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DEVELOPMENT OF A VIRTUAL CHEMISTRY LABORATORY BASED ON GREEN CHEMISTRY TO INCREASE TECHNOLOGICAL LITERACY FOCUSING ON FACTORS AFFECTING REACTION RATES

Sri Mulyani*, Anggie Lutfiyani, Lina Mahardiani

Program Studi Pendidikan Kimia, Fakultas Keguruan dan Ilmu Pendidikan, Universitas Sebelas Maret, Surakarta, Indonesia

Abstract: This study aimed to develop and evaluate the effectiveness of a Green Chemistry-based virtual laboratory learning module in enhancing high school students' technology literacy. The research design utilized the ADDIE model, including Analysis, Design, Development, Implementation, and Evaluation. The study's participants were 12 students for a limited scale test and 36 students for a field test, selected through purposive and cluster random sampling, respectively. The data were collected through questionnaires and analyzed using statistical techniques, including Sudijono's media feasibility interpretation scale and the System Usability Scale (SUS) questionnaire. An Independent-Sample T-Test was used to assess the effectiveness of the media in empowering student technology literacy. The results showed that the developed virtual laboratory learning module effectively enhanced students' technology literacy, with a significant difference between the experimental and control groups. This study's findings indicate that virtual laboratories based on green chemistry provide a more engaging and enjoyable learning experience, allowing students to be more involved in the learning process and better understand chemistry concepts. The utilization of virtual laboratories can also enhance students' ability to use technology, which is essential in today's digital world. Developing and implementing this Green Chemistry-based virtual laboratory learning module can improve chemistry education and students' digital literacy.

Words: Virtual Laboratory, Green Chemistry, Student Technology Literacy

INTRODUCTION

In the current era of globalization, technology is deve-loping rapidly. The use of technology in learning supports the mastery of 21st-century skills for students, especially in science education (Rokhim et al., 2019). Chemistry, one of the science disciplines, is closely related to laboratory activities. Laboratory activities in chemistry play an important role in supporting theoretical explanations. Through Laboratory activities, students can acquire in-depth knowledge through the scientific processof laboratory work (Muchson et al., 2019, p.216). Technology has become an Chemistry is an essential subject for understanding the properties and reactions of chemical substances in our daily lives,

*Alamat korespondensi: Jalan Ir. Sutami 36 A, Jebres, Surakarta, Central Java, Indonesia
e-mail: srimulyaniuns@staff.uns.ac.id

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and laboratory activities play a vital role in the learning process(Barke, 2011).However, the use of technology in laboratory activities is limited due to high costs, limited space, and availability of equipment and materials. Therefore, developing a Green Chemistry-based virtual chemistry laboratory can be a solution to overcome these limitations. A virtual chemistry laboratory is a distance learning platform that allows students to perform chemical experiments and simulations without being physically present in the laboratory (Gilbert,2006). This technology-based solution aims to integrate Green Chemistry concepts into chemistry education and improve students' technological literacy. Developing a Green Chemistry-based virtual chemistry laboratory requires using advanced technology and developing suitable learning modules for students (Ramos,2016).

An attempt to decrease the waste generated from laboratory experiments is by applying the principles of green chemistry (Lancaster, 2002). The fundamental principles of green chemistry include waste prevention, reduction of dangerous chemicals, making reactions more efficient, and designing non-dangerous chemical products (Warner, Cannon, & Dye, 2004).

In current's world, technology plays a crucial role in education, and incorporating the principles of green chemistry through a virtual laboratory is an effective approach (Elisa et al., 2020). Developing virtual laboratories for chemistry education is a potential solution for providing suitable learning media for the 21st century. Technological literacy is also a critical skill that students need to develop, as emphasized by Febliza and Oktariani (2020). The World Economic Forum identified ICT literacy as a fundamental skill necessary for the global population in 2015, and technology has become an essential tool for social needs in the 21st century (Helaluddin, 2019). However, there is a shortage of innovative chemistry laboratory learning programs prioritising student technological literacy, as research shows. Thus, developing virtual laboratory media can help implement chemistry laboratory learning and promote technological literacy in Indonesian schools.

Several studies have looked into ways to improve chemistry education, including using green chemistry principles and virtual laboratories. For example, Chang and Kim (2017) provide effective teaching strategies for incorporating green chemistry principles in chemistry education, while Pileggi et al. (2020) found that virtual laboratories improve students' understanding and skills. Elisa et al. (2020) also suggest that digital technology can facilitate more interactive and flexible learning in chemistry education. Overall, these studies suggest that using green chemistry principles and virtual laboratories can enhance the effectiveness of chemistry teaching and make it more engaging for students.

This article is significant because it presents a new approach to enhance students' learning experience using digital technology to introduce Green Chemistry concepts and improve their technological literacy. The article's uniqueness lies in developing a Green Chemistry-based virtual laboratory focused on factors affecting reaction rates, which previous studies have not explored. In addition, the article proposes solutions such as creating suitable learning modules to improve the virtual laboratory's effectiveness. While other studies have examined incorporating Green Chemistry principles and virtual laboratories in chemistry teaching, this article stands out by combining the two and emphasizing the importance of technological literacy.

METHOD

Research Design

Research design refers to the plan or approach utilized in addressing research questions. This study used the development research design, the ADDIE model (Analysis, Design, Development, Implementation, Evaluation).

A needs analysis is conducted in the Analysis stage and the learning topic is identified. In the Design stage, the virtual laboratory module design plan is developed. The Development stage involves creating the virtual laboratory learning module, including materials, instruction, and media. The Implementation stage applies the virtual laboratory learning module to the classroom learning context. This stage tests and evaluates the quality of the module. Lastly, the Evaluation stage examines the effectiveness and efficiency of the Green Chemistry-based virtual laboratory learning module developed. The research design allows researchers to develop virtual laboratory learning modules that meet the needs of students. This study differs from previous research emphasising technology and teaching strategies in chemistry learning. The research is significant in developing Green Chemistry-based virtual laboratory learning modules that enhance the effectiveness and efficiency of chemistry learning.

Data Analysis

The data analysis in this study was conducted by analyzing the results from the implementation phase, which included teacher and student responses, assessment of the media product's usefulness, and the effectiveness of the media in empowering student technology literacy. This was done using various techniques such as Sudijono's (2008) media feasibility interpretation scale for media validation, student questionnaires on their responses to the media and the System Usability Scale (SUS) questionnaire for assessing the media's usefulness. In addition, an Independent-Sample T-Test was used to determine the effectiveness of the media in empowering student technology literacy. Finally, all data obtained from the trials were analyzed using statistical techniques to evaluate the effectiveness of the developed virtual chemistry laboratory media. The results of this analysis will serve as a basis for determining the conclusion on the success of the virtual chemistry laboratory media development in empowering student technology literacy.

Participant and Instrument

In this study, the participants were high school students in Surakarta. A limited scale test was conducted on 12 students selected through purposive sampling, while a field test was conducted on 36 students selected through cluster random sampling.

The instruments used in this study were questionnaires to collect data on students' technological literacy, their responses to the media, and their evaluation of the media's usefulness based on the System Usability Scale (SUS). Additionally, the researcher also conducted validation by subject matter experts and media experts to evaluate the feasibility of the developed media. Feasibility criteria were based on Sudijono (2008) and evaluated using a media feasibility interpretation scale (Table 1).

Table 1. Scale of Media Feasibility Interpretation

Score	Criteria
$> Mi + 1,5$ SBi	Very feasible
$Mi + 0,5$ SBi $<$ s.d $\leq Mi + 1,5$ SBi	Feasible
$Mi - 0,5$ SBi $<$ s.d $\leq Mi + 0,5$ SBi	Moderately
$Mi - 1,5$ SBi $<$ s.d $\leq Mi - 0,5$ SBi	Less feasible
$< Mi - 1,5$ SBi	Very less feasible

RESULT AND DISCUSSION

The Analysis stage

the Analysis stage plays a crucial role in identifying the research gap and the need to develop a virtual laboratory that incorporates green chemistry materials and principles. The literature review conducted in this stage helped to identify the existing virtual chemistry laboratories and their limitations. The literature review results indicated that no virtual laboratory incorporates green chemistry materials and principles, and innovative chemistry practical learning emphasizing student technological literacy is rare and difficult to find. This highlights the need to develop a virtual laboratory that integrates green chemistry principles and practices and emphasizes student technological literacy.

The field studies and teacher interviews further strengthen the need to develop a virtual laboratory. The interviews revealed that there is no supporting media such as virtual laboratories in practical activities, and the development and use of virtual laboratory media can empower students' technological literacy. The student needs analysis also emphasizes the need for virtual laboratories. Most students agree that virtual laboratories can make lessons more enjoyable, and the availability of supporting media such as virtual laboratories is inadequate.

Based on field studies, interviews with teachers revealed no supporting media such as virtual chemistry laboratories in practical activities. However, they support developing and using virtual laboratory media to empower students' technological literacy. As for student needs analysis, 98% of students agree that virtual laboratories will make lessons more enjoyable, 63% state that the availability of supporting media such as virtual laboratories is inadequate, and 97% agree with the development of virtual laboratory media.

The Analysis stage in this study helped identify the research gap and the need to develop a virtual laboratory that incorporates green chemistry materials and principles (Lutfi, 2017). According to the literature review conducted in this stage, no virtual laboratory incorporates green chemistry materials and principles, and innovative chemistry practical learning emphasizing student technological literacy is rare and difficult to find. Field studies and teacher interviews further strengthened the need to develop a virtual laboratory (Kemdikbud, 2017). The student needs analysis also emphasized the need for virtual laboratories (Erlina et al., 2019).

Design Stage

In this research, a simulation of a chemistry laboratory experiment was designed based on the Basic Competencies of reaction rate material, which are learning outcome 3.6 and 4.7. Through the virtual laboratory activity using a virtual chemistry laboratory application, students can conduct experiments to determine the effect of concentration, surface area of substances, temperature, and pressure on reaction rate. They can also conclude and present the experimental data correctly and independently with an active and responsible attitude. In addition, students will learn how to design, perform, and draw conclusions from experiments related to the factors affecting reaction rate.

The initial design of the virtual laboratory is shown in Figure 1.

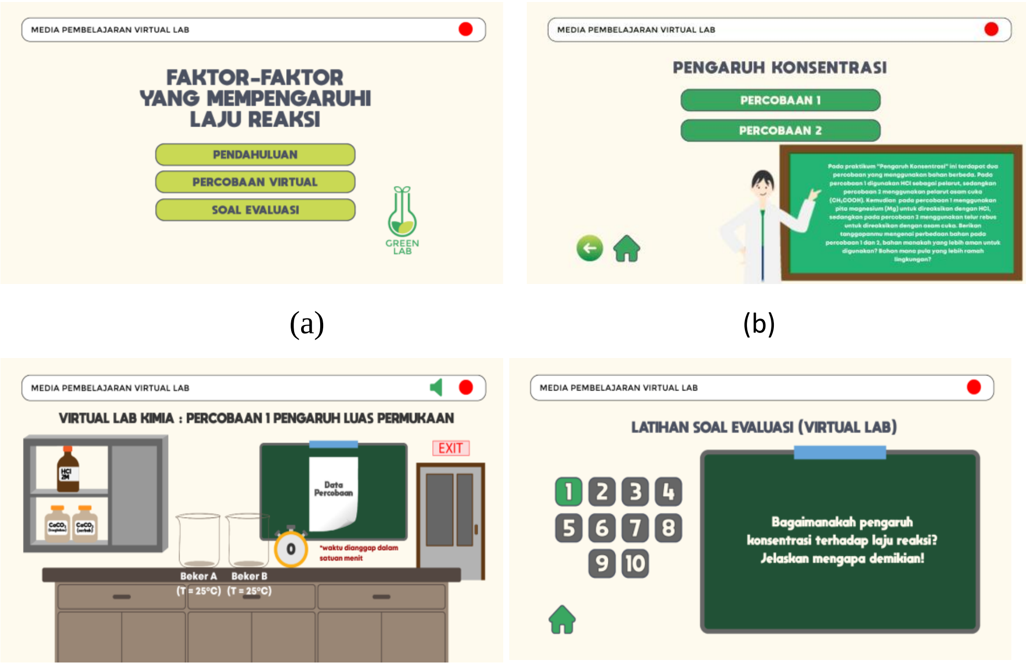

Figure 1. (a) Homepage Design; (b) Initial Display of Experiment; (c) Practicum Simulation Display; (d) Evaluation

Development Stage

At this stage, the media design was realized into a virtual laboratory application which subject matter experts and media experts then validated. The validation results from the media expert and subject matter expert are presented in Figure 2.

The average score of both media experts on the software engineering aspect was 46, which falls within the assessment range of >40 and thus considered "very feasible". Meanwhile, the average score on the visual communication aspect was 38, which falls within the assessment range of >36 and thus considered "very feasible".

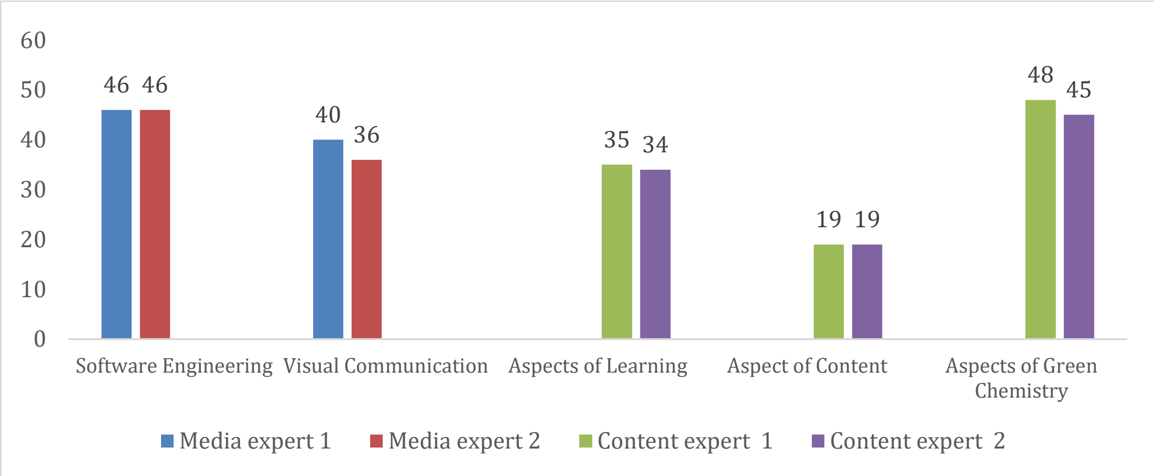

Figure 2 Expert Validation Results

Based on Figure 2, the average score from both content experts for the learning aspect is 34.5, which falls within the "very appropriate" criteria as the assessment range is greater than 28. The average score for the substance aspect is 19, which also falls within the "very appropriate" criteria as the assessment range is greater than 16. Meanwhile, the average score for applying the green chemistry aspect in the media is 46.5, which falls within the "very good" criteria as the assessment range is over 39. Figure 3 shows some media revision summaries from both media and content experts

Implementation

The study described above focuses on developing and implementing a virtual laboratory application for chemistry education. Subject matter experts and media experts validated the media design. The implementation stage involved limited trials on a small group of students and a field trial with a larger group. The results of the validation and implementation stages were analyzed based on various criteria(Table 2 and 3).

Table 2. Student Response Results in Limited Trials

Respondent	Total Score	Average	Criteria
Student 1 – 12	936	78	Very feasible

Table 3. Limited Trial Media Usability Scores

Respondent	Total Score	Total Value	Average
Student 1 –12	388	970	80,83

Based on the validation results, the media design was found to be "very feasible" regarding software engineering and visual communication. In addition, the media was found to be "very appropriate" in learning and substance aspects and "very good" in applying green chemistry. These findings are consistent with the theory that effective multimedia design should consider various aspects such as visual communication, software engineering, and content appropriateness (Mayer, 2009).

The implementation stage involved limited trials and a field trial with students. The response from students in the limited and field trials was positive, with average scores falling within the "very feasible" range. The results of the SUS questionnaire also indicated good usability of the media(Table 4 and 5) . These findings are consistent with the theory that effective multimedia should have good usability and be well-received by the target audience (Nielsen, 1993).

The study also assessed student technology literacy using a questionnaire consisting of 68 statements based on the dimensions of information, communication, content creation, safety, and problem-solving. The results showed that the average technology literacy score in the experimental class was higher than that in the control class. These findings are consistent with the theory that technology can enhance students' digital literacy and problem-solving skills (Kirschner & Karpinski, 2010).

Overall, the findings of this study suggest that the developed virtual laboratory application for chemistry education is effective in terms of media design, usability, and student response. In addition, the study provides evidence to support the use of technology to enhance students' digital literacy and problem-solving skills. However, further research is needed to investigate the long-term impact of the developed media on students' learning outcomes.

Table 4. Student Response Results in Field Tests

Respondent	Total Score	Average	Criteria
Student 1 –36	2933	81.47	Very feasible

Table 5. Field Trial Media Usefulness Scores

Respondent	Total Score	Total Value	Average
Student 1 -36	1183	2957.5	82.15

Evaluation Stage

During this stage, the results of the implementation phase are analyzed. In addition, an evaluation is conducted to determine the effectiveness of virtual laboratory media in enhancing students' technology literacy. To assess the effectiveness of the media, an Independent-Sample T-Test is conducted. This test requires that both sample groups have a normal distribution and homogenous variation.

Table 6. Technology Literacy Data for Experiment Class and Control Class

Statistics of Technology Literacy	Experiment Class	Kelas Kontrol
Highest score	266	250
Lowest value	200	162
Average	221.97	191
Standard deviation	15.92	19.95

The results of the technology literacy data pretest for the experimental and control groups are presented in Table 7. A distribution is considered normal if the significance level is greater than 0.050. Based on Table 6, it can be concluded that the technology literacy data for both the experimental and control groups have normal distributions. A distribution is considered homogenous if the significance level is greater than 0.05. From Table 8, the Sig value is 0.761, greater than 0.05, indicating that the technology literacy questionnaire data for both the experimental and control groups are homogenous.

Table 7. Results of Technology Literacy Data Normality Test

Class	Sig	Decision Test
Experiment	0,125	Normal
Control	0,166	Normal

Table 8. Results of Technological Literacy Data

	Sig	Decision Test
Technology literacy questionnaire	0.761	Homogeneous

Once the prerequisite tests are met, an Independent-Sample T-Test,this test is aimed at determining whether there is a significant difference in technology literacy between the experimental and control groups when using the developed green chemistry-based virtual laboratory media.

The results of the Independent T-Test on the technology literacy data for the experimental and control groups are presented in Table 9.

Table 9. Independent T-Test Test Results for Student Technology Literacy

Parameters	Sig. (2-tailed)
Experimental Class and Control Class Technology Literacy	0,000

Table 9 shows that the 2-tailed significance value for the Independent-Sample T-Test is 0.000, less than 0.05, indicating a significant difference in technology literacy between the experimental and control groups when using the developed green chemistry-based virtual laboratory media.

Therefore, it can be concluded that the developed green chemistry-based virtual laboratory media effectively enhances students' technology literacy. This is supported by the higher average technology literacy scores for the experimental group compared to the control group in all dimensions of technology literacy (information, communication, content creation, safety, and problem solving). Utilizing virtual laboratories based on green chemistry can significantly enhance students' digital literacy. According to research by Sigit et al. (2021), virtual laboratories based on green chemistry in chemistry education can improve students' digital literacy. In addition, the study states that virtual laboratories based on green chemistry provide a more engaging and enjoyable learning experience for students, allowing them to be more involved in the learning process and better understand chemistry concepts.

In addition, the use of virtual laboratories can also enhance students' ability to use technology. In virtual laboratory learning, students must manipulate software to simulate chemical experiments. Therefore, students will learn to use technology to achieve their learning objectives. Additionally, students will gain experience in collecting, organizing, and analyzing experimental data. These skills are crucial in the digital age, where information and communication technology have become integral to daily life (Nada, & Sari, 2020).

Moreover, virtual laboratories based on green chemistry also have other benefits, such as reducing the use of hazardous chemicals in experiments and minimizing the environmental impact of chemical waste. Virtual laboratories based on green chemistry can reduce the cost and time required to prepare traditional chemical experiments, providing a more environmentally friendly and economical alternative(Seery,2016).

Utilising virtual laboratories based on green chemistry can significantly enhance students' digital literacy. Virtual laboratories provide a more engaging and enjoyable learning experience for students, and help improve their ability to use information and communication technology. Additionally, virtual laboratories based on green chemistry have benefits in reducing the environmental impact of traditional chemical experiments. Therefore, virtual laboratories based on green chemistry can be an attractive alternative in chemistry education in the digital era.

Table 10. Average Score for Each Dimension of Technology Literacy

Dimension	Average Score		Maximal Score
	Experiment	Control	
Information	38.36	35.92	48
Communication	79.58	68.44	96
Content Creation	37.92	29.00	48
Safety	33.53	30.14	40
Problem Solving	32.58	27.47	40

Based on Table 10. The experiment group scored higher in the information dimension because virtual laboratories require students to search for and evaluate information, providing them with more opportunities to improve their information literacy skills. Additionally, virtual laboratories allow students to access a vast amount of information, enhancing their understanding of the subject matter (Van Dyke, 2019).

The experiment group also scored higher in the communication dimension because virtual laboratories often require students to communicate their findings and ideas through digital tools and media, providing them with opportunities to improve their communication skills. Moreover, collaborative learning in virtual laboratories enhances communication skills by providing opportunities to work together and share ideas (Cacciatore, & Sevian, 2006).

Regarding content creation, the experiment group scored higher because virtual laboratory-based green chemistry requires students to create digital content such as presentations and videos, providing them opportunities to develop their content creation skills.The experiment group also scored higher in safety because virtual laboratories integrate safety guidelines and practices, emphasizing the importance of safety and providing students with practical guidance on using digital tools and media safely (Gutierrez,2020). Furthermore, virtual laboratories allow students to experiment with different scenarios, enhancing their understanding of safety protocols and preparing them for real-world situations. Finally, using virtual laboratory-based green chemistry in learning can enhance students' technology literacy skills, particularly in information, communication, content creation, and safety (Tatli, & Ayas, 2013).

CONCLUSION

Data analysis was conducted using various techniques such as Sudijono's media feasibility interpretation scale for media validation, student questionnaires, and the System Usability Scale questionnaire. The participants were high school students, and the instruments used were questionnaires and tests to assess technological literacy. An Independent-Sample T-Test was conducted to determine the effectiveness of the developed virtual laboratory media in enhancing students' technology literacy. The results showed that green chemistry-based virtual laboratory media enhanced students' technology literacy. The study is significant in developing Green Chemistry-based virtual laboratory learning modules that enhance the effectiveness and efficiency of chemistry learning. Using virtual laboratories based on green chemistry can significantly enhance students' digital literacy..

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