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Assessing High School Students' Creative Thinking Skills on Green Chemistry Material Using STEM-Based Creative Content Electronic Portfolios

Rahman M. Fiqri[1*], Nahadi[1], Siswaningsih W.[1]

[1] Chemistry Education Major, University of Education, Bandung, Indonesia.

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Corresponding Author:
Rahman M. Fiqri
m.fiqri2002@upi.edu

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Abstract: This study aims to develop a valid and reliable STEM-based electronic assessment portfolio instrument to instill creative thinking skills in high school students on the topic of Green Chemistry. This study uses a Design Development Research (DDR) approach with the ADDIE model, which is specifically limited to the development phase. This study involved 16 grade 10 science students. The Assessment Portfolio was designed with three tasks: a summary of the Green Chemistry topic, a poster about the 12 principles of Green Chemistry, and an educational vlog about the principle of "Prevention". The findings indicate that the developed instrument has valid content validity, as assessed by five validators. This instrument was also proven reliable through an inter-rater reliability test conducted by four raters. Furthermore, Wilcoxon test analysis indicates that feedback provided during the electronic portfolio assessment process is effective in significantly improving students' creative thinking skills, with the revision process being the main driver of this improvement. In conclusion, the resulting instrument is effective and can serve as a valid alternative assessment tool.

Keywords: Assessment instrument; Creative thinking; Electronic portfolio; Green chemistry; STEM

Introduction

The development of science and technology in the 21st century requires science education to emphasize not only conceptual mastery but also the development of a generation capable of creative, innovative, and responsible thinking regarding environmental sustainability. Various global issues such as pollution, resource crises, and environmental degradation demand science-based solutions oriented toward sustainability. Therefore, science education plays a strategic role in instilling the value of ecological responsibility and the ability to design safe, effective, and sustainable solutions for human life.

Chemistry, as part of the Natural Sciences (IPA) group, is a combination of processes and products that are closely related to everyday life (Hemayanti et al., 2020), but at the high school level, it is often perceived as abstract and complexly interconnected (Kusumaningrum et al., 2018). One topic that has strong relevance to sustainability issues is green chemistry, an approach to designing chemical products and processes to reduce or eliminate the use and formation of hazardous substances (Puspaningsih et al., 2021). The principles of green chemistry explain various chemical phenomena in the surrounding environment (Maulidiningsih et al., 2023), so it has great potential to be developed through contextual and applied learning. To achieve this, a learning approach is needed that can integrate science with technology, engineering, and mathematics, namely through the STEM approach, which has been proven to encourage students to think critically, creatively, and innovatively in solving problems (Mulyani, 2019; Widya et al., 2019).

However, in practice, green chemistry learning still faces various obstacles. Students have difficulty understanding the concepts and principles of green chemistry because learning is still dominated by lecture

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methods and summary assignments, resulting in low student interest, activeness, and learning outcomes (Maulidiningsih et al., 2023; Suci et al., 2023). Students' scientific abilities are also relatively low, such as in identifying problems, drawing conclusions, and understanding scientific concepts (Rohmaya et al., 2022). Similar findings have been reported in various schools, such as SMAN 74 Jakarta (Sari, 2025) and SMA Negeri 7 Jambi City (Ningsih, 2024), where the majority of students did not reach the Minimum Competency (KKM) and stated the need for digital learning media. On the other hand, teachers also face limitations in time, knowledge, teaching materials, and varying perceptions of the urgency of green chemistry (Auliah et al., 2018; Braun et al., 2006; Eunice et al., 2020; Nersesian et al., 2019). This situation indicates that green chemistry learning is not yet fully supported by learning strategies and assessment systems relevant to the demands of the 21st century.

One potential solution to address these issues is through digital assignments based on electronic portfolios integrated with a STEM approach. Electronic portfolios allow teachers to archive, assess, and monitor students' comprehensive learning progress through digital artifacts such as videos, posters, and reflections (Duncan-Pitt et al., 2006; Zhang et al., 2022), while also encouraging metacognitive skills and creative thinking (Meyer et al., 2010; Sumarni et al., 2019; Susilawati et al., 2025). Although previous research has demonstrated the effectiveness of portfolio assessments (Bakri et al., 2022; Firmansyah et al., 2019; Miftakhul, 2022), there is limited research explicitly integrating creative content, electronic portfolios, and a STEM approach as a single assessment instrument for green chemistry.

Therefore, this study aims to design an electronic portfolio assessment instrument for STEM-based creative content on green chemistry to assess high school students' creative thinking skills. Developing this instrument is crucial for providing authentic, contextual, and relevant assessments to meet the needs of sustainability-oriented learning.

Literature Review

According to Puspaningsih et al. (2021), green chemistry is defined as an approach to designing chemical products and processes that aims to reduce or eliminate the use and formation of hazardous substances. Based on this definition, the essence of green chemistry is design efforts oriented towards human safety and environmental sustainability. The meaning of "reducing or eliminating" extends beyond replacing hazardous chemicals and encompasses a shift in thinking in designing chemical processes to be more environmentally friendly. Thus, green chemistry is viewed not only as a concept but also as a scientific value that instills an awareness of ecological responsibility in everyday life (Maulidiningsih et al., 2023).

In the context of education, chemistry, as part of the natural sciences, is often perceived as abstract and difficult to understand (Kusumaningrum et al., 2018). This makes it difficult for students to connect green chemistry concepts to real-world phenomena. However, through green chemistry, various chemical phenomena in everyday life can be explained more contextually (Maulidiningsih & Kusumaningrum, 2023). Therefore, green chemistry learning needs to be presented with an approach that not only emphasizes memorization of concepts but also encourages students to think and act as solution designers.

One relevant approach to this goal is the STEM approach. According to Mulyani (2019), STEM is the integration of science, technology, engineering, and mathematics in a problem-solving-oriented learning process. This integration connects scientific concepts with technological applications, engineering processes, and mathematical calculations in a unified whole. Widya et al. (2019) emphasize that the goal of STEM learning is to improve students' skills in these four areas to enable them to face the challenges of the 21st century. Thus, the STEM approach encourages students not only to understand the concepts of green chemistry but also to design applicable science-based solutions.

In STEM-based learning, assignments are an important tool for representing students' thinking processes. Bariah et al. (2018) define assignments as assessment techniques that require students to engage in specific activities outside of class. Referring to this definition, assignments serve not only as an evaluation tool but also as a means for students to express ideas, develop creativity, and demonstrate conceptual understanding. Kunandar (2013) and Sani (2014) emphasize that meaningfully designed assignments can reflect students' overall learning development.

With the advancement of technology, assignments can now be developed digitally. Duncan-Pitt set al. (2006) state that an electronic portfolio is a collection of digital artifacts that represent students' learning processes and outcomes. Zhang et al. (2022) adds that electronic portfolios enable teachers to continuously monitor students' learning progress. The purpose of using an electronic portfolio is not only to store assignments but also as a means of reflection, documentation of thought processes, and providing ongoing feedback (Meyer et al., 2010).

One skill that can be developed through an e-portfolio is creative thinking. According to Torrance (2012), creative thinking encompasses fluency, flexibility, originality, and elaboration. Lestari et al. (2018) explains that creative thinking involves the processes of synthesis, planning, and idea development.

Apriliana et al. (2018) adds that the ability to express original ideas reflects the development of student creativity. Therefore, creative content-based assignments through e-portfolios are an appropriate means to foster students' creative thinking skills in green chemistry learning.

Method

This research was conducted in the even semester of the 2024/2025 academic year. The research location was a public high school in Bandung City, West Java, Indonesia.

This study uses a qualitative approach with a Design and Development Research (DDR) research design according to Richey et al. (2014) which focuses on product development and evaluation. The study adopts the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model according to Branch (2009) which is limited to the Development stage. The population in this study were all 10th grade students at a high school in Bandung City who had studied green chemistry. The research sample consisted of 16 10th grade science students selected using a purposive sampling technique, namely a sampling technique with certain considerations to achieve specific research objectives. The variables in this study include an electronic portfolio instrument as the independent variable and students' creative thinking skills as the dependent variable. Data collection methods were carried out through field studies with questionnaires, literature studies, expert validation, inter-rater reliability tests, and limited trials using assessment for learning. The tools and materials used in this study included a computer/smartphone, internet connection, the Google Form platform, Instagram social media, the WhatsApp application, and green chemistry teaching materials based on the Merdeka Curriculum.The research procedure includes the following stages:

Analysis Phase: Aims to identify problems in chemistry learning and the need for assessment instruments. This phase involves field studies through the distribution of questionnaires to teachers and students, as well as a literature review of journals and books. Material analysis was also conducted on the Learning Outcomes (CP) and Learning Objectives (TP) of the Independent Curriculum for green chemistry.

Design Stage: This stage focuses on designing the main product, namely an electronic portfolio assessment instrument consisting of tasks and an assessment rubric. Tasks are designed based on creative thinking skill indicators and are tailored to the green chemistry material. The platforms used for assignment submission are Google Forms and Instagram (Snapgram and Reels features).

Development Stage: In this stage, the instrument was refined and tested for feasibility. This process included validation by experts (five validators, consisting of chemistry lecturers and teachers) and reliability testing using inter-rater reliability techniques with four assessors. After being declared valid and reliable, a limited trial was conducted to assess the instrument's effectiveness. This trial adopted an assessment for learning approach, where feedback is provided to students to encourage improvement and reflection.

Content validity data was analyzed using the Content Validity Ratio (CVR) based on the assessment results of five validators. Reliability data was analyzed using inter-rater reliability techniques with the Intraclass Correlation Coefficient (ICC) test. To assess the effectiveness of the instrument in improving creative thinking skills, data from limited trials were analyzed using the Wilcoxon test to compare the significance of student scores before and after the revision.

Result and Discussion

Needs Analysis and Instrument Design

The design of this instrument draws on a STEM framework that connects green chemistry concepts with social media technology. This aligns with findings that creative project-based learning can significantly enhance collaboration and creativity.

The results of the field study indicate that digital learning media is still rarely used by teachers, with 43.7% of students stating that teachers only "sometimes" use it. There is a perception gap where teachers feel they have frequently used digital media, but students feel otherwise. This result is supported by the statement that the need shows that the use of digital media in chemistry learning in high school is still limited. These findings form the basis for the development of a STEM-based electronic portfolio instrument that integrates social media (Instagram and WhatsApp) and creative content (Vlogs and Posters) to be more relevant to students' learning styles. The design of this instrument refers to the STEM framework that connects the concept of green chemistry with social media technology. This shows that creative project-based learning can significantly increase collaboration and creativity. Similarly, Mulyani (2019) stated that the STEM approach can stimulate students to think creatively in solving problems through applicable contexts.

Instrument Feasibility: Validity and Reliability

The instruments developed through the Design and Develop stages have been tested for their feasibility by experts.

Content Validity: The test results by five validators showed a CVR value of 1.00, which means the instrument has very good content validity and is able to measure the elements that should be measured (Rahman et al., 2025).

Reliability: The results of the inter-rater reliability test by four assessors showed an ICC value in the range of 0.526 to 0.884, thus declaring the instrument reliable for use. This finding demonstrates that the designed instrument meets technical standards as an objective assessment tool (Nahadi et al., 2022, 2024). This consistency is crucial to ensure fairness in digital portfolio assessment (Adom et al., 2020).

Effectiveness of Instruments on Creative Thinking Skills

The results of a limited trial on 16 students showed a significant increase in creative thinking skills. Statistical Test Results: the Wilcoxon test analysis shows that the calculated W value (0) < W table (24), which indicates a very significant increase in scores for each task.

The Role of Feedback: this improvement was driven by the implementation of assessment for learning, where constructive feedback encourages students to reflect on and revise their work. This revision process is the primary driver of more mature creative ideas.

Comparison with Previous Research: These findings reinforce Fauzi's (2012) research on the effectiveness of portfolios on learning outcomes, but also provide added value by integrating STEM elements and creative social media content, making assessments more engaging and less rigid for students. This is also supported by Zhang's (2022) theory that e-portfolios are effective for digitally monitoring student progress.

Research Limitations and Follow-up

Although this instrument has proven effective, there are several limitations that need to be considered in its application: Communication Limitations: The use of communication platforms like WhatsApp can sometimes tend to be one-way, making it less than ideal for in-depth interactive discussions. Task Integrity Risk: There is a potential for students to "copy-paste" from internet sources when making posters without understanding the essence of the material. Follow-up: as a follow-up, educators are advised to closely monitor the content creation process and provide more specific instructions to ensure originality. This instrument can also be adapted to other chemistry topics requiring creative solutions and STEM-based problem-solving with careful adjustments to the rubric.

Conclusion

Based on the research findings, the STEM-based creative content electronic portfolio assessment instrument designed to assess high school students' creative thinking skills showed the following results: Design Process: This instrument was designed through a series of systematic stages, including field studies, literature reviews, analysis of materials and tasks, preparation of instruments and rubrics, and validation and reliability. Validity: This instrument was declared valid based on the content validity test by five validators with a CVR value of 1.00 after improvements were made according to the validators' suggestions. Reliability: The instrument was proven reliable based on the results of an inter-rater reliability test by four assessors. The Intraclass Correlation Coefficient (ICC) values for all assessment aspects ranged from 0.526 to 0.884. Effectiveness: This instrument is effective in assessing students' creative thinking skills. The Wilcoxon test shows a significant increase in scores on each task, where the calculated W value (0) is smaller than the W table (24). This proves that this instrument can be used as an effective alternative assessment tool.

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