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Digital Green Education through Green Chemistry Supports the Green Economy by Improving Science Skills and Entrepreneurial Character

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Abstract: Green education is integrated into chemistry learning to support the green economy, as it offers numerous applications in everyday life, including waste management and sustainable reforestation programs. Based on the Merdeka Curriculum, one aspect of chemistry learning in grade 10 is green chemistry, which explores global issues and problem-solving. Science skills are closely linked to green education in chemistry learning, as students gain scientific knowledge and attitudes from the theories they learn. All these efforts are directed toward achieving the Sustainable Development Goals (SDGs). The research used a quasi-experimental Design. The study had two groups, **the** experimental and the control groups**.** The sample was SMA Negeri 1 Gunung Meria, Deli Serdang Regency students. The research instruments used were essay tests and observations. The results of the posttest t-test analysis between the control and the experimental group at a significance level of 0.05, then 0.00 <0.05, then Ho is rejected and Ha is accepted. The results of the students' entrepreneurial character scores can be seen in Figure 1, where the experimental class has an average score of 77.70 and the control class 42.85. The results of the study can be concluded that education has a significant influence on students' science process skills. Students' entrepreneurial character shows a **substantial** difference, in that in the experimental class, there is good development.

Keywords: Entrepreneurship; Green_Education; Green_Economy; Chemistry; Science

Introduction

The Sustainable Development Goals (SDGs), a sustainable development goal to be achieved by 2030, are designed to address all existing societal issues. Quality education plays a crucial role in shaping a country's economic future (Azzahra et al., 2024). Chemistry is a subject that needs to be taught in a way that involves students' abilities and thinking skills, so that students can understand well and consider chemistry as a process and its results. (Rahmawati & Haryani, 2014). Chemistry can essentially be seen as a process and a product, however, in practice, chemistry learning is only theoretical, resulting in a lack of development of science process skills (Isnaini & Utami, 2020).

One of the global issues that continues to be discussed is environmental pollution. From an anthropocentric perspective, where the environment is intended to meet all human needs, the damage that occurs is caused by human behavior that is not in line with environmental sustainability (Nizaar & Si, 2022)(Kurniawan et al., 2024). Furthermore, student learning outcomes can be more focused on improving

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positive attitudes through entrepreneurial traits, such as creating products with economic value and in line with environmental developments.

Chemistry is a crucial field of study in the industrial world. Experts are developing alternatives to prevent further damage from pollution, thus employing the concept of green chemistry (KumparanTECH, 2024). Material Green Chemistry is one of the theme aspects in class X of high school which aims to utilize products through chemical processes by minimizing or even eliminating the dangers that occur due to chemical processes and substances. The knowledge they gain from school will better prepare the younger generation to face global challenges. They will not only understand the problems but also be encouraged to be part of the solution (Raharjo et al., 2023). Green Education builds conservative character in children in maintaining environmental sustainability, but it must be combined with progressive character through entrepreneurship that produces a generation that is able to maintain environmental conditions while being skilled in managing resources for sustainable living (Luko & Kollarics, 2013).

The low level of science process skills possessed by students is something that needs to be paid attention to, so it is necessary to implement learning that can develop reasoning skills in planning and solving problems faced by providing direct experience (Fitriani, 2017). Carrying out a series of scientific processes and connecting them between science and technology and the positive and negative impacts of this technology on society and the environment (Wismaningati et al., 2019). Science process skills play a crucial role in training students to develop scientific ideas independently. Science process skills can strengthen learning, support long-term learning, and help students learn research methods and techniques (Karacop & Diken, 2017). Students' science process abilities can be improved by applying chemistry learning through entrepreneurial skills, so that it can enrich human resources and encourage students' potential through skills education (Kurniawati et al., 2021).

This research is very important to be carried out in supporting the ultimate goal of sustainable development, namely improving the quality of education and improving community welfare through digital-based green education on the green chemistry aspect in supporting the green economy to improve science skills and entrepreneurial character. Green education can support a green economy because it involves students engaging in a series of scientific processes and developing entrepreneurial skills through effective and efficient business management strategies.

Science and Green Education (GE) learning is one of the flagship subjects that is the identity of the Al Muslim Foundation. Science learning focuses on everyday experiences, with an emphasis on practical learning, both in the classroom and in the laboratory, with the environment as a learning resource. Science learning is often combined with character education about the environment. Character education is a teaching system aimed at internalizing specific character values in students, which includes elements of knowledge, awareness, or intention, and behavior to apply those values. Character education about the environment at the Al Muslim Foundation is known as Green Education (GE). GE learning is closely linked to an understanding of the environment. The character formed in GE learning is a sense of.Efforts to integrate green economy into education will also provide dual benefits, namely creating awareness of the importance of environmentally friendly practices and preparing individuals to play an active role in the development of the nation (Sitompul et al., 2024). Sustainability leading to the achievement of SDGs (Sitompul et al., 2024). Furthermore, implementing a green economy in education can also help strengthen the connection between education and the implementation of the SDGs. By enhancing students' understanding of the relationship between the economy, the environment, and society, education can prepare future generations to be effective agents of change in achieving the SDG targets (Alissa et al., 2023).

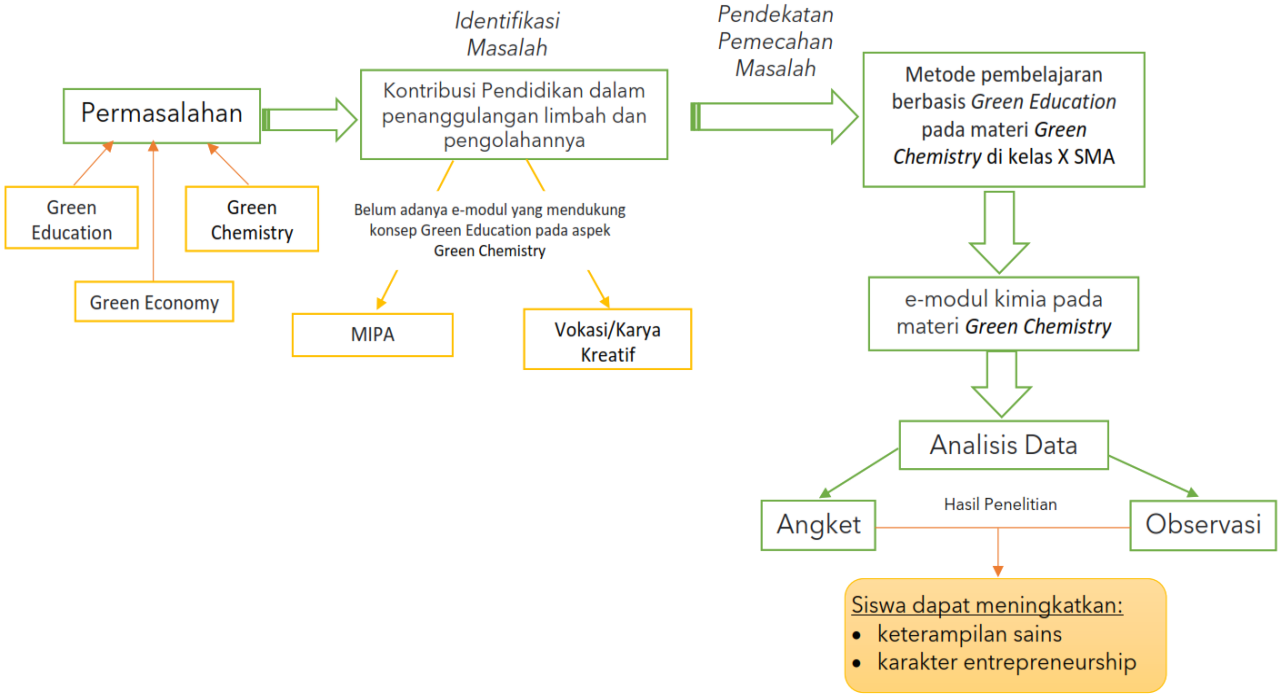
Several researchers have implemented green Education. The integration of Green Education in the learning process at school can form a character that cares about environmental sustainability through science skills, while at the same time increasing ecological resources to be processed into products of economic value related to students' entrepreneurial character (Cahya et al., 2024). Green education itself can foster a green entrepreneurial spirit in students (Hendratni et al., 2024).Based on the findings of the study analyzing students' science process skills through project-based learning, it was concluded that 100% of students had good science process skills. Learning models need to accommodate the diverse potential of students without encouraging comparisons (Sitompul et al., 2024). Students need to get more recognition and make such actions an integral part of everyone's reflective efforts to improve the quality of learning (Simangunsong et al., 2024). Green education Previously, it was limited to looking at the character of environmental concern and here it will be developed from the digital learning aspect which looks at science process skills and entrepreneurial character in green chemistry learning in class X of high school (Khairi et al., 2022). This is the best strategy forsocial human welfare and reducing environmental pollution in accordance with the objectives of the Sustainable Development Goals (SDGs).

Methods

The method used in this study is a Quasi-Experimental Design, which aims to predict conditions that can be obtained through real experiments, even though there is no control or manipulation of all relevant variables. In this study, there is a control group, but its role cannot completely control the experimental group. The control group only serves as a comparison to the results obtained from the experimental group (Sudaryono, 2021)(Sudaryono, 2021).

The research population was all high school students who had implemented the independent curriculum in chemistry subjects, green chemistry material in grade X. The sample used was 80 students of SMA Negeri 1 Gunung Meria, Deli Serdang Regency, consisting of 2 sample classes. The sampling technique used in this study was non-probability sampling. Non-probability sampling is a sampling method that provides equal opportunity and chance for all members of the population to be selected as a sample. This sampling technique is divided into several types, but the technique used in this study is purposive sampling. Purposive sampling is a method of taking and determining samples based on certain considerations (Sugiyono, 2022).

Data collection in this study was conducted through a science process skills test, which served as the research instrument, conducted before and after the implementation of digital-based green education in green chemistry in the experimental class and the conventional learning model in the control class. The test used was a descriptive test with 10 essay questions. Data collection in this study to observe entrepreneurial traits used an observation instrument to assess changes in students' attitudes towards entrepreneurial interest.



Fugure 1. Research flow

The data analysis technique used a one-tailed t-test, a right-tailed test using *SPSS*. Data analysis in this study, to examine entrepreneurial character, used observation instruments analyzed using the t-test formula. The percentage of Science Process Skills was grouped into five categories: very high, high, medium, low, and very low.

Result and Discussion

Based on data from the pre-test and post-test of both groups, namely the control group and the experimental group. The pre-test was conducted before teaching and learning activities on the topic of Green Chemistry, while the post-test was conducted after learning with the Digital-Based Green Education model on the Green Chemistry material (experimental class) and conventional learning on the topic of Green Chemistry (control class). Students' science process abilities (SPE) were evaluated using an essay test instrument consisting of 10 questions. The measuring instrument had previously met test requirements, including validity, reliability, difficulty level, and discrimination power. Thus, the test instrument is

suitable for use in assessing students' chemistry science process abilities. Students' entrepreneurial character was assessed based on observations during learning activities and student assignments using an observation sheet instrument.

Pretest Results of Science Process Skills of Control Group and Experimental Group

The results of the posttest data calculations for the control group and the experimental group after being given different treatments can be seen in Table 1.

Table 1. Results of the Group Science Process Skills Posttest Control and Experiment

Data	*Posttest*	
	Control	Experiment
Lowest Value	49	61
The highest score	82	97
Average	66.48	83.59
Median	67	85
Mode	55	73
Standard Deviation	10.01	10.30
Number of Students	37	37

Based on Table 1, it can be seen that the average posttest scores in the control and experimental groups were 67.31 and 83. The standard deviations of the posttest results in the control and experimental groups were 10.34 and 10.18.

Table 2 indicates that the average post-test of science process skills in the control group was in the medium category, namely 68.55, while the experimental group was in the high category with a score of 84.89. The control group had the highest science process skills, namely data interpretation 96.55, while the experimental group was planning experiments 96.55. The lowest science process skill in the control group was the use of tools and materials with a score of 41.37, while the lowest science process skill in the experimental group was observation with a score of 71.83.

Table 2. Percentage (%) of Posttest Achievement of KPS Aspects Control Group and Experimental Group

PPP Aspects				*Posttest*
	Control	Information	Experiment	Information
Observation	58.62	Currently	71.83	Currently
Hypothesize	67.81	Currently	87.35	Tall
Planning an Experiment	76.72	Tall	96.55	Very high
Using Tools and Materials	41.37	Low	83.33	Tall
Data Interpretation	96.55	Very high	95.40	Very high
Applying the Concept	73.27	Currently	86.20	Currently
Communicate	65.51	Tall	73.56	Tall
Average	68.55	Currently	84.89	Tall

Hypothesis Testing of Science Process Skills Pretest and Posttest

The test for equality of the two average pretest and posttest results was conducted to determine whether there was a significant difference between the pretest and posttest scores of the control and experimental groups. The results of the test for equality of the averages of the experimental and control groups are presented in Table 3.

Table 3. Average Equality Test (t-Test) of Pretest and Posttest Results Control and Experimental Groups

Data	Pretest		Posttest	
	Control	Experiment	Control	Experiment
Mean	16.55	18.31	66.48	83.59
Sig. (2-tail)		1.48		0.00
Sigmoid		<0.05		<0.05
Conclusion	There is no significant difference		There is a significant difference	

According to the analysis shown in Table 3, the results of the pre-test t-test between the control group and the experimental group are at a significance level of <0.05. Based on the criteria mentioned from the research data, the criteria for this study are Sing. 2-tailed 1.48>0.05. Therefore, Ho is accepted and Ha is rejected, so it can be concluded that there is no difference in the pre-test results between the control group and the experimental group. The results of the post-test t-test analysis between the experimental group and the control group show a Sig value of 0.00, so that 0.00 <0.05 is obtained. Based on these results, the criteria for this study indicate that Ho is rejected and Ha is accepted. Thus, it can be concluded that there is a significant difference in the post-test results between the control group and the experimental group. Therefore, there is an impact of the digital-based green education model through green chemistry on improving students' science abilities in the topic of green chemistry.

Hypothesis Testing of Experimental and Control Classes on Entrepreneurship Character

The analysis was used to determine students' entrepreneurial character through entrepreneurial character indicators, namely curiosity, task and results orientation, creativity, cooperation, risk-taking, communication, and self-confidence. Students' entrepreneurial character was measured using an observation sheet. The results of the entrepreneurial character assessment calculation can be concluded as follows: Digital-Based Green Education through Green Chemistry in Supporting the Green Economy can improve students' Entrepreneurial Character. The observation results obtained can be seen in table 4

Table 4. Observation Results Student Entrepreneurship Characteristics

Class	Average Value	Information
Control	42.85	Not yet visible
Experiment	77.70	Starting to grow

The results of students' entrepreneurial character scores can be seen in Figure 1, where the experimental class had an average score of 77.70 and the control class 42.85. Students in the experimental class began to show a growing interest in entrepreneurship, while in the control class this was not yet apparent.

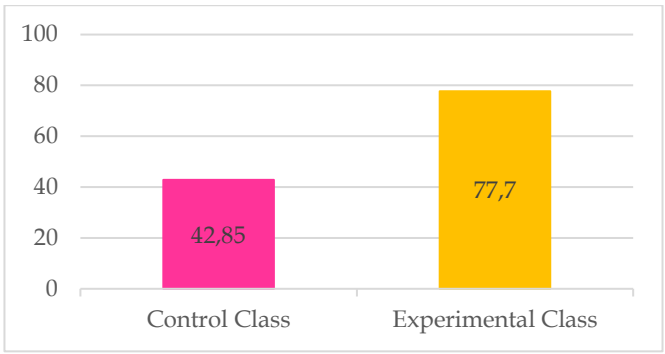


Figure 2. Graph Observation Results Student Entrepreneurship Characteristics

This study aims to improve science process skills on green chemistry material for grade X high school students and develop their entrepreneurial character. Based on the examination of the research data analysis requirements conducted at SMA Negeri 1 Gunung Meriah, Deli Serdang Regency, it was found that the pretest and posttest data of science process skills were normally distributed and homogeneous, so that hypothesis testing could be carried out using the t-test. Based on hypothesis testing of the pretest data, no significant differences were found in science process skills between the control group and the experimental group, with Sig 1.48>0.05, which indicates that the control group and the experimental group have similar initial science process skills. After applying the Digital-Based Green Education learning model through Green Chemistry to the experimental group and the conventional method to the control group, the average score of the experimental group was higher than that of the control group. The average posttest for the experimental group was 83.59, while the control group got an average of 66.48. To see a comparison of the average posttest results between the experimental group and the control class, see Figure 3.

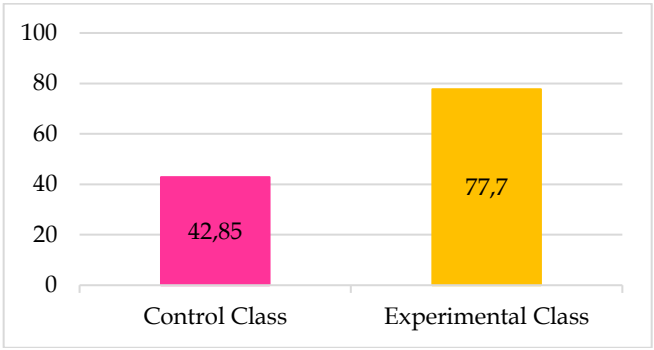


Figure 3. Comparison of the Posttest Average of the Control Group and the Experimental Group

Figure 2. Overall, it shows that students in the experimental class implementing the Digital-Based Green Education learning model achieved better mastery of science process skills than those in the control class using conventional methods. Conny also stated that by honing information processing skills, children will be able to independently discover and develop facts and concepts, as well as develop the necessary attitudes and values. Hypothesis testing of the posttest data from the experimental and control groups using a t-test revealed a significant difference between them. This was demonstrated by a Sig. 0.00. This indicates a significant difference in the implementation of the learning model.

This study measured seven aspects of science process skills: observation, formulating hypotheses, designing experiments, utilizing equipment and materials, analyzing data, applying concepts, and communicating. The figure below shows the percentage increase in science process skills between the pretest and posttest results in the experimental group.

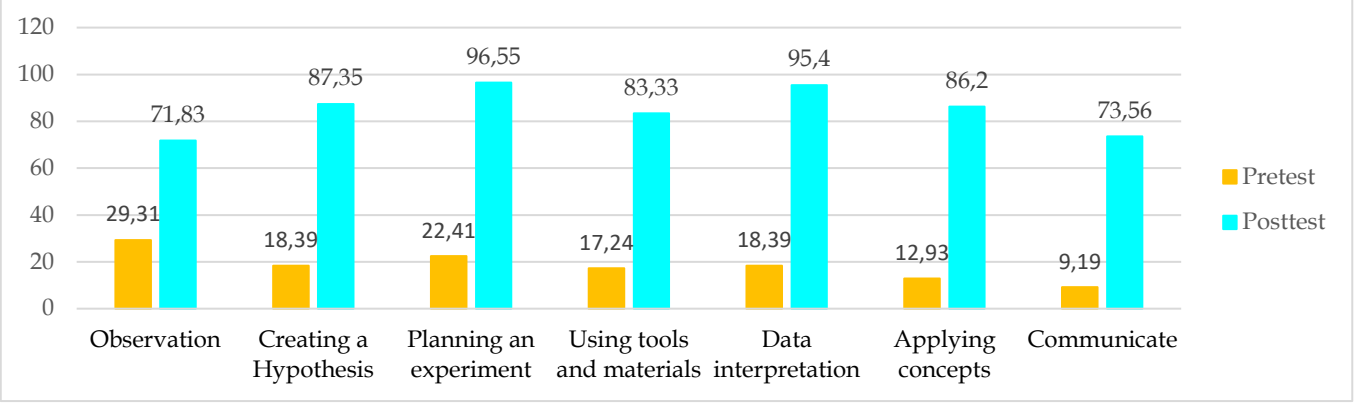


Figure 4. Percentage of pretest and posttest of Science Process Skills Experimental Group

Digital-Based Green Education focuses on students' scientific process skills in sustainable chemistry. The application of the Digital-Based Green Education learning model can explore environmental issues directly related to the green chemistry movement. By applying the 12 principles of green chemistry, it is hoped that pressing environmental issues such as pollution, energy shortages, waste management, and workplace safety and security can be addressed. The goal of green chemistry is to emphasize chemicals and products that are environmentally friendly and safe for health. Students' problem-solving, critical thinking, and scientific research skills can be realized and enhanced through education focused on green chemistry by contributing to the use of products and chemical processes that are environmentally friendly and efficient in resource use.

Several studies have shown that teaching Green Chemistry at the higher education level has a positive impact on students' environmental awareness. According to Alberto et al. (2017), integrating Green Chemistry principles into college curricula in the United States can increase students' knowledge of sustainable chemical solutions that can reduce environmental impact. Furthermore, research conducted by Díaz et al (2020), in Europe revealed that the application of the Green Chemistry concept in educational programs can introduce more environmentally friendly industrial practices, while supporting the achievement of Green Economy goals.

Research by Freeman et al (2014), revealed that the use of digital technology in science education, including Green Chemistry, not only improves students' understanding but also introduces them to virtual experiments that replace conventional laboratory practices. This technology helps students understand the principles of Green Chemistry through more cost-effective and environmentally friendly simulations. Furthermore, a study by (Zhao & Zhu, 2017), shows that digital platforms enable more flexible Green Chemistry teaching and can be tailored to individual learning needs.

Based on the results of observations regarding entrepreneurial character During the learning process, the experimental class actively engaged students in designing products during the learning process. Observations conducted during two meetings revealed a highly dynamic entrepreneurial character during the learning process. This fact demonstrates the importance of developing entrepreneurial character to address unemployment. Integration into the subject is intended as a solution that creates an atmosphere through entrepreneurship education, and human resource competitiveness must be developed quickly and systematically.

Conclusion

The conclusion of the study shows that the use of a directed inquiry learning model has a significant impact on students' science process skills, with the results of the t-test of the posttest data showing that Sig 2-tailed 0.00 <0.05. Thus, there is an influence of the digital-based environmentally friendly education model through green chemistry on improving students' science skills in green chemistry material. The posttest results show that the average science process skills in the experimental group are in the high category, while the control group is in the medium category. The highest science process skills in the experimental class are the skills of designing experiments, while the lowest are the skills of making hypotheses.

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Author Contributions
Conceptualization, methodology, investigation, resources, data curation, visualization, H.S.S and D.P; formal analysis, M.I; writing and editing of the original draft, H.S.S; review, I.M. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
This research was conducted on the mandate of the institution to improve the competence and capacity of lecturers. It is expected that the findings of this study can provide a significant positive impact on the development of human resources, especially in the academic environment, as well as support the creation of innovation and progress in the world of education

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