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EFFECTIVENESS OF THE DETECTIVE GAME OF CHEMISTRY MEDIA ON STUDENTS LEARNING OUTCOMES IN GREEN CHEMISTRY MATERIAL

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Abstract

This study was motivated by the topic of green chemistry, which requires an understanding of reducing or eliminating the use of hazardous chemicals for humans and the environment; therefore, innovative and engaging learning media are needed. This study aimed to determine the effectiveness of Detective Game of Chemistry in improving students' learning outcomes on green chemistry topics. This study used the 4D model adapted from Thiagarajan, which consists of the Define, Design, Develop, and Disseminate stages. This study used a one-group pretest-posttest design, where the pretest was used to measure students' initial abilities and the posttest was used to measure learning outcomes after the treatment. Data analysis was conducted using the Wilcoxon Signed Rank Test, classical completeness (mastery learning), and N-gain. The results showed a significance value of 0,001, indicating that there was an improvement in learning outcomes, as posttest scores were higher than pretest scores. The classical completeness result was 96%, categorized as very good and exceeding the success criterion of ≥75%, indicating that the learning process was effective. The N-gain analysis showed that 4% of students were in the low category, 50% in the medium category, and 46% in the high category, with an average N-gain of 0,73, which is classified as high. Based on these results, Detective Game of Chemistry is considered effective in improving students' learning outcomes in green chemistry using Android-based learning media.
Keywords: detective game of chemistry, learning media, effectiveness, learning outcomes, green chemistry

INTRODUCTION

In 1998, Paul Anastas, known as the "Father of Green Chemistry," together with John Warner, introduced the term green chemistry. Under the Environmental Protection Agency (EPA) of the United States government, they developed 12 principles of green chemistry aimed at providing guidance for the chemical industry so that chemical processes do not pollute the environment [1].

Green chemistry is one of the chemistry topics taught in grade X. Green chemistry is concerned with how to design chemical products and processes in order to reduce or eliminate the use of chemicals that are hazardous to humans, animals, and the environment in which we live. These hazards may include physical explosions, flammability, toxicological effects such as mutagenicity and carcinogenicity, as well as global climate change, ozone layer depletion, and other forms of environmental pollution and chemical exposure. The effects of hazardous substances on the environment, water, air, food, agriculture, climate change, and many other aspects of life make us more aware of the importance of focusing on and applying greener concepts. Therefore, every chemistry teacher is expected to be able to present chemistry content in a more engaging and innovative way.

The rapid development of technology today requires educators to continuously adapt to creative and modern learning trends. This aims to ensure that the learning process remains relevant to students' characteristics and becomes more

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effective. Generation Z generally prefers activities that are creative, practical, and enjoyable in various aspects of life, including learning [2].

Susanto (2016) in [3] explains that learning outcomes refer to changes that occur in students, including cognitive, affective, and psychomotor aspects, as a result of learning activities, because learning is a process by which a person attempts to acquire a relatively permanent form of behavior. The achievement of learning outcomes in accordance with the desired objectives can be determined through evaluation.

Based on the description above, the research problem of this study is: how effective is the Detective Game of Chemistry in improving learning outcomes in green chemistry material, viewed from students' learning outcomes?

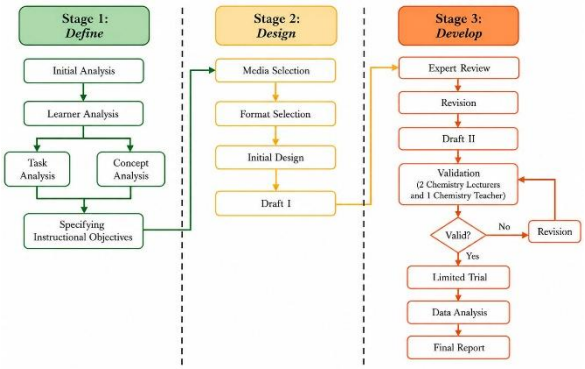
This study aims to determine the effectiveness of the Detective Game of Chemistry in improving learning outcomes in green chemistry material, viewed from students' learning outcomes.

This study is expected to provide benefits: (a) for schools: to provide learning media that is in line with the development of information and communication technology in education; (b) for teachers: to serve as an alternative teaching aid in selecting learning methods, especially on green chemistry topics, making them more engaging and easier to understand; (c) for students: (1) students are directly involved in active learning; (2) it creates a more enjoyable learning atmosphere; (3) students have a learning medium in the form of a game that can be accessed anytime and anywhere.

The scope of this study is limited to ensure that the problem remains focused and does not deviate from the original research problem, as follows: (1) the taxonomy domains studied are limited to cognitive and affective domains. The cognitive domain relates to knowledge, understanding, and learning ability. The affective domain relates to feelings, emotions, and attitudes. (2) The green chemistry components studied are limited to only three principles of green chemistry.

METHOD

This study used the 4D model adapted from Thiagarajan, which consists of the Define, Design, Develop, and Disseminate stages. However, in this study, the development process was limited only to the Develop stage because the research focused on testing the effectiveness of the Detective Game of Chemistry learning media. The explanation of each development stage was adapted from Siregar et al. (2022, pp. 56–68). The research design can be described in detail as follows:



[4]

Figure 1. Flowchart of the Research Design of Detective Game of Chemistry

1. Define

The purpose of this stage is to determine and define the requirements needed in instruction. There are five phases carried out in this stage:

a. Front-end Analysis

In this stage, an analysis is conducted on the basic problems faced by teachers and to determine the level of teacher performance. In conducting this analysis, several aspects need to be considered as alternatives for developing learning tools, including learning theories, future challenges, and future demands.

b. Learner Analysis

At this stage, the characteristics of the students who will be involved are identified. The characteristics referred to include students'

competencies and background experiences, general behavior toward the learning topic, as well as the selection of media, format, and language.

c. Task Analysis

At this stage, the activities carried out involve identifying the main skills required and breaking them down into more specific skills that are necessary and sufficient.

d. Concept Analysis

At this stage, the activities carried out involve identifying the main concepts that must be taught, organizing these concepts into a hierarchy, and detailing the nature or characteristics of each concept.

e. Specifying Intructional Objectives

At this stage, the activities carried out involve converting the results of task analysis and concept analysis into objectives in the form of expected behaviors.

2. Design

The purpose of this stage is to design the initial draft of the learning material.

a. Media Selection

The selection of appropriate media to present the learning content.

b. Format Selection

This phase is closely related to the previous media selection stage. The term learning format itself refers to the combination of media, teaching strategies, and usage techniques.

c. Initial Design

This phase is closely related to the previous media selection stage. The term learning format itself refers to the combination of media, teaching strategies, and usage techniques.

3. Develop

a. Expert Appraisal

It is a technique used to obtain suggestions for improving the material. Several experts are asked to evaluate the material from the perspectives of learning and presentation techniques.

b. Validation

In this step, the material is subjected to professional review in order to obtain objective opinions regarding its adequacy and relevance.

Table 1. Likert Scale

Assessment	Score
Very Poor	1
Poor	2
Fair	3
Good	4
Very Good	5

The data from the assessment were analyzed for each indicator using the mode to determine the score that most frequently appeared from the validators' ratings. The data were considered valid if the score was ≥ 4 [5].

c. Limited Trial

The purpose of the trial is to collect data in order to make the instructional material more effective.

d. Data Analysis

This study used a one-group pretest-posttest design. The One Group Pretest–Posttest Design is an experimental design in which there is no random assignment and no control group, but a single group is given a pretest, treatment, and posttest [6]. The pretest is used to determine students' learning outcomes before being given treatment, while the posttest is used to determine students' learning outcomes after being given treatment. The subjects of this development research on the Detective Game of Chemistry are 26 students of grade X at SMAN 4 Bojonegoro. From the results of the pretest and posttest, it can be determined whether students' learning outcomes have increased or even decreased.

The analysis of students' learning outcomes data is conducted to determine students' achievement before (pretest) and after (posttest) using the Detective Game of Chemistry. The pretest and posttest questions are used to measure students' cognitive abilities by observing the improvement in learning outcomes, which later serves as a benchmark for the effectiveness of the developed Detective Game of Chemistry.

Data analysis was conducted using the Wilcoxon Signed Ranks Test to determine the differences in students' learning outcomes before and after using the Detective Game of Chemistry. Furthermore, the pretest and posttest results were compared with the Learning Objective Mastery Criteria (KKTP), after which the class's classical mastery was calculated.

1. Wilcoxon Signed Ranks Test

The Wilcoxon Signed-Rank Test is a nonparametric statistical method that differs from parametric statistics. This test is usually used when the number of research participants is small. In some situations, researchers choose the Wilcoxon test not only for specific purposes, but also because nonparametric tests can serve as a solution when a study has certain limitations.

The Wilcoxon Signed-Rank Test is an alternative test for comparing the means of two related samples. This test is used when the Paired Sample t-test does not meet the assumptions (i.e., the data are not normally distributed). The Wilcoxon Signed-Rank Test was conducted using IBM SPSS Statistics 25. In this test, a right-tailed (one-sided) test is applied, where the null hypothesis (H_0) states "less than or equal to," while the alternative hypothesis (H_a) states "greater than." The hypotheses proposed are as follows:

a. H_0: μ posttest ≤ μ pretest, meaning the posttest scores are less than or equal to the pretest scores.
b. H_a: μ posttest > μ pretest, meaning the posttest scores are greater than the pretest scores.

The hypothesis decision is based on the significance value as follows:

a. If Sig < 0,05, then H_0 is rejected and H_a is accepted.
b. If Sig > 0,05, then H_0 is accepted and H_a is rejected.

Thus, it can be concluded that there is an improvement if the significance value is < 0,05 according to Wilcoxon (1945) as cited in [7].

2. Individual Mastery

The pretest and posttest results were also analyzed to determine students' individual mastery using the following formula.

$$Score = \frac{\sum Obtained\ score}{Maximum\ total\ score} \times 100$$

Individual mastery is determined based on the Minimum Learning Achievement Criteria (KKTP) used in the school, which is ≥ 75.

3. Classical Mastery

Classical mastery is calculated based on the posttest results, because the posttest is used to determine students' learning achievement after the learning process or the use of learning media. Classical mastery is used to determine the level of instructional success based on the percentage of students who meet a certain criterion. The following is the table of classical mastery intervals.

Table 1. Classical Mastery Interval

Percentage	Category
81%–100%	Very Good
61%–80%	Good
41%–60%	Fair
21%–40%	Poor
0%–20%	Very Poor

A learning process is considered classically complete when most students in a class have achieved scores that meet the Minimum Completeness Criteria (KKM). In educational research, classical mastery is generally achieved when ≥75% of students obtain passing scores [8]. This concept is used to determine the overall level of learning success in a class. Classical mastery is calculated using the following formula.

$$Score = \frac{\sum Students\ who\ achieve\ mastery}{Number\ of\ students} \times 100\%$$

4. N-Gain

Then, the pretest and posttest scores are also used to determine students' gain categories. To calculate the gain (improvement), the following gain formula is used:

$$gain(g) = \frac{(\text{posttest score} - \text{pretest score})}{(\text{ideal score} - \text{pretest score})}$$

The gain categories are presented in Table 2.

Table 2. Gain Categories

Average score (%)	Category
g < 0,3	Low
0,7 > g ≥ 0,3	Medium
g ≥ 0,7	High

Based on these gain categories, the Detective Game of Chemistry as a learning medium can be considered feasible in terms of effectiveness if students' learning outcomes show an improvement in the "Medium" and "High" categories [9].

RESULTS AND DISCUSSION

This study applied the 4D development model proposed by Thiagarajan, which consists of four stages: (1) Define, (2) Design, (3) Develop, and (4) Disseminate. However, in this study, the development process was limited to the fourth stage, namely Disseminate. The stages of this research can be explained in detail as follows.

1. Define

This stage aims to determine and establish the learning process that will be used in the research. In addition, this stage is also intended to analyze and collect information in the initial stage of the Detective Game of Chemistry. There are five steps in this stage, which are described in detail as follows:

a. Front-end Analysis

In this analysis, the activities carried out include an initial diagnosis regarding factual conditions, expectations, and alternative solutions to basic problems in order to facilitate the selection of learning media or learning tools to be developed.

b. Learner Analysis

Based on the results of the learner analysis, it is necessary to develop technology-based learning media that can utilize gadgets as an effective and engaging learning tool. Through the use of digital learning media, students are expected to become more active, motivated, and have a more enjoyable learning experience. The integration of technology in learning can also help create a more modern learning environment that is in accordance with the characteristics of today's generation.

c. Task Analysis

This activity was carried out during the learning process on green chemistry material with the assistance of the Detective Game of Chemistry game media. The achievement of this analysis is described in detail in the Learning Objectives Flow (ATP) as follows:

1) Students are able to classify types of waste and identify their characteristics and impacts on the environment.
2) Students are able to determine efforts for waste prevention, reduction, and management through the concepts of reduce, reuse, recycle, treatment, and disposal.
3) Students are able to identify gases that cause air pollution and explain their impacts on health and the environment.
4) Students are able to analyze the process of acid rain formation as well as the formation and decomposition of ozone in the atmosphere.
5) Students are able to evaluate efforts to prevent air pollution based on environmental issues.
6) Students are able to identify GHS symbols of hazardous substances and personal protective equipment (PPE) used in the laboratory.
7) Students are able to explain the functions of laboratory equipment and the importance of

safety and self-protection in laboratory activities.

d. Concept Analysis

In this analysis, the activities carried out include analyzing learning outcomes and learning objectives, followed by analyzing learning resources to collect and identify materials that support the development of the Detective Game of Chemistry. This analysis will produce a concept map.

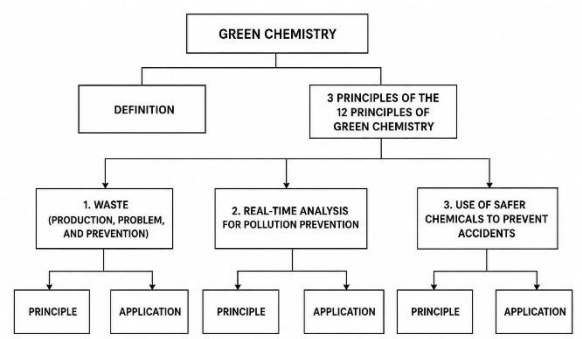


Figure 2. Concept Map of Green Chemistry

e. Specifying Intructional Objectives

In this analysis, the activities carried out include formulating learning objectives as the basis for preparing the final test (posttest) and designing the learning media, namely the Detective Game of Chemistry, which will be integrated into green chemistry material.

2. Design

This stage aims to produce the initial design of the learning media to be developed. There are three steps used in this stage, namely:

a. Media Selection

The first type of digital media used to support learning is interactive multimedia, which is widely used to facilitate learning activities [10]. In line with this, the Detective Game of Chemistry is developed as an interactive learning medium that actively engages students in the learning process and can be adapted to their learning needs.

b. Format Selection

The Detective Game of Chemistry application was developed using Unity software, which facilitates developers in designing and creating game-based learning media in accordance with the desired needs and concepts. In addition, this application can be used on devices with the Android operating system, making it more accessible for students.

c. Initial Design

The initial stage in the media design process was carried out through the integration of basic components that had been developed based on the previously established media criteria and format. These components were then further processed using Unity software version 6.2 and subsequently exported or built into an Android application. The developed media is in the form of an application that can only be used on devices with the Android operating system. The initial media design serves as a draft to be used in the development stage. The initial design of the Detective Game of Chemistry on green chemistry material is presented as follows.

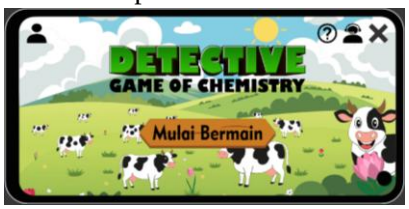


Figure 3. Initial Display of the Detective Game of Chemistry

The initial display contains five main buttons, namely the start button to begin the game, the developer profile button, the game instructions button, the help menu button, and the exit button. The arrangement of these menus is designed to allow users to access each feature of the application more easily and in a more structured way.

3. Develop

a. Expert Appraisal

Before the developed media underwent expert appraisal, it was first reviewed by the supervising lecturers. The suggestions and revisions obtained from the expert appraisal process are presented as follows.



Figure 4. Menu Display After Expert Review

After the expert review, the application underwent several improvements and feature additions based on the suggestions and feedback obtained. The changes included adding two new menus, bringing the total number of menus in the application to five. The additional menus consist of a tutorial menu and a practice question menu.

Furthermore, the application is equipped with a lock system for each principle. The next principle cannot be accessed until the player has completed the previous one. This feature is designed to ensure that players learn the material in a gradual and sequential manner so that their understanding of green chemistry concepts can be more structured.



Figure 5. Score Display After Expert Review

After the expert review, the evaluation result display underwent several improvements, including the addition of a “read material” button designed to help students review material they have not yet fully understood. In addition, attractive cartoon characters were added to motivate students to learn more enthusiastically and to try again. The result display was also enhanced with “success” or “failure” labels accompanied by different background images for each condition, making the application more engaging and interactive.

b. Validation

At the validation stage, the Detective Game of Chemistry that had been revised based on the review results was validated by three validators consisting of two Chemistry Education lecturers from Universitas Negeri Surabaya and one Chemistry teacher from SMAN 4 Bojonegoro. Based on the validation results, it can be concluded that both the content validity and construct validity of the Detective Game of Chemistry are categorized as valid, as indicated by assessment items that obtained a mode score of 4 or 5.

The validation process did not only focus on collecting scores from the validators but also included gathering suggestions and feedback, which were used as the basis for revising the Detective Game of Chemistry. Based on the validation data, the media was declared feasible for use in the trial phase involving Grade X students of SMAN 4 Bojonegoro. This feasibility is based on the suggestions and feedback provided by the validators during the validation process.

c. Limited Trial

The Detective Game of Chemistry media that had been validated was then conducted in a limited trial involving the research subjects, namely 26 Grade X students at SMAN 4 Bojonegoro.


Figure 6. Limited Trial of the Detective Game of Chemistry in Class X-6 of SMAN 4 Bojonegoro

This trial was conducted in the even semester of the 2025/2026 academic year, specifically on Monday, 13 and 20 April 2026.

d. Data Analysis

The effectiveness of the Detective Game of Chemistry was measured using a test method to determine the improvement in students’ learning outcomes after using the game-based learning

media in the learning process. The assessment of learning outcomes was conducted through two stages of testing, namely a pretest and a posttest. The implementation of both tests aimed to compare students' abilities before and after using the Detective Game of Chemistry in green chemistry material.

The questions used in the pretest and posttest were identical, consisting of 15 multiple-choice questions related to green chemistry content. The use of the same set of questions was intended to ensure that the comparison of students' learning outcomes could be conducted more objectively and systematically. These questions were developed based on learning indicators that had been aligned with the intended learning objectives.

The pretest was administered at the beginning of the lesson before students used the Detective Game of Chemistry. This test aimed to identify students' prior knowledge of green chemistry material. After that, students participated in learning activities using the Detective Game of Chemistry. Once the entire learning process was completed, students took the posttest at the end of the lesson. The posttest aimed to assess students' understanding after using the game-based media in the learning process. The following presents the results of the students' pretest and posttest.

Table 3. Students' Pretest and Posttest Results

No.	Name	Pretest Score	Posttest Score
1	ANA	87	93
2	ANS	73	100
3	AAR	73	93
4	AP	80	100
5	AMDP	53	73
6	ADPP	80	93
7	AQAF	80	93
8	CAER	73	100
9	DTP	60	87
10	DYEP	73	87
11	FOKD	73	100
12	MDM	87	100
13	MHR	80	100
14	MHIS	73	87
15	NS	93	100
16	NCP	80	100
17	NPNU	73	87
18	NFA	73	87
19	NPA	80	93
20	PAW	73	80
21	RAK	80	100
22	RNRZ	80	93
23	SDF	80	87
24	SAA	87	93
25	SRP	67	93
26	VKCM	80	100

1. Wilcoxon Signed Ranks Test

The Wilcoxon Signed-Rank Test is a nonparametric statistical method used to compare the means of two related samples, and it is applied when the assumption of normal distribution required for the Paired Sample t-test is not met. The following presents the results of the Wilcoxon Signed-Rank Test.

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Post test - Pre test	Negative Ranks	0[a]	.00	.00
	Positive Ranks	26[b]	13.50	351.00
	Ties	0[c]		
	Total	26		

a. Post test < Pre test
b. Post test > Pre test
c. Post test = Pre test

Test Statistics[a]

	Post test - Pre test
Z	-4.477[b]
Asymp. Sig. (2-tailed)	<,001

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

Figure 7. Wilcoxon Signed-Rank Test Results

Based on the results of the Wilcoxon Signed-Rank Test analysis, a significance value of 0,001 was obtained. This indicates that H_0 is rejected and H_a is accepted, meaning that the posttest scores are higher than the pretest scores. Therefore, it can be concluded that there is an improvement in students' learning outcomes.

2. Individual Mastery

Next, the pretest and posttest scores were also analyzed to determine students' individual mastery. Mastery was determined based on the Minimum Mastery Criteria applied in the school. The following presents the results of students' individual mastery.

Table 4. Students' Individual Mastery Results

No	Name	Criteria Pretest Score	Criteria Posttest Score
1	ANA	T	T
2	ANS	TT	T
3	AAR	TT	T
4	AP	T	T
5	AMDP	TT	TT
6	ADPP	T	T
7	AQAF	T	T
8	CAER	TT	T
9	DTP	TT	T
10	DYEP	TT	T
11	FOKD	TT	T
12	MDM	T	T
13	MHR	T	T
14	MHIS	TT	T
5	NS	T	T
16	NCP	T	T
17	NPNU	TT	T
18	NFA	TT	T
19	NPA	T	T
20	PAW	TT	T
21	RAK	T	T
22	RNRZ	T	T
23	SDF	T	T
24	SAA	T	T
25	SRP	TT	T
26	VKCM	T	T

3. Classical Mastery

Based on Table 4, which was processed using the classical mastery formula based on the posttest results, a result of 96% was obtained. This indicates that 96% of students achieved the Minimum Mastery Criteria (KKM) set for the posttest results. Thus, only a small proportion of students did not achieve learning mastery. This percentage of classical mastery falls into the "Very Good" category, meaning that most students were able to understand the learning material well after participating in learning using the Detective Game of Chemistry.

This high level of mastery shows that the learning media used was effective in helping students understand the concepts of the material being studied and supported the achievement of optimal learning outcomes. In addition, since the percentage of classical mastery exceeded the learning success criterion of ≥75%, the Detective Game of Chemistry can be considered effective for use in the learning process.

4. N-Gain

Next, the test results were analyzed to determine the improvement between the pretest and posttest scores of the Detective Game of Chemistry on green chemistry material. It is stated to be effective if students' learning outcomes show an improvement in the medium or high category, namely ≥ 0,3. The improvement in students' pretest and posttest scores is presented in the following Table 5.

Table 5. N-Gain Results

No.	Name	Gain	Category
1	ANA	0,50	Medium
2	ANS	1,00	High
3	AAR	0,75	High
4	AP	1,00	High
5	AMDP	0,43	Medium
6	ADPP	0,67	Medium
7	AQAF	0,67	Medium
8	CAER	1,00	High
9	DTP	0,67	Medium
10	DYEP	0,50	Medium
11	FOKD	1,00	High
12	MDM	1,00	High
13	MHR	1,00	High
14	MHIS	0,50	Medium
15	NS	1,00	High
16	NCP	1,00	High
17	NPNU	0,50	Medium
18	NFA	0,50	Medium
19	NPA	0,67	Medium
20	PAW	0,25	Low
21	RAK	1,00	High
22	RNRZ	0,67	Medium
23	SDF	0,33	Medium

24	SAA	0,50	Medium
25	SRP	0,80	High
26	VKCM	1,00	High

Based on the table above, students' learning outcomes showed a significant improvement, as evidenced by the increase in pretest and posttest scores. This improvement was analyzed using the N-gain method. Learning is considered effective if ≥ 75% of students achieve an N-gain in the medium category (≥ 0,3) to the high category (≥ 0,7) [9]. In detail, 1 student (4%) was in the low category, 13 students (50%) were in the medium category, and 12 students (46%) were in the high category. Thus, almost all students (96%) achieved a significant improvement. The overall average N-gain obtained was 0,73, which is classified as high.

CONCLUSION

Based on the results of the data analysis and discussion, it can be concluded that the android-based Detective Game of Chemistry is feasible to be used as a learning medium to improve students' learning outcomes on green chemistry material. This conclusion is supported by the following findings.

Based on the effectiveness aspect, the Android-based Detective Game of Chemistry learning media for green chemistry material can be considered effective in improving students' learning outcomes. This is indicated by the comparison of students' pretest and posttest scores, which were analyzed using classical mastery and resulted in a percentage of 96%. In addition, the Wilcoxon Signed-Rank Test showed a significance value of 0,001, indicating that H_0 is rejected and H_a is accepted, meaning that the posttest scores are higher than the pretest scores; thus, there is an improvement.

The improvement in pretest and posttest results produced an average N-gain score of 0,73, which falls into the high category. This indicates that students' learning outcomes after using the Detective Game of Chemistry are higher than before its use. Therefore, it can be concluded that the Detective Game of Chemistry is categorized as effective.

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