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Analysis of Differentiated Learning Implementation Using a 3D Chemistry Periodic Table Application to Improve Students' Cognitive Ability

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Abstract

The cognitive ability of each student is different. To improve it, it needs to be trained and optimized. The purpose of cognitive skills is the implementation of differentiated learning using a 3D Chemistry Periodic Table Application to improve the students' cognitive ability. This research was implemented in the even semester academic year 2023 / 2024 at State Senior High School 1 Tambang. The method used in this research was mixed-method research with a research design Sequential Explanatory model, with research samples consisting of three classes of Grade X at State Senior High School 1 Tambang, namely two (2) experimental classes and one (1) control class. The post-test research result showed a significance of 0.000 < 0.05 until indicating a significant difference between the experimental and control classes. Besides, the average N-Gain of the experimental class namely 0.77, and the second experimental class was 0.71, with high category, and the control class was 0.60, with medium category. In other words, it is proven that differentiated learning with a 3D application increases cognitive ability. The students' response after gaining the learning by using 3D was excellent, with a percentage of 81.41 %. The results of this research are expected to help teachers improve the students' cognitive abilities.

Keywords: Differentiated learning, 3D application, chemistry periodic table, cognitive skills

Introduction

Throughout the years, changes have been made to the education system, including the shift from using blackboards to utilizing various media for knowledge transfer. The focus of learning styles has also evolved to maximize students' potential in meeting global challenges, aligning with the Merdeka Curriculum (previously known as the prototype curriculum). This curriculum is designed to be more flexible, emphasizing essential content and developing students' character and competencies. The Merdeka Curriculum introduces the fundamental principles and concepts of student-centered new paradigm learning (Kemdikbud, 2023).

The Merdeka Curriculum includes the development of the Pancasila Student Profile character, with additional emphasis on fundamental skills such as literacy and numeracy. It allows teachers to conduct more flexible, differentiated learning based on student competencies (Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi, 2020). The curriculum's learning implementation involves three stages: diagnostic assessment, planning, and learning. The diagnostic stage helps identify the appropriate type of differentiated learning. Differentiated learning is tailored to meet students' needs in terms of readiness, interests, and profiles, and it addresses the challenge of low cognitive abilities among students. Research by Santosa & Us (2016) also reflects the issue of low cognitive ability among students. Studies by Zakiah & Khairi (2019) and Ismail (2023) indicate that addressing the low cognitive ability of students requires educational institutions to seek effective learning strategies that can enhance students' cognitive abilities in alignment with the 2013 curriculum.

Based on Mulyasa's (2017) findings, there is a concern about the low cognitive abilities of students. The research in the 2013 curriculum emphasizes the development of cognitive, affective, and psychomotor aspects to shape students' personality and spiritual, social, knowledge, and skill competencies. Educators and teachers must now think creatively and innovatively to effectively transfer knowledge and skills to students to achieve educational goals. According to Jensen (2010), teachers, as the main drivers of learning activities, must possess the ability to develop effective learning strategies. The learning environment

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should be structured to enable students to develop their potential through engaging and beneficial activities.

It is essential to address the diverse needs of students in the classroom, as teachers must consider these factors when selecting teaching methods. Educators must be innovative and resourceful in developing and implementing instructional strategies. The objectives are to promote effective learning, cater to students' distinct learning requirements, and enhance their learning potential. A student's ability to learn independently, demonstrating their understanding of the material, reflects their success in learning. Therefore, it is vital to employ strategies or techniques that engage students' interest throughout the educational process.

In the educational process, teachers are encouraged to utilize a variety of models, strategies, and techniques that cater to their students' distinct characteristics and abilities. They must also establish a learning environment suitable for the classroom context, which can be partly achieved through implementing differentiated learning. Corley refers to this practice as differentiated teaching or differentiated instruction. The term "differentiated teaching," also known as "differentiated instruction" or "differentiated learning," was coined by Carol Ann Tomlinson to describe an approach that enables teachers to devise plans tailored to the specific needs of each student (Lailiyah, 2016; Nahdhiah & Suciptaningsih, 2024; Siburian et al., 2019).

Incorporating differentiated learning allows students to explore their initiative, creativity, and independence based on their talents, interests, and developmental stages. By utilizing differentiated learning, students' diverse needs in studying Natural Sciences (IPA), particularly in chemistry, can be addressed according to their unique learning preferences and profiles. Researchers have identified issues with the current approach, noting that differentiated learning is not utilized while the school has implemented a rigid curriculum. The existing teaching method is one-sided, leading to student passivity, limited cognitive development, and a lack of engagement with teachers' explanations due to boredom. Chemistry education mainly relies on textbooks and teacher-led instruction, which is ineffective in stimulating interest, particularly in a subject that demands a deep understanding like chemistry. Consequently, students are inclined to perceive chemistry as a challenging subject.

The challenge of mastering chemistry is tied to the inherent qualities of the subject, which include abstract ideas, a sequential structure, a quick pace of content advancement, and its role as a simplification of various other scientific disciplines (Maku et al., 2023; Sirhan, 2007). Therefore, there is a need to develop an innovative approach that integrates differentiated chemistry learning with a 3D Chemistry Periodic Table application, creating a virtual three-dimensional object by combining a real three-dimensional object in real-time.

The 3D chemistry periodic table application is used for differentiated learning to address student variances and transform the traditional one-way approach to education. According to Heacox, differentiated instruction is not just a program, method, or strategy but a mindset and a philosophy for addressing diverse student needs. The new educational media aims to make it easier for students to comprehend and visualize the three-dimensional structure of chemical compounds as described (Ditasona, 2017).

This study aimed to determine the difference in cognitive abilities between classes given differentiated learning with 3D implementation, differentiated learning without 3D, and conventional classes, and whether differentiated learning using a 3D chemistry periodic table application can improve students' cognitive abilities.

Methods

This study uses a mixed-methods approach (Mixed Methods Research). Analyzing the same phenomenon using quantitative and qualitative methods offers a more comprehensive understanding (Kurniawati, 2019). One kind of mixed research is the Sequential Explanatory model, which starts with collecting and analyzing quantitative data in the first phase and then moves on to qualitative analysis in the second phase to strengthen the results of the first phase (Sugiyono, 2014).

Three SMA Negeri 1 Tambang classes comprised the study's sample, including two experimental and one control group. Simple random sampling was the sampling strategy used in this study. Differentiated learning with 3D media was used to teach the first experimental class, while differentiated learning without 3D was used for the second experimental class. The control group did not use either differentiated learning or 3D media. Before the treatments, all three classes underwent a pretest and were given a posttest post-treatment.

The subjects of this study comprised 104 students from three X classes. The first experimental class, (X Unggul 2), included 17 male and 18 female students, engaged in differentiated learning utilizing a 3D application. The second experimental class (X Unggul 5) also included 20 male and 15 female students, and participated in differentiated learning without using a 3D application. Lastly, the control class (X Unggul 4) consisted of 17 male and 17 female students, who experienced conventional learning methods. This research occurred during the academic year 2023 / 2024 at SMAN 1 Tambang.

The research utilized a testing instrument comprising objective questions in the form of pre-tests and post-tests, along with questionnaires, a data collection method consisting of opinions or information provided as questions or statements to respondents (Kurniawati, 2018), serving as a qualitative measurement tool. The questionnaire administered in this study assessed student responses to the 3D Chemistry Periodic Table media. Initially, the data were analyzed through normality and homogeneity tests. The ANOVA test was employed to evaluate the differences in means across groups for the final analysis. This investigation used a One-Way ANOVA, which tests the average values resulting from an experimental treatment involving one factor with three or more groups (Payadnya & Jayantika, 2018). The N-Gain test was also applied to measure the improvement in knowledge and thinking abilities before and after the educational intervention (Sukarelawa et al., 2024). Descriptive Analysis processed data from the student response questionnaires in this study. This analysis thoroughly describes the research through data collection, allowing students to select alternative responses accompanied by scores on a Likert scale. The Likert scale was used to capture respondents' perspectives regarding the statements presented in the questionnaire (Ani & Lazulva, 2020).

Results and Discussion

To assess the initial cognitive abilities of the students and ensure that the three classes had similar cognitive levels before any intervention, the study began with a pretest. Analyzing the average scores from each class makes it possible to compare the pretest outcomes of the experimental and control classes. The average pretest score for experimental class one was 41.69. The control group had an average pretest score of 39.69, while the other experimental group scored an average of 41.63.

After their respective treatments, the three sample classes were given a posttest. The students were unaware that the questions on the posttest were identical to those on the earlier pretest. The posttest results for the first two experimental classes were 85.09, 82.77, and 76.60, while the control group scored 76.60. **Figure 1** illustrates the difference in cognitive ability outcomes between the experimental and control groups.

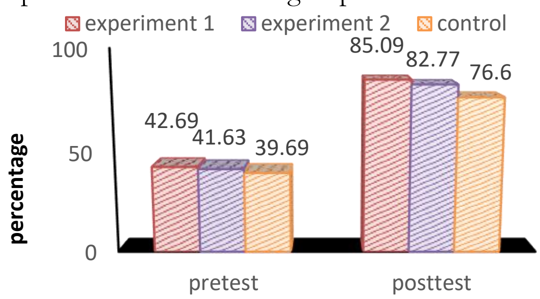

Figure 1. Cognitive ability score diagram

The average pretest-posttest scores of the students' cognitive abilities in the experimental and control groups differ (**Figure 1**). Experimental class one and the control class had a pretest score difference 2, and experimental class two and the control class had a pretest score difference 1.94. There is an 8.49-point difference in posttest scores between experimental class one and the control group, and a 6.17-point difference between experimental class two and the control group.

The Sig value obtained from the ANOVA test analysis of pretest data for the three classes is 0.756, greater than the significance level of 0.05, indicating acceptance of H0. The obtained F count of 0.280 is less than the F Table value of 3.34, leading to the decision that the three classes' initial ability is the same before different learning takes place. The descriptive results of the ANOVA pretest are presented in the following table.

Table 1. Descriptive results of the pretest anova test

Class	N	Min.	Max.	Mean	Std. Deviation
Experimental Class 1	35	18	73	41.69	11.894
Experimental Class 2	35	18	73	41.63	11.919
Class Control	35	9	73	39.69	14.223
Total	105	9	73	41.00	12.637

The first experimental class that utilized 3D media for differentiated learning achieved an average score of 41.69, with a standard deviation of 11.894, and the scores ranged from a high of 73 to a low of 18. In contrast, the second experimental class, which did not incorporate 3D media for differentiated learning, also recorded an average score of 41.69, with a standard deviation of 11.919, the highest score being 73 and the lowest 18. The control group had an average score of 39.69, a standard deviation of 14.223, with the highest score reaching 73 and the lowest score falling to 9.

The posttest data analysis using ANOVA revealed a significance level 0.000, indicating rejection of the null hypothesis (H_0) as it is less than 0.05. The obtained F count of 18.834 exceeded the F Table value of 3.34, indicating a significant difference in ability between the experimental and control classes. The descriptive results of the ANOVA posttest can be found in the table below.

Table 2. Descriptives of posttest anova test results

Class	N	Min.	Max.	Mean	Std. Deviation
Experimental Class 1	35	73	91	85.09	5.321
Experimental Class 2	35	73	91	82.77	6.316
Class Control	35	64	82	76.60	6.251
Total	105	64	91	81.49	6.930

Table 2 shows that in experimental class two, after differentiated learning using 3D media obtained an average of 85.09 with the highest score of 91, the lowest score of 73, and a standard deviation of 5.321. After differentiated learning without using 3D media, experimental class two obtained an average learning outcome of 82.77, with the highest score of 91, the lowest score of 73, and

a standard deviation of 6.316. At the same time, the control class obtained an average of 76.60 with the highest score of 82, the lowest score of 64, and a standard deviation of 6.930.

Further tests were carried out using the Tukey HSD comparison test. Analysis using Tukey HSD was conducted to see the average difference between the three, as seen in the following table.

Table 3. Discussion of Tukey HSD analysis

(I) Class	(J) Class	*Mean Difference (I-J)*	*Std. Error*	*Sig.*
Experimental Class1	Experimental Class 2	2.314	1.429	.242
	Class Control	8.486*	1.429	.000
Experimental Class 2	Experimental Class 1	-2.314	1.429	.242
	Class Control	6.171*	1.429	.000
Class Control	Experimental Class 1	-8.486*	1.429	.000
	Experimental Class 2	-6.171*	1.429	.000

In **Table 3,** the analysis results using Tukey's HSD from experimental class one (1), which received differentiated learning treatment using 3D, experimental class two (2), which received differentiated learning treatment without using 3D, and the untreated control class.

As a result, the difference between the three averages, namely, experimental class one (1) and experimental class two (2), obtained a sig = 0.242. Sig value. These results indicate no significant difference in cognitive ability, greater than the significance level of 0.05 or (0.242 > 0.05), so accepting H0. The experimental class one (1) and the control class obtained a value of sig = 0.000. Sig value. Smaller than the significance level of 0.05 or (0.000 > 0.05), these results indicate a significant difference in cognitive abilities. Experimental class two (2) and experimental class one (1) obtained a sig value = 0.242. Sig value. These results indicate no significant difference in cognitive ability, greater than the significance level of 0.05 (0.242 > 0.05). Experimental class 2 and control class obtained a sig value = 0.000. Sig value. Smaller than the significance level of 0.05 or (0.000 > 0.05), these results indicate significant differences in cognitive abilities. The control class with experimental classes 1 and 2 obtained a sig value = 0.000. Sig value. Smaller than the significance level of 0.05 or (0.000 > 0.05), these results indicate significant differences in cognitive abilities. So, it can be concluded that there is an influence.

Cognitive abilities increase as seen from the N-gain test, by averaging the initial data scores, namely the pretest, and the final data scores, namely the posttest, which will be compared, and the improvement will be tested. The results of the test are then compared with the established criteria. If the calculated N-gain is ≤ 0.3, then the increase is low; if the calculated N-gain is < 0.7, then the increase is moderate; and if the calculated N-gain is ≥ 0.7, it can be achieved. It was concluded that the increase was high. The following are the results of the N-gain of students' cognitive abilities in Figure 2.

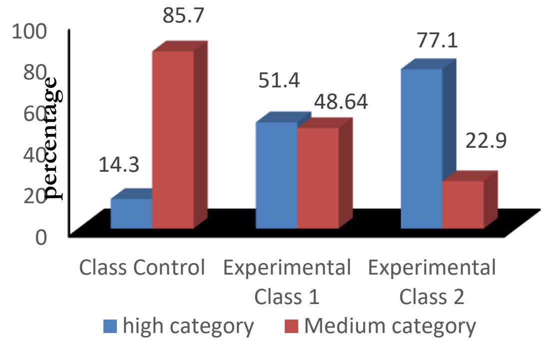

Figure 2. N-gain diagram of cognitive abilities

The N-gain results for students' cognitive abilities in experimental class one show that 27 (77.1 %) were in the high category. In contrast, 8 students (22.9 %) had an average N-gain of 0.77 and were in the low category. In experimental class two, 18 students (51.4 %) were in the high category, and 17 students (48.6 %) had an average N-gain of 0.71. In the control class, five students (14.3 %) experienced an increase in the high category, while 30 students (85.7 %) had an average N-gain of 0.60 and were in the medium category.

In assessing cognitive ability, researchers evaluate students' capacity to explain the significance of nanotechnology through various sources (question 11) and to elucidate the evolution of atomic theory from Dalton to quantum mechanics (questions 1, 2, and 3). Furthermore, students' ability to analyze atomic structure and constituents is assessed (question 5), as well as their proficiency in determining element placement in the periodic table based on electron configurations (questions 6, 7, 8, and 9). Students' analytical skills about electron configurations according to the Bohr atomic model theory are also evaluated (question 10), and their capability to analyze the trend of atomic radii concerning the nature of the element (question 4).

Based on the results, the highest values in the control class were in indicators 2 and 6 in questions 1, 2, and 4. This can be seen in **Figure 3.**

Figure 3 shows that students' scores in the experimental class are higher than in the control class. This is supported by most students' scores on the question indicators in the control class being lower than those in the experimental class. This difference is because the control class did not integrate differential learning and 3D media in the learning process.

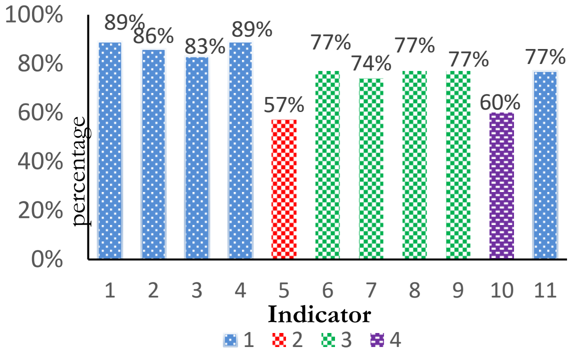

Figure 3. Control class student scores based on indicators

The results from experimental class two indicate that high scores on questions 1, 2, and 4 are associated with indicator 2, which explains the development of atomic theory from Dalton to quantum mechanics, and indicator 6, which pertains to analyzing the tendency of atomic radius in elemental parenthood. These findings are illustrated in **Figure 4.**

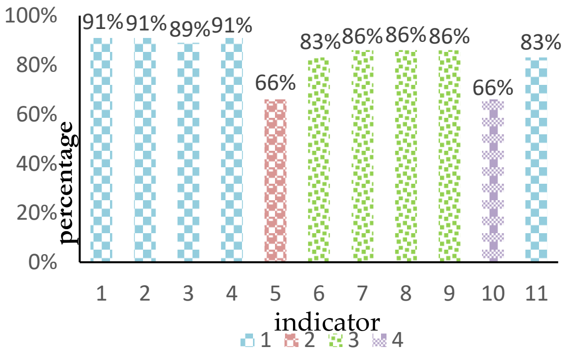

Figure 4. Grades of experimental class two students based on indicators

In **Figure 4,** it can be seen that the highest achievement for students in the second experimental class is in indicator 1, which involves the ability to articulate the evolution of atomic theory from Dalton, Thomson, Rutherford, Bohr, to quantum mechanics, with the peak percentage being 91 % on question number 1. Observing the substantial progress in the first experimental class, it is noted that both the second and control classes experienced gains in indicator 1, specifically in question number 1. This phenomenon can be attributed to C1 (memory), where remembering signifies that students who acquire information must endeavor to retain that knowledge (Dishinta & Hadi, 2023). Although this aspect represents the lowest level, it is essential for advancing to the subsequent level. In this regard, students formulate their responses based solely on memorization.

Based on the results, the highest value in experimental class one was for indicator 1 in question 1. This can be seen in **Figure 5.**

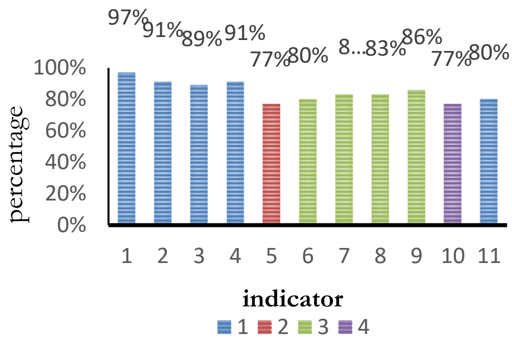

Figure 5. Grades of experimental class one students based on indicators

In **Figure 5,** it is evident that the experimental class one has the highest concentration of students excelling in indicator 1, which involves the ability to elucidate the progression of atomic theory from Dalton, Thomson, Rutherford, Bohr, and quantum mechanics. This proficiency is observed in questions 1, 2, and 3, with the highest percentage, 97%, achieved in question 1. Using 3D learning tools in the experimental class has contributed to this success by fostering greater enthusiasm and interest in learning among the students.

In indicator C1 (memory), experimental class one demonstrates cognitive ability 6 % and 7 % higher than experimental class two and the control classes. In indicator C2 (understanding), cognitive ability in experimental classes one and two surpasses that of the control class by 6 %. In indicator C3 (application), the cognitive ability of experimental classes one and two exceeds that of the control class. The analysis of students' cognitive ability in indicator C4 (Analyzing) with numbers 5 and 10 reveals that it is 77 % and 77 % in experimental class one, and 66 % and 66 % in experimental class two. In contrast, the control class's cognitive ability in C4 falls within the lowest category at 57 % and 60 %, compared to experimental classes one and two. These findings indicate that the highest cognitive ability in C4 is observed in the experimental class, attributed to using 3D media in the learning process. According to the theory (Subali, 2012), which defines C4 as students' ability to analyze relationships, the questions presented in C4 revolve around elements in 3D form.

Media for learning serves as a tangible tool for presenting educational content. According to Ruth Lautfer, learning media is a teaching aid for educators to communicate instructional material, enhance student creativity, and improve student engagement during the educational process (Tafonao, 2018).

Engaging with 3D media related to the periodic table can enhance students' comprehension skills at the introductory level (Yasmin & Yoto, 2023). The application of three-dimensional resources during learning significantly impacts cognitive skills by boosting motivation and stimulating learning activities, and it can also have psychological effects on students (Susanti et al., 2018).

The results of the research and data analysis can be said that where the experimental class one and experimental class two show a significance value of 0.756 more than 0.05 indicates there is no difference, however, the N-gain percent of the experimental class one is higher, namely 0.77 while the experimental class two is 0.71 with the same category, namely high, this is due to the influence of differentiated learning which has characteristics in differentiated learning including a focus on the main concepts and principles of the subject matter, assessment of student readiness and learning development integrated into the curriculum, flexible grouping of students, and the active role of students as learning explorers (Sarnoto, 2024).

The posttest research revealed a significance value 0.000, indicating a significant difference between the experimental and control classes. The N-gain for the experimental class was 0.77, while the control class achieved 0.60, both falling within the moderate category. This demonstrates that using 3D applications in differentiated learning has enhanced cognitive abilities, leading to a noteworthy disparity between the classes implementing this approach. Furthermore, an increase in student participation during the learning process was observed. As supported by Yasmin & Yoto (2023), as well as Dalila et al. (2022) and research conducted by Naibaho (2023), the average results of the research indicate an improvement in students' cognitive abilities through differentiated learning.

The analysis of cognitive ability enhancement indicates that there has been an increase across the three classes. Nevertheless, the percentage growth in cognitive skills among students in the experimental class who underwent treatment was greater than that observed in the experimental class two and the control group. This suggests that utilizing 3D media for teaching the periodic system of elements is more effective in enhancing students' cognitive abilities, as the android-based learning resources are accessible at any time and place, allowing students to engage in independent study, thereby fulfilling the expected outcomes for scientific literacy (Kusumawardhani et al., 2019).

Based on the analysis of student responses derived from questionnaire data distribution, the assessment of the developed learning media was measured using the Likert scale method (Kartini & Putra, 2020). The analysis revealed that students provided positive feedback regarding the 3D media utilized for the periodic system of elements, achieving an average percentage of 81.49 %, which falls within the very good category. Furthermore, students expressed that the 3D media is engaging, contributing to their enthusiasm for learning, as indicated by the very good category rating.

Conclusions

The experimental class, which received differentiated learning using 3D media, and the control class, which only used the Problem-Based Learning learning model, exhibited a significant difference. This difference is apparent in the average posttest results of cognitive abilities, with the experimental class one scoring 85.09, the experimental class two scoring 82.77, and the control class scoring 76.60. Furthermore, the One-Way Anova test results indicate a significant difference, with a significant value. The Anova test (Sig.) at $0.000 < 0.05$ confirms the acceptance of Ha and the rejection of H0.

Differentiated learning through 3D media has improved students' cognitive abilities on the periodic system of elements at SMA Negeri 1 Tambang. This is supported by the N-gain results, which demonstrate a high category improvement in cognitive abilities for experimental class one at 77.1 % and a moderate category at 22.9 %, indicating effectiveness.

In SMA Negri 1 Tambang, differentiated learning through 3D media improves students' cognitive skills regarding the periodic table of elements. This is supported by the N-Gain results, with class 1 trials showing a high increase in cognitive performance of 77.1 % and a moderate increase of 22.9 %, indicating efficacy.

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