in supporting teamwork, role distribution, and coordination during the development of environmentally themed digital video products. The increase in critical thinking (0.73) also falls into the high category, suggesting that investigative activities on environmental issues, data collection, and solution design helped students strengthen their analytical skills. These findings align with Lijo et al. [22], who emphasized that YouTube serves not only as an entertainment platform but also as an effective pedagogical tool when designed with clear educational objectives. The improvements in creativity (N-gain = 0.63) and communication

(N-gain = 0.66) fall into the medium category, consistent with Chamidah et al. [22], who stated that PjBL does promote the development of 21st-century skills, though it requires a gradual experiential process. Barran et al. [23] also found that PjBL projects enhance creativity and communication because students must produce concrete outputs, while Oanh & Dang [24] confirmed that project-based learning effectively strengthens creative thinking and collaboration, although the effects may vary. Thus, these two aspects reflect the inherent nature of PjBL, which requires repeated project experiences for creativity and communication to develop more optimally. Moreover, today's learners—including pre-service chemistry teachers—belong to the “YouTube Generation,” who are naturally skilled and comfortable using digital platforms as tools for learning and knowledge sharing. This finding is supported by Barry et al. [24], who adapted the characteristics of the Connected Generation, demonstrating that project-based learning through YouTube is pedagogically relevant and aligned with the learning styles and digital identities of 21st-century students. This model provides opportunities for students to create and communicate effectively, contributing to the significant improvements observed in these two skills.

2. Improvement in Digital Literacy

Digital literacy was measured using a 1–5 Likert-scale questionnaire covering five key dimensions. The analysis results show an increase across all dimensions, as presented in the following table 2. The greatest improvement appears in the digital communication and collaboration dimension (N-gain = 0.76). This aligns with students' intensive use of digital platforms such as WhatsApp, Google Docs, and YouTube Studio for communication, coordination, and collaboration during the project development process. The access and use of technology dimension also shows a high increase (N-gain = 0.67), indicating that students became more proficient in using laptops, smartphones, video editing applications, and other digital tools.

Table 2. Results of Pretest and Posttest on Digital Literacy

Digital Literacy Dimension	Pretest	Post-test	N-gain
Access and use of technology	70	90	0.67
Evaluation and processing of digital information	60	84	0.60
Digital communication and collaboration	66	92	0.76
Digital content creation	68	88	0.63
Digital security	64	84	0.56
Average	65.60	87.60	0.64

The digital content creation dimension shows a good level of improvement (N-gain = 0.63). Producing educational videos on environmental issues encouraged students to develop editing skills, select appropriate visuals, write scientific scripts, and manage audio quality. The evaluation of the digital information dimension shows a moderate increase

(0.60), suggesting that students became more capable of selecting scientific sources, verifying data, and processing accurate information for their video content. The lowest improvement is found in the digital security dimension (0.56). This result is common, as digital security—such as password management, data protection, and copyright awareness—is often not taught explicitly. Nevertheless, improvement still occurred as students were required to consider copyright, privacy, and source attribution when uploading their content to YouTube. These findings are consistent with Herrington & Sweeder [25], who emphasized that the quality of digital products is strongly influenced by students' digital literacy in evaluating and packaging information.

Overall, the average N-gain of 0.64 indicates that the digital-assisted green project-based learning model has moderate effectiveness in improving students' digital literacy. The integration of Green Education within PjBL adds ethical and reflective dimensions to digital literacy. Students not only become capable digital tool users but also develop social responsibility in disseminating scientific content and promoting environmental awareness. These results support the findings of Barco [26], who stated that project-based science learning enhances cognitive, social, and eco-pedagogical aspects.

3. Project Assessment Results (YouTube Video Products)

A project assessment rubric was used by two independent raters to ensure objectivity in evaluating the seven student-produced videos. The assessment was conducted across six aspects, as illustrated in Fig. 1.

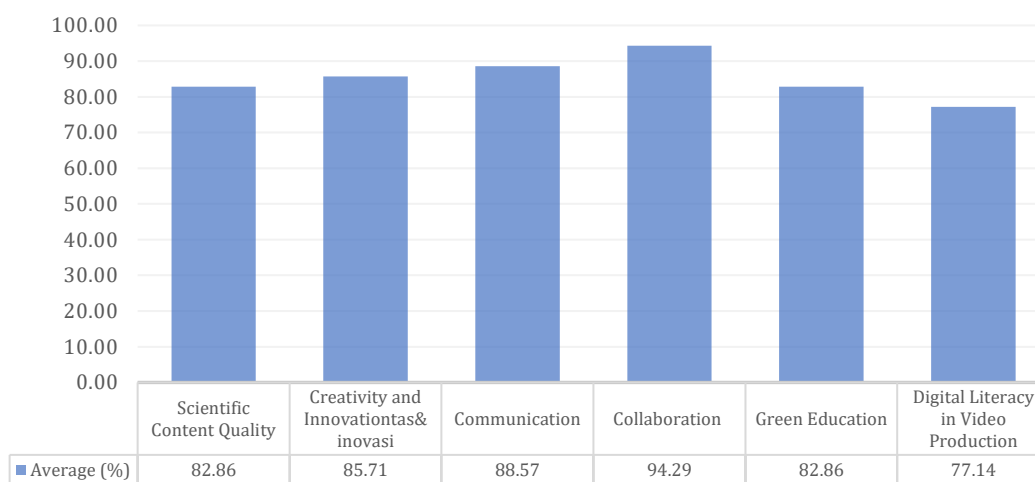


Fig. 1. Results of the Video Project Assessment of Pre-Service Teachers

Students presented environmental chemistry concepts accurately and relevantly, supported by empirical data, graphs, infographics, and clear scientific explanations. The depth of thematic analysis (e.g., pollution, global warming) was generally strong and aligned with scientific literature, although some students still need to improve consistency

in terminology and scientific precision. The use of YouTube-based PjBL increased students' learning engagement by providing space for experimentation, creativity, and problem-solving through contextual scientific video projects [26].

Students demonstrated a high level of creativity in designing storyboards, recording footage, selecting visuals, and integrating scientific narration with creative elements such as simple animations, digital infographics, and environmental illustrations. This high score reflects their ability to transform complex environmental chemistry concepts into visual content that is engaging, communicative, and contextual. Their use of various digital tools shows that students not only understand scientific concepts but also innovate in presenting them. This aligns with Sanchez et al. [27], who state that YouTube serves not only as a content dissemination platform but also as an interactive learning space requiring pedagogical creativity and digital literacy from both teachers and learners.

Students' videos exhibit strong visual and verbal communication skills. Messages were conveyed clearly, the video structure was coherent, subtitles were used effectively, and integrated visuals enhanced audience comprehension. Positive comments from YouTube viewers reinforced the quality of their scientific communication. This aspect reflects students' ability to communicate scientific concepts in a clear and accessible manner for the general public. They optimized YouTube features such as video descriptions, tags, and subtitles to broaden audience reach. These findings align with Bote [28], who emphasizes the importance of evaluative competence in producing credible and scientifically sound educational content, which aligns with the study's goal of strengthening digital literacy in pre-service chemistry teachers.

The video production process required division of roles (scriptwriter, editor, narrator, videographer). Observations showed that teamwork improved week by week, consistent with the quantitative increase in collaboration skills. This is supported by García-Sampedro [29], found that video creation among pre-service teachers enhances pedagogical abilities, digital literacy, teamwork, creativity, and professional reflection skills essential in teacher education.

Student videos highlighted key messages such as environmental education, ecological solutions, calls for sustainable lifestyles, impacts of pollution, and eco-friendly practices. The integration of sustainability values demonstrates that students understand Green Education not merely as theory but as a practical approach that can be promoted through digital media. These findings correspond with Li et al. [30], who assert that education plays a critical role in fostering sustainability awareness and action. Similarly, Cheng et al. [31] note that environmental education supports behaviors and policies that encourage clean energy. By presenting ecological messages, sustainable solutions, and advocacy for green

lifestyles, students successfully applied Green Education principles through digital media. This aspect includes the use of editing software (CapCut, Canva, Kinemaster, Premiere), visual and audio quality, content originality, aesthetic visual layout, and effective use of YouTube features (descriptions, hashtags, thumbnails). Most groups showed significant improvement in video editing and production skills, consistent with the increase in digital literacy—particularly in content creation and digital collaboration. Navarrete [32] states that video learning characteristics such as visuals, text, and interactivity play a crucial role in improving learning effectiveness, especially in digital education contexts.

Digital literacy improved because students were actively involved in project-based digital content production. This activity required them to practice all digital literacy dimensions, including searching for information, processing data, working in digital teams, editing content, and publishing videos. The quality of the final video products shows that Project-Based Green Education effectively trains 21st-century competencies while promoting sustainability values. The greatest improvement across skills was observed in digital communication and collaboration, consistent with the nature of PjBL, which emphasizes group work, discussion, and iterative collaboration. The lowest improvement was found in digital security, indicating the need for future learning to include explicit instruction on digital ethics, plagiarism, and copyright. The two-rater rubric assessment showed consistency in evaluating student projects, reinforcing that the products demonstrate not only creativity but also a strong scientific and pedagogical foundation. The following are the thumbnails of each video that has been published on YouTube.

B. Qualitative Analysis Results

The implementation of the PjBL–Green Education model was carried out through four systematic stages. The following describes each stage in detail:

1. Stage 1: Exploration and Review of Scientific Sources

In the first stage, students received an introduction to the concepts of PjBL, Green Education, 21st-century skills, and digital literacy, and were then assigned to form project groups. Students were tasked with searching for scientific articles or relevant sources related to environmental issues. At this stage, students were required to practice their digital literacy skills by searching for, selecting, and evaluating credible scientific sources. Findings show that students demonstrated significant development in critical digital literacy, particularly in locating, evaluating, and integrating reputable journal sources on environmental chemistry issues such as air pollution, water pollution, global warming, acid rain, microplastics, and the greenhouse effect. This stage shows that students were already capable of independently navigating scientific information through online databases and open-access journals, as well as assessing the quality and relevance of the articles they

found. This aligns with Ng [32], who states that digital literacy includes critical thinking and the ability to assess online information credibility. Furthermore, students began to demonstrate collaborative inquiry skills by discussing and comparing sources within their groups. This indicates that digital literacy development was not only individual but also socially constructed through interaction and shared evaluation processes.



Video 1



Video 2



Video 3



Video 4



Video 5



Video 4



Video 7

Fig. 2. Thumbnail of the Video Project Published on YouTube

Table 3 presents a comprehensive, detailed description of each video project uploaded to YouTube, including key aspects such as content, objectives, production features, and intended audience engagement.

Table 3. Details of Video Projects and Their YouTube Links

Video	Title	Link
1	The Terrifying Effects of Global Warming	https://youtu.be/csYDOPTPNXk
2	Beware! Water Pollution Threatens the Environment	https://youtu.be/wYLe2cvTM74
3	Beware of Microplastic Threats	https://youtu.be/JRC-GgB4bCI
4	Oh No! The Ozone Layer Is Thinning	https://youtu.be/egKIsfn6JIE
5	The Horror of the Greenhouse Effect	https://youtu.be/XD8ZFaoxRcE
6	The Horrors of Air Pollution	https://youtu.be/liZl-HEiFVU
7	Why Is the Rain Acidic?	https://youtu.be/Cty6Ss3F0js

2. Stage 2: Collaboration and Information Elaboration

The second stage emphasized the importance of group collaboration in elaborating the scientific articles selected. Students discussed key points from the articles, identified significant environmental data, and drafted the video script framework. Collaboration and communication skills were essential during this process. Students engaged in role distribution, including scriptwriters, editors, narrators, and video designers. Effective task division allowed each member to contribute optimally based on their strengths. Discussions occurred actively both in person and online via collaborative platforms such as Google Meet and WhatsApp Group. Digital collaboration strengthened teamwork, communication, and individual responsibility for the group's outcomes. These findings support Vygotsky's [33] theory of social constructivism, which emphasizes that knowledge is constructed through social interaction. Through group collaboration, students learned not only from the instructor but also from their peers, creating an effective peer-learning environment.

3. Stage 3: Production and Publication of YouTube-Based Videos

The third stage constituted the project phase, in which students transformed their synthesis of scientific articles into engaging and informative educational videos to be uploaded on YouTube. This stage required students to think both critically and creatively in developing scientific narratives and packaging them into audio-visual content. Students used various free applications such as CapCut, Canva, Animaker, and Powtoon during video production. This process trained them to innovate with limited resources while still producing high-quality outputs. The application of the Design stage in PjBL helped students understand problems contextually, design creative ideas, and produce innovative products [34]. In the context of YouTube-based learning, this was manifested through video creation, which required critical and creative thinking. Observations showed that the resulting videos demonstrated high creativity, including the use of illustrations, animations, simulations, and accessible data presentation. These findings align with Billing [35], who stated that Generation Z learners tend to prefer technology-based and visual media learning, making YouTube an effective platform for expressing their scientific ideas.

YouTube has become a popular medium for learning due to its flexibility and open access to educational content [36].

4. Stage 4: Interviews

Students' Perceptions of PjBL–Green Education Learning. Analysis of interviews with 14 informants revealed three major themes:

a) Contextual and meaningful learning

Students reported that connecting real-world issues such as global warming, acid rain, and water pollution made environmental chemistry concepts easier to understand and more relevant to daily life.

"Usually we learn acid–base concepts or redox reactions without knowing their impact, but when making a video about acid rain, we finally understood the process and its social effects." (M2)

b) Improvement in collaborative and digital skills

Students felt more confident in editing videos, creating data visualizations, and communicating scientific ideas through digital media.

"We learned to use Canva, CapCut, and even AI voice-over. So, it wasn't just theory—we really practiced digital communication." (M5)

c) Internalization of Green Education values

Students became more aware of ecological responsibility and the important role teachers play in fostering environmentally conscious generations.

"It turns out that chemistry teachers can contribute to environmental education through digital media." (M8)

The PjBL–GE model practically addresses the challenges of Education 5.0 by integrating humanity, sustainability, and technology. Students not only learned scientific concepts but also communicated them digitally with humanistic and sustainability-oriented values.

C. Integration Analysis of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings indicates that the implementation of Project-Based Learning with Green Education through YouTube media had a significant impact on improving the digital literacy and 21st-century skills of chemistry education students. Quantitatively, the improvement was reflected in the N-gain score for 21st-century skills of 0.71 (high category) and the N-gain score for digital literacy of 0.64 (medium category). The quantitative data revealed substantial improvement, particularly in collaboration, which aligns with the characteristics of PjBL that emphasize team interaction, negotiation of ideas, and the co-construction of solutions to real environmental issues.

Qualitative data supported these findings: students described how environmental inquiry, group discussions, and video production trained them to analyze problems, construct solutions, and work effectively as a team. The increase in digital literacy was reflected in the questionnaire results, showing improvement across all domains: access, evaluation, digital

collaboration, content creation, and digital safety. Interviews further clarified that this improvement was directly related to the experience of producing videos, gathering scientific data, and interacting through digital platforms such as YouTube.

Rubric assessments from two evaluators demonstrated that the students' project outcomes were of high quality across six aspects: scientific content accuracy, creativity and innovation, communication, collaboration, Green Education, and digital literacy within the video product. The content presented was accurate, the narrative was coherent, supporting visuals were used effectively, and sustainability values were integrated explicitly through environmental campaigns and ecological calls to action.

Regarding digital literacy, the students' videos showed substantial progress in mastering editing tools, visual design, content originality, audio-visual quality, and the use of YouTube features such as descriptions, hashtags, and thumbnails. YouTube content analysis also showed positive public responses through educational comments and likes, supporting the quality of the projects. Students improved their technical skills and their ability to optimize YouTube as a digital dissemination platform. Their information literacy also strengthened, as students became more critical in selecting trustworthy scientific journals to ensure the accuracy of environmental chemistry concepts prior to publication.

Social-emotional and collaborative competencies were reflected in their ability to distribute roles, manage conflicts, maintain communication, and sustain commitment throughout the project. Students also demonstrated increased creativity by transforming abstract chemistry concepts into visually engaging content through animations, infographics, and narrative videos on environmental issues. This indicates that the PjBL process enhanced not only conceptual understanding but also digital content design skills.

Interview results reinforced that students perceived this project-based learning approach as more meaningful because it connected environmental chemistry theory with real phenomena such as air pollution, water contamination, and the greenhouse effect. They acknowledged challenges such as limited time, varying technical abilities within groups, and coordination issues, but noted that these challenges served as catalysts for developing digital literacy, problem-solving abilities, and resilience in dealing with technical obstacles. Students also felt more motivated because their videos were published for a real audience, which created a sense of authenticity in the learning process. These findings align with Tom [37], who argues that authentic projects foster meaningful learning and that the development of digital competencies can begin as early as teacher education.

These findings are supported by prior studies. Olivares [38] emphasized that YouTube enhances students' visual and contextual understanding. Basgall [39] demonstrated that integrating YouTube in pedagogy strengthens teachers' digital competence. Sumanik et al. [39]

confirmed that digital media supports active, reflective, and critical learning. Lichter [40] highlighted the effectiveness of videos in bridging abstract chemistry concepts with more accessible visuals. Hernandez [41] emphasized that PjBL effectively enhances cognitive and emotional engagement in science education. Dhimitruka [42] found that PjBL remains effective even under limited-resource conditions, making it relevant to diverse student contexts.

Unique Value of Integrating Digital Learning and Green Education. The integration of digital learning through YouTube with Green Education added a unique dimension that strengthened not only technological skills but also students' ecological awareness. Students not only analyzed environmental problems but also designed environmental solutions and disseminated them to the public through digital platforms, creating a wider impact. These findings align with the direction of Education 5.0, which emphasizes the synergy of creativity, humanity, and technology to shape adaptive and reflective educators. Producing scientific content on YouTube allowed students to connect theory with modern technological practice, making chemistry learning more contextual and engaging.

Overall, the Project-Based Green Education model proved to be significantly effective, supported by strong qualitative evidence in enhancing 21st-century skills (critical thinking, creativity, collaboration, communication) and digital literacy among chemistry education students. The model is relevant, contextual, and suitable as an innovative strategy for environmental chemistry instruction in the digital era. Thus, it is highly appropriate for preparing future chemistry teachers to face the demands of 21st-century learning and the challenges of the Education 5.0 era.

Conclusion

This study concludes that the implementation of YouTube-based Project-Based Green Education Learning proved effective in enhancing student competencies, indicated by a high increase in 21st-century skills ($N\text{-gain} = 0.71$) and a moderate increase in digital literacy ($N\text{-gain} = 0.64$). The quality of the student video projects was also rated as good, with an average score of 85.24% based on assessments from two evaluators. Qualitative analysis strengthens these findings by showing that students experienced improvements in reflective thinking, effective collaboration, and the ability to produce innovative digital products that are relevant to environmental issues.

The application of the Project-Based Green Education Learning model also fostered ecological awareness, social responsibility, and the ability to use technology ethically and productively. However, several challenges were identified, including limited time, internet access issues, and the need for technical guidance in digital content creation. Therefore, the integration of green education within a project-based learning approach not only enhances

cognitive aspects but also cultivates environmental awareness, 21st-century skills, and digital literacy that are essential in the Education 5.0 era.

Recommendations for lecturers and educational institutions include expanding the implementation of Project-Based Green Education Learning with stronger digital infrastructure support, clear technical guidelines, and interdisciplinary collaboration to strengthen the relevance and sustainability of chemistry education toward green innovation and digital technology. This study also recommends the continuous application of digital PjBL in other courses, the integration of additional digital platforms beyond YouTube, and an expansion of sample size to achieve stronger generalization within higher education contexts in the digital and Green Education era.

Conflict of Interest

The author declares no conflict of interest.

References

- [1] W.-C. V. Wu, K. Manabe, M. W. Marek, and Y. Shu, "Enhancing 21st-century competencies via virtual reality digital content creation," *J. Res. Technol. Educ.*, vol. 55, no. 3, pp. 388–410, 2023, doi: 10.1080/15391523.2021.1962455.
- [2] S. Aslan, M. Alanoğlu, and S. Karabatak, "Enhancing 21st-century teaching competencies: The key role of digital literacy in connecting pre-service teachers' TPACK," *Inf. Dev.*, e0266666925, 2025, doi: 10.1177/026666669251315841.
- [3] J. R. G. Niño, L. P. Á. Delgado, A. Chiappe, and E. O. González, "Gamifying learning with AI: A pathway to 21st-century skills," *J. Res. Child. Educ.*, vol. 39, no. 4, pp. 735–750, 2025, doi: 10.1080/02568543.2024.2421974.
- [4] S. Syam *et al.*, *Transformasi Kurikulum: Menyongsong Era Pendidikan Baru di Indonesia*. Medan: Yayasan Kita Menulis, 2024.
- [5] M. Mousa, "AI-supported formative assessments: Enhancing student-centered learning and teacher perceptions," *J. Pedagog. Educ. Sci.*, vol. 4, no. 2, pp. 127–141, 2025, doi: 10.56741/jpes.v4i02.857.
- [6] H. S. Park, H. Kim, and H. W. Park, "A scientometric study of digital literacy, ICT literacy, information literacy, and media literacy," *J. Data Inf. Sci.*, vol. 6, no. 2, pp. 116–138, 2021, doi: 10.2478/jdis-2021-0001.
- [7] A. Haris *et al.*, *Pendidikan Tanpa Batas*. Padang: CV Dunia Penerbitan, 2025.
- [8] N. B. Sumanik and I. Natsir, "Augmented reality: Development of android-based atomic structure learning media," *EDUSAINS*, vol. 16, no. 1, pp. 27–37, 2024, doi: 10.15408/es.v13i2.37569.
- [9] M. Son and M. Ha, "Development of a digital literacy measurement tool for middle and high school students in the context of scientific practice," *Educ. Inf. Technol.*, vol. 30, no. 4, pp. 4583–4606, 2025, doi: 10.1007/s10639-024-12999-z.
- [10] H. Subakti *et al.*, *Inovasi Pendidikan dan Pembelajaran Abad 21*. Medan: Yayasan Kita Menulis, 2024.
- [11] S. Yin, X. Liu, Z. Yang, and H. Xing, "The impact of green education on resource extraction and consumption sustainability for green growth," *Resour. Policy*, vol. 90, no. 104785, 2024, doi: 10.1016/j.resourpol.2024.104785.
- [12] H. H. Teow, P. K. Ahmed, M. S. Nair, and S. Vaithilingam, "Green education divide: A comparative case study analysis of countries of the Association of Southeast Asian Nations," *Lancet Planet. Heal.*, vol. 8, no. 20, 2024, doi: 10.1016/S2542-5196(24)00085-8.
- [13] C. Y. Chang, H. C. Kuo, and Z. Du, "The role of digital literacy in augmented, virtual, and mixed reality in popular science education: A review study and an educational framework development," *Virtual Real.*, vol. 27, no. 3, pp. 2461–2479, 2023, doi: 10.1007/s10055-023-00817-9.
- [14] N. B. Sumanik *et al.*, "The influence of POGIL learning model by mind mapping and summary assignment of salt hydrolysis outcomes," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 473, e012136, 2019,

- doi: 10.1088/1755-1315/473/1/012136.
- [15] C. C. Chung, S. L. Huang, Y. M. Cheng, and S. J. Lou, "Using an iSTEAM project-based learning model for technology senior high school students: Design, development, and evaluation," *Int. J. Technol. Des. Educ.*, vol. 33, no. 2, pp. 905–941, 2022, doi: 10.1007/s10798-020-09643-5.
 - [16] R. Mursid, A. H. Saragih, and R. Hartono, "The effect of the blended project-based learning model and creative thinking ability on engineering students' learning outcomes," *Int. J. Educ. Math. Sci. Technol.*, vol. 10, no. 1, pp. 218–235, 2022, doi: 10.46328/ijemst.2244.
 - [17] Z. L. and M. Y., "A study of the impact of project-based learning on student learning effects: A meta-analysis study," *Front. Psychol.*, vol. 14, 2023, doi: 10.3389/fpsyg.2023.1202728.
 - [18] A. Darmuki, F. Nugrahani, I. Fathurohman, M. Kanzunudin, and N. A. Hidayati, "The impact of inquiry collaboration project-based learning model of Indonesian language course achievement," *Int. J. Instr.*, vol. 16, no. 2, pp. 247–266, 2023, doi: 10.29333/iji.2023.16215a.
 - [19] N. B. Sumanik, A. Arismunandar, N. Nurhikmah, and N. Indrawati, "Green chemistry learning transformation: YouTube integrated interactive video to improve critical thinking skills," *Indones. J. Educ. Dev.*, vol. 5, no. 3, pp. 346–357, 2024, doi: 10.59672/ijed.v5i3.4218.
 - [20] M. Rodríguez-Peñarroja, "Integrating project-based learning, task-based language teaching approach and YouTube in the ESP Class: A study on students' motivation," *Teach. English with Technol.*, vol. 22, no. 1, pp. 62–81, 2022. [Online]. Available: <https://tewtjournal.org/download/integrating-project-based-learning-taskbased-language-teaching-approach-and-youtube-in-the-esp-class-a-study-on-students-motivation-by-manuel-rodriguez-penarroja/>.
 - [21] J. Simarmata et al., *E-Learning dan Blended Learning*. Medan: Yayasan Kita Menulis., 2024.
 - [22] F. D. Guillén-Gámez, E. Colomo-Magaña, J. Ruiz-Palmero and Ł. Tomczyk, "Teaching digital competence in the use of YouTube and its incidental factors: Development of an instrument based on the UTAUT model from a higher order PLS-SEM approach," *Br. J. Educ. Technol.*, vol. 55, no. 1, pp. 340–362, 2024, doi: 10.1111/bjet.13365.
 - [23] M. Baran, M. Baran, F. Karakoyun, and A. Maskan, "The influence of project-based STEM (PjBL-STEM) applications on the development of 21st century skills," *J. Turkish Sci. Educ.*, vol. 18, no. 4, pp. 798–815, 2021, doi: 10.36681/tused.2021.104.
 - [24] D. T. K. Oanh and T. D. H. Dang, "Effect of STEAM project-based learning on engineering students' 21st century skills," *Eur. J. Educ. Res.*, vol. 14, no. 3, pp. 705–721, 2025, doi: 10.12973/eurjer.14.3.705.
 - [25] D. G. Herrington and R. D. Sweeder, "Is this a helpful YouTube video? A research-based framework for evaluating and developing conceptual chemistry instructional videos," *J. Chem. Educ.*, vol. 102, no. 2, pp. 621–629, 2025, doi: 10.1021/acs.jchemed.4c01085.
 - [26] M. Hernández-Barco, J. Sánchez-Martín, I. Corbacho-Cuello, and F. Cañada-Cañada, "Emotional performance of a low-cost eco-friendly project-based learning methodology for science education: An approach in prospective teachers," *Sustainability*, vol. 13, no. 6, e3385, 2021, doi: 10.3390/su13063385.
 - [27] V. Sanchez-Gonzaga and N. Ruiz-Morillas, "Differences and similarities between face-to-face and YouTube chemistry teaching," *J. Chem. Educ.*, vol. 101, no. 5, pp. 1905–1913, 2024, doi: 10.1021/acs.jchemed.3c01182.
 - [28] J. J. Bote-Vericad, "Information-seeking and content creation: The impact of YouTube educational videos on learning practices in library and information science," *J. Librariansh. Inf. Sci.*, 2025, doi: 10.1177/09610006241309102.
 - [29] M. García-Sampedro, S. Agudo Prado, and A. Torralba-Burrial, "Pre-service teachers' skills development through educational video generation," *Eur. J. Teach. Educ.*, vol. 49, no. 2, pp. 296–314, 2024, doi: 10.1080/02619768.2024.2323925.
 - [30] X. Li, L. Ma, S. Khan, and X. Zhao, "The role of education and green innovation in green transition: Advancing the United Nations agenda on sustainable development," *Sustainability*, vol. 15, no. 16, p. 12410, 2023, doi: 10.3390/su151612410.
 - [31] Y. Cheng, G. Zhao, W. Meng, and Q. Wang, "Resources utilization, taxation and green education: A path to sustainable power generation," *Resour. Policy*, vol. 88, e104389, 2024, doi: 10.1016/j.resourpol.2023.104389.
 - [32] E. Navarrete, A. Nehring, S. Schanze, R. Ewerth, and A. Hoppe, "A closer look into recent video-based learning research: A comprehensive review of video characteristics, tools, technologies, and learning effectiveness," *Int. J. Artif. Intell. Educ.*, pp. 1–64, 2025, doi: 10.1007/s40593-025-00481-x.
 - [33] V. L.S., *Mind in Society: The Development of Higher Psychological Processes*. Cambridge: MA:

Harvard University Press, 1978.

- [34] L. R. Ananda, Y. Rahmawati, F. Khairi, and I. Irwanto, "Developing the computational thinking skills of chemistry students by integrating design thinking with STEAM-PjBL," in *AIP Conference Proceedings*, 2024, p. 040007. doi: 10.1063/5.0183005.
- [35] D. M. Billings, K. Kowalski, B. Shatto, and K. Erwin, "Moving on from Millennials: Preparing for Generation Z," *J. Contin. Educ. Nurs.*, vol. 47, no. 6, pp. 253–254, 2016, doi: 10.3928/00220124-20160518-05.
- [36] G. A. Breslyn W, "Learning science with YouTube videos and the impacts of Covid-19," *Discip. Interdiscip. Sci. Educ. Res.*, vol. 4, e13, pp. 1-20, 2022, doi: 10.1186/s43031-022-00051-4.
- [37] Ł. Tomczyk, A. Cívico-Ariza, E. Colomo-Magaña, and F. D. Guillén-Gámez, *A study on the digital competence of teachers in the use of YouTube as a teaching resource according to gender, age, and years of teaching experience*. 2023.
- [38] P. Olivares-De la Fuente, E. Jiménez-García y Ó. García-López, "Twitter and YouTube as digital tools in higher education: A systematic review," *Front. Educ.*, vol. 10, p. 1625803, 2025, doi: 10.3389/educ.2025.1625803.
- [39] L. Basgall, F. Guillén-Gámez, E. Colomo-Magaña, and E. Al., "Digital competences of teachers in the use of YouTube as an educational resource: Analysis by educational stage and gender," *Discov. Educ.*, vol. 2, no. 28, 2023, doi: 10.1007/s44217-023-00054-x.
- [40] J. Lichter, "Using YouTube as a platform for teaching and learning solubility rules," *J. Chem. Educ.*, vol. 89, no. 9, pp. 1133–1137, 2012, doi: 10.1021/ed200531j.
- [41] M. Hernández-Barco, J. Sánchez-Martín, I. Corbacho-Cuello, and F. Cañada-Cañada, "Emotional performance of a low-cost eco-friendly project-based learning methodology for science education: An approach in prospective teachers," *Sustainability*, vol. 13, no. 6, e3385, 2021, doi: 10.3390/su13063385.
- [42] I. Dhimitruka and G. Surendran, "Adaptation of project-based learning concepts to the organic chemistry I laboratory curriculum in a small college environment," *J. Coll. Sci. Teach.*, vol. 52, no. 4, pp. 61–69, 2023, doi: 10.1080/0047231X.2023.12290633.

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