

THE EFFECT OF ASSEMBLR EDU INTEGRATED INTO THE PROBLEM-BASED LEARNING MODEL ON STUDENTS' MOTIVATION AND LEARNING OUTCOMES IN REACTION RATE MATERIAL AT SMAN 1 GOWA

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Abstract. *This study employed a quasi-experimental approach to investigate how the integration of augmented reality (AR) technology, specifically Assemblr Edu, within a Problem-Based Learning (PBL) model influenced the motivation and learning outcomes of eleventh-grade students at SMA Negeri 1 Gowa, with a focus on reaction rate as the subject matter. A post-test only control group design was adopted as the methodological framework. The findings demonstrated that students in the experimental group outperformed their counterparts in the control group across both measured variables. In terms of learning motivation, the experimental group recorded a mean score of 80.61, compared to 73.94 in the control group. Regarding academic achievement, the experimental group similarly obtained a higher mean score of 82.91, while the control group attained 75.69. Statistical analysis was conducted through inferential methods, employing the independent samples t-test and the Mann-Whitney test where appropriate. For learning motivation, the calculated t-value (3.33) exceeded the critical t-value (1.67), indicating a statistically significant difference. Likewise, for learning outcomes, the obtained Z-value (1.99) surpassed the critical Z-value (1.64), confirming significance. These results collectively suggest that the incorporation of Assemblr Edu AR-based media within a PBL model exerts a meaningful and statistically significant influence on both the motivational engagement and academic performance of students in reaction rate instruction.*

Keywords: *Assemblr Edu, Problem Based Learning, Learning Motivation, Learning Outcomes, Reaction Rate*

INTRODUCTION

The quality of human resources is a key determinant of a nation's progress, and one of the strategic efforts to improve it is through high-quality education [1]. Quality education cannot be separated from curriculum reform as a framework for implementing effective learning processes. In this context, the Merdeka Curriculum (Independent Curriculum) was introduced as a response to the evolving demands of 21st-century education. The Independent Curriculum is an improvement of the 2013 Curriculum, designed to provide greater flexibility for schools and teachers in creating meaningful, contextual, and student-

centered learning experiences [2]. The Independent Curriculum in its implementation can use the problem-based learning model. Substantively, this curriculum emphasizes the development of character-based competencies, creativity, and 21st-century skills such as critical thinking, communication, collaboration, and creativity (4C) in response to global changes and the dynamics of Society 5.0. Its implementation began gradually in the 2022/2023 academic year in schools that met specific criteria and was subsequently introduced progressively across all educational institutions in Indonesia during the 2023/2024 academic year [3]. The Independent

Curriculum has been shown to encourage more focused student learning activities and strengthen character development through a student-centered learning approach [4].

One of the learning approaches recommended for the implementation of the Independent Curriculum is Problem-Based Learning (PBL). This model positions students at the center of the learning process by presenting them with authentic, real-world problem scenarios as the foundation for inquiry, which in turn fosters the development of critical thinking and problem-solving competencies [5]. In practice, students engage with contextually relevant problems that are either introduced by the teacher or identified independently by the students themselves, while the teacher assumes the role of a facilitator who supports and steers the processes of exploration and collaborative discussion [6]. The application of PBL in science instruction at the secondary school level has demonstrated significant positive effects on students' academic achievement. PBL has consistently proven to be more impactful than conventional instructional approaches [7]. Furthermore, the implementation of PBL with a contextual education perspective significantly enhances students' creative thinking skills [8]. Therefore, the PBL model has considerable potential to improve students' motivation and learning outcomes when integrated with appropriate and innovative learning media.

Learning media constitute a crucial component in supporting the successful implementation of PBL. Appropriate learning media can guide teachers in delivering instructional materials while simultaneously increasing students' interest, motivation, and learning outcomes. The incorporation of technological tools in the development of instructional media enables teachers to present materials in a more engaging, interactive, and comprehensible manner, while also promoting independent learning [9]. Various technologies utilized in instructional media development include video, audio, interactive digital multimedia, Virtual Reality (VR) environments, and Augmented Reality (AR) applications. AR technology has increasingly been applied in chemistry education and is recognized as an important pedagogical

resource that assists students in understanding abstract concepts across different educational levels, as reflected by the growing number of related publications over the past three years [10].

Augmented Reality (AR) is a technology that allow people to view and engage with virtual things overload onto the actual environment via mobile devices or computers, facilitating a seamless fusion of the real and virtual realms [11]. In education, AR technology can function as an interactive and enjoyable learning medium that helps students understand difficult concepts that are abstract or microscopic in nature [12].

One of the AR platforms that has gained popularity and has been widely implemented in Indonesian educational contexts is Assemblr Edu. This platform was developed to create interactive content by combining various available virtual objects and includes features for content management, storage, and sharing, thereby facilitating the learning process between teachers and students [9]. Assemblr Edu is capable of presenting objects realistically and comprehensively, both in terms of structure and functionality, thus providing students with a deeper understanding through exclusive and immersive learning experiences.

Based on observations and interviews conducted with a chemistry teacher of Grade XI students at SMAN 1 Gowa, it was found that chemistry learning on the topic of reaction rates was still predominantly conducted using conventional methods, such as lectures and discussions, supported by Smartboard media. Although the PBL model was occasionally implemented, its application had not yet been optimal. This condition affected students' active participation in the learning process; many students were not actively involved and even engaged in unrelated activities during discussions because the learning process was perceived as monotonous and uninteresting. The low level of student engagement was directly associated with their learning achievement, as approximately 50% of the students had not achieved the Minimum Learning Mastery Criteria (KKTP) and therefore required remedial instruction. This issue was presumed to result from the use of inappropriate and less engaging learning media,

which failed to stimulate students' intrinsic motivation.

To address this issue, the proposed solution is the implementation of AR-based learning media, specifically Assemblr Edu, integrated into the PBL model for teaching reaction rate material. SMAN 1 Gowa has supported the use of smartphones by students as learning tools, making the implementation of AR-based media highly feasible. AR-based Assemblr Edu media are expected to enhance students' learning motivation and improve their learning outcomes in eleventh-grade chemistry classes. The development of AR-based Assemblr Edu media for the topic of chemical reaction rates has been shown to significantly improve students' learning outcomes [13]. In addition, the implementation of AR-based Assemblr Edu media has been proven to enhance students' learning motivation because it provides interactive and realistic visualizations that can be observed from multiple perspectives, thereby creating a more engaging and meaningful learning experience [14].

Building upon the aforementioned theoretical and empirical foundations, the present study sought to investigate the degree to which the incorporation of Assemblr Edu augmented reality media within a Problem-Based Learning (PBL) model influences the motivation and learning outcomes of eleventh-grade students at SMAN 1 Gowa, with particular reference to the topic of reaction rates.

METHOD

This research adopted a quasi-experimental methodology and was carried out at SMA Negeri 1 Gowa throughout the first semester of the 2024/2025 academic year. A Posttest-Only Control Group design was employed to evaluate the degree to which the integration of Assemblr Edu media into the Problem-Based Learning (PBL) model affected students' learning motivation and academic achievement. The quasi-experimental approach was deemed appropriate given that random assignment of students to groups was not feasible, as class groupings had already been established by the institution prior to the study. This design is particularly suited to research contexts in which the investigator lacks full

control over external variables yet still seeks to establish a causal relationship between the independent and dependent variables [15]. Furthermore, this design facilitates a structured comparison of outcomes between the experimental and control groups following the administration of distinct instructional treatments to each group. The corresponding research design is illustrated in Table 1.

Table 1. Research Design

Groups	Treatment	Posttest
Experimental Group	X	O
Control Group	C	O

Description:

- X = Treatment using Assemblr Edu media
- C = Treatment without using Assemblr Edu media
- O = Administration of the posttest

The study population encompassed all eleventh-grade students enrolled in chemistry courses at SMA Negeri 1 Gowa during the 2024/2025 academic year, spanning a total of four classes. From this population, two classes were selected as the study sample through the application of a simple random sampling technique, given that each class held an equal probability of being included in the study. This sampling method is considered appropriate when the population exhibits a relatively homogeneous composition and every member of the population possesses an equal likelihood of being selected as a sample participant [26]. Based on the random selection process, Class XI.3 was assigned as the experimental group consisting of 36 students, who were taught using Assemblr Edu media integrated into the Problem-Based Learning (PBL) model. Meanwhile, Class XI.1 was assigned as the control group consisting of 36 students, who were taught using the PBL model without the use of Assemblr Edu media.

The instruments employed for data collection comprised a learning motivation inventory containing 20 validated items. This inventory was developed to assess students' level of learning motivation across six key indicators: (1) the desire and willingness to achieve success, (2) the internal drive and necessity to engage in learning, (3) future hopes and aspirations, (4) the perceived value and

appreciation of learning, (5) the presence of stimulating and engaging learning activities, and (6) the availability of a supportive and conducive learning environment [16]. Responses were measured using a Likert scale with five response categories, spanning from strongly agree to strongly disagree, with each category assigned a corresponding numerical value on a scale of 1 to 5, where a score of 5 reflected the most favorable response and a score of 1 indicated the least favorable. The complete scoring criteria applied to the motivation instrument are outlined in Table 2 [17].

Table 2 Learning Motivation Instrument Scoring System

No.	Likert Scale	Positive Statements	Negative Statements
1.	Strongly Agree	5	1
2.	Agree	4	2
3.	Neutral	3	3
4.	Disagree	2	4
5.	Strongly Disagree	1	5

The cognitive domain achievement test comprised 20 multiple-choice items that had been verified for validity and reliability, and was administered as a summative assessment to both the experimental and control groups. Concurrently, a learning motivation questionnaire was distributed to participants in both groups during the same assessment session. To analyze the collected data, this study employed two inferential statistical techniques: the independent samples t-test and the Mann-Whitney test. Prior to hypothesis testing, the data were subjected to prerequisite assumption tests, namely normality and homogeneity tests, to ensure the appropriateness of the selected statistical procedures.

RESULTS AND DISCUSSION

This study primarily aimed to examine the extent to which the integration of the augmented reality-based Assemblr Edu platform into a Problem-Based Learning (PBL) instructional model influences the learning motivation and academic achievement of

eleventh-grade students at SMAN 1 Gowa, with particular emphasis on the topic of reaction rates. Assemblr Edu is a digitally interactive, AR-powered educational platform that equips educators with the tools necessary to develop creative and engaging learning media tailored to student needs. Its accessibility through both mobile applications and an official web-based interface makes it a versatile and user-friendly resource that promotes active student participation throughout the learning process [18].

This study compares learning motivation and academic achievement between the experimental group (Class XI.3) and the control group (Class XI.1). Both groups employed the Problem-Based Learning model; however, the experimental group specifically integrated Assemblr Edu into the learning process. During the learning activities, students were divided into small groups to facilitate discussion, problem-solving, and the exchange of ideas. This grouping strategy fostered a collaborative learning environment that supported students in developing a deeper understanding of reaction rate concepts, as students experiencing learning difficulties tended to feel more comfortable discussing problems with their peers rather than directly with the teacher.

The PBL model has been widely recognized for its potential to stimulate students' curiosity, enhance learning engagement, and provide opportunities for critical thinking, exploration, and independent concept construction [19]. The integration of Assemblr Edu into the problem-orientation phase of the PBL syntax further strengthened the instructional advantages of the model. Through Assemblr Edu, students were exposed to contextual problems closely related to real-life situations, which helped them understand reaction rate concepts in a more concrete and meaningful manner. In addition, the use of Assemblr Edu contributed to a more interactive learning experience between students and instructional content, making the learning process more engaging and memorable [14].

Learning Motivation

Learning motivation refers to the psychological driving force originating from both internal and external factors that encourages, sustains, and directs students' learning activities toward the achievement of

educational goals. In science learning, particularly in chemistry, motivation plays an important role in determining the depth of conceptual understanding, persistence in overcoming learning difficulties, and the ability to transfer knowledge to new situations. Therefore, the selection of instructional media capable of enhancing students' learning motivation is considered an essential factor, especially in abstract chemistry topics such as reaction rates [20].

This study investigated students' learning motivation using a validated questionnaire consisting of six indicators: (1) the desire and willingness to achieve success, (2) the internal drive and necessity to engage in learning, (3) future hopes and aspirations, (4) the perceived value and appreciation of learning, (5) the presence of stimulating and engaging learning activities, and (6) the availability of a supportive and conducive learning environment. The data were obtained from the experimental group (Class XI.3, n = 36), which implemented the Problem-Based Learning (PBL) model integrated with Assemblr Edu media, and the control group (Class XI.1, n = 36), which implemented PBL without the integration of Assemblr Edu. The analysis was conducted progressively, beginning with descriptive statistical analysis, followed by indicator-based analysis and inferential testing, in order to obtain a comprehensive and meaningful interpretation of students' learning motivation.

Table 3 Descriptive Statistical Results of Learning Motivation in the Experimental and Control Groups

No.	Descriptive Statistics	Experimental Group	Control Group
1.	Number of Students	36	36
2.	Highest Scores	99.00	92.00
3.	Lowest Rate	64.00	60.00
4.	Mean	80.61	73.94
5.	Median (Me)	79.50	74.00
6.	Modus (Mo)	74.00	74.00
7.	Standard Deviation (S)	8.88	8.09

As reflected in the descriptive statistical results summarized in Table 3, a notable difference in learning motivation was observed between the experimental and control groups. The experimental group recorded a maximum score of 99, a minimum score of 64, and a mean score of 80.61, whereas the control group obtained a maximum score of 92, a minimum score of 60, and a mean score of 73.94. Descriptively, the experimental group demonstrated a comparatively higher level of learning motivation than the control group. Nevertheless, given that the gap between the two group means was relatively modest, further inferential analysis was warranted to determine whether this difference reached statistical significance.

The standard deviation for the experimental group (8.88), which was slightly higher than that of the control group (8.09), indicates that the use of Assemblr Edu tends to produce more varied motivational responses among students. Some students have shown a significant increase in learning motivation, while others are still in the process of adapting to the augmented reality learning environment. Previous research has also reported that the impact of augmented reality on learning motivation and engagement tends to vary depending on instructional design, student characteristics, and the duration of AR implementation [21].

Table 4 Results of Students' Learning Motivation in the Experimental and Control Groups

Value	Category	Experimental Group		Control Group	
		Frequency	%	Frequency	%
20-39	Very Low	0	0	0	0
40-54	Low	0	0	0	0
55-69	Moderate	2	5.56	4	11.11
70-84	High	22	61.11	27	75.00
85-100	Very High	12	33.33	5	13.89

The categorical distribution analysis presented in Table 4 revealed a more comprehensive pattern than a simple comparison of mean scores. In the experimental group, no students were classified into the low or very low motivation categories. The distribution was concentrated in the high category (61.11%, n = 22) and very high category (33.33%, n = 12), with only 5.56% (n = 2) classified in the moderate category. A

similar pattern was observed in the control group in terms of the absence of low motivation categories; however, the proportion of students in the very high category was considerably lower (13.89%, $n = 5$), while the proportion in the moderate category was higher (11.11%, $n = 4$). These findings indicate that although the overall distributional differences between the two groups were not highly pronounced, the use of Assemblr Edu tended to increase the proportion of students who achieved very high levels of learning motivation. Furthermore, the implementation of augmented reality-based Assemblr Edu demonstrated a significant positive influence on students' learning motivation compared to instruction without the integration of the media [14]. The use of Assemblr Edu, which provides interactive augmented reality visualizations, has also been reported to support students' conceptual understanding and promote more engaging learning activities [22].

The most notable difference in the categorical distribution was observed in the very high motivation category. The experimental group demonstrated a proportion of 33.33%, whereas the control group accounted for only 13.89%, representing a difference of 19.44 percentage points. These findings suggest that the integration of Assemblr Edu contributed positively to increasing the number of students who achieved very high levels of learning motivation compared to the conventional application of PBL without AR support. In other words, the incorporation of AR media demonstrated a favorable influence on students' learning motivation and tended to increase the probability of learners achieving optimal motivational levels. The application of augmented reality has been reported to effectively strengthen the attention and satisfaction components within the ARCS motivational model, thereby increasing students' engagement and enthusiasm during the learning process [23].

On the other hand, the proportion of students categorized in the high motivation level was greater in the control group (75.00%) than in the experimental group (61.11%). This finding does not indicate that the control group possessed better overall learning motivation; rather, it reflects differences in the motivational

distribution patterns between the two groups. Learning motivation in the control group tended to be concentrated within the high category, whereas the experimental group displayed a more distributed pattern because some students successfully reached the very high category, while others were still adapting to the augmented reality-based learning environment. This distribution pattern suggests that the effectiveness of AR media may be influenced by students' readiness and adaptability toward interactive technology-based learning environments [20].

A more comprehensive understanding was gained through the indicator-based analysis presented in Table 5, which offered greater analytical depth compared to aggregate mean comparisons alone. Across all six indicators of learning motivation, the experimental group consistently outperformed the control group. Nonetheless, the degree of influence varied among indicators, suggesting that the use of Assemblr Edu contributed differentially to distinct dimensions of students' motivational engagement.

Table 5 Percentages of Learning Motivation Indicators in the Experimental and Control Groups

No.	Indicator	Experimental Group		Control Group	
		%	Category	%	Category
1	The desire and willingness to achieve success	82.44	High	72.00	High
2	The internal drive and necessity to engage in learning	84.44	High	75.56	High
3	Future hopes and aspirations	81.85	High	77.59	High
4	The perceived value and appreciation of learning	79.07	High	74.81	High
5	The presence of stimulating and engaging learning activities	79.03	High	72.22	High
6	The availability of a supportive and conducive learning environment	72.22	High	65.56	Medium

The indicator-based analysis presented in Table 5 revealed that the percentage scores for all learning motivation indicators in the experimental group were higher than those in the control group. Indicator 1 (the desire and willingness to achieve success) showed a

percentage of 82.44% in the experimental group and 72.00% in the control group. This difference was reflected in the greater enthusiasm demonstrated by students in the experimental group during the learning process, as well as their persistence in preparing summaries of the reaction rate material, which was stimulated by the engaging visualizations and animations provided through Assemblr Edu.

Indicator 2 (the internal drive and necessity to engage in learning) reached 84.44% in the experimental group and 75.56% in the control group. Students in the experimental group appeared to be more active in asking questions and seeking information from various learning resources, whereas students in the control group tended to rely primarily on textbooks. This finding is consistent with the characteristics of Assemblr Edu, which enables the visualization of three-dimensional objects in a realistic manner, thereby stimulating students' curiosity and encouraging them to explore information more deeply [18].

Indicator 3 (future hopes and aspirations) achieved 81.85% in the experimental group and 77.59% in the control group. Students in the experimental group demonstrated greater effort to achieve better learning outcomes because the contextual learning experiences provided through Assemblr Edu helped them better understand the relevance of reaction rate concepts to real-life situations. Indicator 4 (the perceived value and appreciation of learning) obtained percentages of 79.07% in the experimental group and 74.81% in the control group. Although the forms of appreciation provided in both groups were relatively similar, the difference in percentages suggests that a more interactive learning experience contributed to students' perceptions of appreciation during the instructional process.

Indicator 5 (the presence of stimulating and engaging learning activities) obtained percentages of 79.03% in the experimental group and 72.22% in the control group. Meanwhile, Indicator 6 (the availability of a supportive and conducive learning environment) reached 72.22% in the experimental group, exceeding the control group, which obtained only 65.56% and fell within the moderate category. The superiority of the experimental group in these last two

indicators was closely associated with the interactive features and animations provided by Assemblr Edu. The augmented reality visualizations fostered a more interactive and conducive learning environment, which in turn prompted greater active participation among students throughout the successive stages of the instructional process [14].

Subsequent to the descriptive analysis, inferential statistical procedures were carried out to evaluate the research hypotheses. Prerequisite assumption tests, including normality and homogeneity of variance, were first performed. Since the learning motivation data from both groups satisfied the criteria of normal distribution and variance homogeneity, hypothesis testing proceeded using a parametric approach, specifically the independent samples t-test. The test yielded a calculated t-value of 3.33, which exceeded the critical t-value of 1.67 at a significance level of $\alpha = 0.05$ with 70 degrees of freedom. As $t_{\text{count}} (3.33) > t_{\text{table}} (1.67)$, the null hypothesis (H_0) was rejected in favor of the alternative hypothesis (H_1). Accordingly, at a 95% confidence level, it can be concluded that the integration of the Assemblr Edu AR-based platform within the PBL model exerts a statistically significant effect on students' learning motivation.

Although the differences in mean scores and motivational category distributions between the two groups appeared moderate descriptively, the inferential statistical results confirmed that these differences were statistically significant. This finding indicates that students' active engagement facilitated through Assemblr Edu consistently contributed to improvements in learning motivation [24]. The use of Assemblr Edu demonstrated a positive influence on students' learning motivation because the media provided a learning experience that differed from conventional instructional approaches [18]. Learning motivation represents an internal driving force that encourages individuals to learn and achieve educational goals; therefore, the selection of instructional media capable of stimulating and sustaining students' motivation plays an essential role in determining the success of the learning process [19].

Learning Outcomes

Learning outcomes in this study were measured through a post-treatment cognitive test consisting of ten learning objectives related to the topic of reaction rates. These objectives covered conceptual understanding domains (LO 2, 3, and 8), phenomenon analysis domains (LO 5 and 6), as well as procedural and calculation-based skills (LO 1, 4, 7, 9, and 10). The Minimum Criteria for Learning Objective Achievement (KKTP) implemented at SMAN 1 Gowa was set at a score of ≥ 75 for individual mastery, while classical mastery was achieved when at least 80% of students attained individual mastery. The diversity of learning objectives across different cognitive domains provided a comprehensive analytical framework for identifying which domains were most influenced by the use of Assemblr Edu, while also enabling comparisons with learning outcomes obtained through conventional instructional approaches.

Table 6 Descriptive Statistical Results of Learning Outcomes in the Experimental and Control Groups

No.	Descriptive Statistics	Experimental Group	Control Group
1.	Number of Students	36	36
2.	Highest Scores	100.00	95.00
3.	Lowest Rate	65.00	50.00
4.	Mean	82.91	75.69
5.	Median (Me)	80.00	80.00
6.	Modus (Mo)	80.00	90.00
7.	Standard Deviation (S)	10.37	13.42

Table 6 presents a descriptive statistical analysis of the learning outcomes across the two groups. Students in the experimental group attained a mean score of 82.91 (SD = 10.37), with a maximum score of 100 and a minimum score of 65. In contrast, the control group attained a mean score of 75.69 (SD = 13.42), with a maximum score of 95 and a minimum score of 50. The mean difference of 7.22 points indicates a notable descriptive disparity between the two groups, especially when interpreted in conjunction with the mastery learning data.

Beyond the difference in mean scores, the most notable aspect of this comparison lies in

the variability of the data. The standard deviation of the control group was comparatively higher than that of the experimental group, indicating greater heterogeneity in student achievement. While some students in the control group achieved high scores, others obtained relatively low results, leading to a wider score distribution. In contrast, the experimental group demonstrated a more consistent and evenly distributed pattern of learning outcomes.

These findings suggest that the integration of Assemblr Edu tends to produce more consistent learning outcomes among students. Furthermore, augmented reality-based learning not only contributes to improved average performance but also shows potential for reducing academic achievement gaps among students.

Table 7 Individual Completeness of Student's Learning Outcomes

Score Range	Category	Experimental Group	Control Group
≥ 75	Complete	30	23
< 75	Incomplete	6	13

Table 8 Classical Completeness of Students' Learning Outcomes

Group	Percentage of Individual Mastery	Percentage of Individual Non-Mastery	Category
Experimental Group	83.33%	16.67%	Complete
Control Group	63.88%	36.12%	Incomplete

Tables 7 and 8 present the analysis of individual learning mastery and class-level mastery for both groups. In the experimental group, 30 out of 36 students (83.33%) achieved individual mastery, while 6 students (16.67%) did not meet the Minimum Category for Learning Objective Achievement (KKTP). In the control group, 23 students (63.88%) achieved mastery, whereas 13 students (36.12%) did not reach the expected standard. Based on the classical mastery criteria applied at SMAN 1 Gowa, the experimental group was categorized as classically complete because more than 80% of students achieved individual mastery, whereas the control group did not meet the classical mastery threshold. The

difference of 19.45 percentage points between the two groups indicates that the integration of Assemblr Edu within the Problem-Based Learning model contributes positively to the attainment of expected learning standards. This finding is consistent with previous research indicating that Assemblr Edu-assisted instructional media can enhance students' cognitive learning outcomes through interactive and contextual visualization [6]. The augmented reality features of Assemblr Edu enable students to observe abstract chemical phenomena in a more concrete and meaningful way, thereby facilitating conceptual understanding and strengthening knowledge retention.

Further analysis of the learning objectives revealed an interesting pattern regarding the comparative effectiveness of Assemblr Edu. Learning Objective 2 (introducing the concept of reaction rate using collision theory and activation energy) showed a mastery rate of 91.67% in the experimental group compared to 87.50% in the control group. Learning Objective 3 (classifying reaction rate phenomena in everyday life) recorded 86.11% in the experimental group and 69.44% in the control group. Learning Objective 5 (analyzing reaction rates based on changes in concentration) reached 88.89% in the experimental group, significantly higher than the 60.11% in the control group. Learning Objective 8 (interpreting reaction sequence graphs) showed 97.22% in the experimental group compared to 83.33% in the control group. The superiority of the experimental group in these concept-based objectives indicates that Assemblr Edu tends to help students better associate abstract reaction rate concepts with real-world phenomena. Instructional design supported by Assemblr Edu has been shown to improve students' cognitive achievement in chemistry, as its three-dimensional visualization strengthens conceptual understanding that cannot be adequately achieved through textbooks alone [23].

In contrast, for several calculation-based and procedural learning objectives, the control group demonstrates higher achievement. Learning Objective 1 (linking collision theory and activation energy concepts) shows 84.72% in the control group compared to 73.61% in the experimental group. Learning Objective 7

(determining reaction order) records 84.72% in the control group and 80.28% in the experimental group. Learning Objective 9 (deriving the rate equation from experimental data) shows 61.11% in the control group compared to 52.78% in the experimental group. Learning Objective 10 (calculating the rate constant) reaches 91.67% in the control group and 83.33% in the experimental group. This pattern suggests that conventional instruction, which provides more structured practice in numerical problem-solving and direct engagement with mathematical formulas, may offer advantages in developing procedural analytical skills. Problem-Based Learning combined with structured conventional methods has been reported to be more effective for learning outcomes that require step-by-step procedural reasoning [6]. Therefore, Assemblr Edu and conventional instruction exhibit different but complementary strengths.

The overall average achievement across learning objectives shows that the experimental group obtained 82.87%, higher than the control group at 77.12%. This difference indicates the influence of the treatment applied to the experimental group. The use of Assemblr Edu enables students to interact directly with three-dimensional objects representing reaction rate concepts, making problem contexts more concrete and easier to understand [13]. This aligns with the characteristics of Problem-Based Learning, which emphasizes real-world problem presentation as the foundation for conceptual exploration, where Assemblr Edu functions as a bridge between abstract chemical representations and students' real learning experiences [5].

With respect to academic achievement, inferential analysis was similarly conducted to test the corresponding hypotheses. However, assumption testing revealed that the learning outcome data did not conform to a normal distribution, despite both groups exhibiting homogeneous variances. Consequently, the Mann-Whitney test was applied as a nonparametric alternative to the independent samples t-test. The analysis produced a Z-value of 1.99, which surpassed the critical Z-value of 1.64 at a significance level of $\alpha = 0.05$. As $Z_{\text{count}} (1.99) > Z_{\text{table}} (1.64)$, H_0 was rejected and H_1 was accepted. These findings confirm that the utilization of Assemblr Edu AR-based

media within the Problem-Based Learning model has a statistically significant effect on students' learning outcomes.

Overall, the findings indicate that the integration of Assemblr Edu in the PBL framework contributes positively to students' learning outcomes compared to instruction without augmented reality support. This effect is particularly evident in learning objectives that emphasize conceptual understanding, interpretation of chemical phenomena, and contextual analysis. Through three-dimensional visualization and interactive learning experiences, Assemblr Edu assists students in understanding abstract chemical concepts in a more concrete manner. However, conventional learning still demonstrates comparative advantages in several procedural and calculation-based objectives, suggesting that both approaches are complementary in chemistry education.

The positive contribution of Assemblr Edu to learning outcomes can be explained through several cognitive and pedagogical mechanisms. First, augmented reality visualization reduces students' extraneous cognitive load in understanding abstract chemical concepts. With direct access to three-dimensional representations, students are no longer fully dependent on mental interpretation of static textbook diagrams, allowing greater cognitive resources to be allocated to meaningful learning processes. This visualization strengthens conceptual understanding by simultaneously engaging visual and verbal processing channels [25].

Second, more contextual problem presentation within the PBL framework helps students activate prior knowledge more effectively. Through augmented reality visualization, reaction rate phenomena can be directly linked to real-life contexts such as combustion, fermentation, and corrosion. This contextualization supports schema construction and enhances long-term understanding.

Third, previously identified increases in learning motivation also contribute to improved learning outcomes. Learners with higher motivation tend to exhibit elevated levels of engagement, persistence, and concentration throughout the instructional process. The reciprocal relationship between motivation and achievement forms a positive reinforcement

cycle in which engagement enhances understanding, which in turn strengthens confidence and motivation. This highlights a positive relationship between augmented reality-based learning environments, student engagement, and academic achievement [23].

CONCLUSIONS AND SUGGESTIONS

The findings of this study, corroborated by the preceding discussion, demonstrate that incorporating Assemblr Edu augmented reality media into a Problem-Based Learning (PBL) model produced a statistically significant and positive effect on both the learning motivation and academic achievement of eleventh-grade students at SMA Negeri 1 Gowa in the domain of reaction rate instruction. The experimental group consistently obtained higher mean scores across both measured variables, recording a mean motivation score of 80.61 in comparison to the control group's 73.94, and a mean academic achievement score of 82.91 relative to the control group's 75.69. These results collectively affirm the effectiveness of the applied instructional intervention in improving student learning outcomes.

Therefore, Assemblr Edu integrated with Problem-Based Learning can be considered an effective alternative pedagogical approach for fostering student engagement and academic performance, particularly in abstract chemistry topics such as reaction rates.

Chemistry educators are therefore encouraged to consider adopting Assemblr Edu as a supplementary instructional medium within their classroom practice. Furthermore, future investigations are warranted to evaluate its applicability across diverse subject areas, educational levels, and instructional contexts, with the aim of broadening and consolidating the generalizability of these findings.

ACKNOWLEDGEMENT

The researchers wish to convey their deepest appreciation to SMA Negeri 1 Gowa for granting permission and providing support for the implementation of this research. The researchers also sincerely appreciate the cooperation and participation of the chemistry teacher as well as the students of class XI.1 and XI.3 who were involved in the learning

activities during the course of the study. Furthermore, the researchers offer their gratitude to all parties who contributed to the collection of data, statistical analysis, and the completion of this research report.

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