



## **The influence of project-based learning assisted by augmented reality-based photosynthesis diorama on improving learning outcomes**

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**Abstract:** This study investigated the effect of AR-based diorama-assisted project-based learning on fourth-grade students' understanding of photosynthesis and learning outcomes at Kalibanteng Kidul 01 Elementary School. A quasi-experimental non-equivalent control group design was employed, involving 60 Grade 4 students divided into an experimental group and a control group. The experimental group received instruction through project-based learning supported by an AR-based photosynthesis diorama, while the control group was taught using conventional instructional methods. Data were collected through pretests and posttests and analysed using normality and homogeneity tests, independent-samples t-tests, and N-Gain analysis. The results showed that the data met the assumptions of normality and homogeneity. The independent samples t-test indicated a statistically significant difference in posttest learning outcomes between the experimental and control groups ( $t = -5.088$ ,  $p < 0.05$ ). In addition, the experimental group achieved a higher mean posttest score and a higher N-Gain value than the control group. These findings demonstrated that AR-based diorama-assisted project-based learning was more effective than conventional instruction in improving students' understanding of photosynthesis and learning outcomes.

**Keywords:** augmented reality, photosynthesis diorama, project-based learning, learning outcomes

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### **Introduction**

Education is generally understood as a deliberate process to organise learning activities and environments to discover students' potential. The definition reflects the learners' holistic development, which constitutes the fundamental goals of education including spiritual values, moral character, intellectual capacity, and 21st-century skills (Bulkani et al., 2025; Yuni et al., 2021). In Indonesia, recent efforts to improve education are reflected in the draft National Education System Law (*RUU SISDIKNAS*), currently under discussion in the House of Representatives. The draft emphasises extending compulsory education to 12 years, strengthening governance, and expanding access to quality education. These measures are constitutionally grounded in Article 31, Paragraph 1 of the 1945 Constitution, which guarantees every citizen the right to education (Wingkolatin et al., 2024).

Introduced in 2022, the Merdeka Curriculum has become Indonesia's predominant curriculum (Astuti et al., 2024; Efendi et al., 2023; Syahrir et al., 2024). Merdeka, meaning "freedom", refers to the curriculum's focus on autonomy and flexibility in the educational process, allowing teachers to design, develop, and implement learning programs centered to students' needs (Nisa & Andaryani, 2023; Sukarno & Jinabe, 2024). The curriculum has been the subject of controversy, prompting the government to discuss its improvement. One issue concerns the merger of elementary-level Natural Science and Social Science into a single subject, known as *Ilmu Pengetahuan Alam dan Sosial* (IPAS) or natural and social sciences (Rizqi et al., 2023). This merger remains controversial, as the two represent distinct fields of knowledge (Suryani et al., 2025; Wulansari & Tyas, 2025). Despite this, the subject



continues to play a central role in students' self-development, as teachers are encouraged to develop lesson plans focused on literacy and numeracy skills (Zainatunnisa et al., 2025).

Challenges persist in implementing Natural and Social Sciences learning at the elementary level due to the merger. Preliminary observations at Kalibanteng Kidul 01 Elementary School indicated that grade 4 students' learning outcomes are generally low, as reflected in academic scores and supported by teacher interviews. Several students have yet to meet the Merdeka Curriculum's *Kriteria Ketercapaian Tujuan Pembelajaran* (KKTP), which is comparable to learning objectives and success criteria in Anglophone educational contexts. Furthermore, students generally show limited engagement during classroom activities, particularly when exploring abstract scientific concepts such as photosynthesis.

Several learning models align with the Merdeka Curriculum's objectives, with project-based learning serving as one that uses projects as the core of its instruction (Mustadi et al., 2024). It guides students to discover, evaluate, interpret, and synthesise information through complex, contextual activities to produce meaningful learning outcomes (Asytri et al., 2023; Maharani & Nurharini, 2024; Nawangsari et al., 2022). It is regarded as an effective learning model that improves students' motivation, participation, learning outcomes, and deep conceptual understanding (Fahrezi et al., 2020; Rahmawati et al., 2024; Salaman et al., 2023). Besides learning models, the use of instructional media helps to facilitate students' engagement in the learning process (Budiarto et al., 2025; Saputri et al., 2025). Once limited to supporting teachers' needs, instructional media now encompass digital tools that enhance learning through technological advancement, including augmented reality, which projects three-dimensional illustrations into the physical environment (Alfitriani et al., 2021; Kristanto, 2016; Rahmawati & Andaryani, 2025).

Numerous studies have examined the implementation of project-based learning assisted by digital tools to improve students' learning outcomes. Saadiyah and Anjarwati (2022), Wahyuningsih et al. (2024), and Wijaya and Purwati (2024) found that project-based learning combined with AR-based media improved students' learning outcomes, particularly in creating among digital-native learners and in understanding the solar system. Muliawati et al. (2023) applied a different medium and method using a diorama through quasi-experimental design, which resulted in improvements in students' learning, particularly in creative thinking related to biodiversity. At the secondary level, Biazus and Mahtari (2022) confirmed the effectiveness of project-based learning in improving secondary school students' critical thinking in Lombok. Beyond the Indonesian context, Yusri et al. (2024) provided global evidence of project-based learning's effectiveness through a review of 34 Scopus-indexed studies, which reported consistent positive effects on student learning outcomes. Similarly, Guo et al. (2020) identified project-based learning as a potentially effective instructional approach that improves student learning in higher education.

Prior studies demonstrate the effectiveness of project-based learning when assisted by digital tools, yet several gaps remain. Many, such as Biazus and Mahtari (2022), did not integrate specific and tangible instructional media that connect digital learning with physical learning experiences. Second, meta-analyses by Yusri et al. (2024) and Guo et al. (2020) revealed limited attention to the synergy between instructional media and the physical products during the project-based learning activities. Thus, an empirically grounded approach is needed to address the low learning outcomes observed among grade 4 students at Kalibanteng Kidul 01 Elementary School, particularly in understanding abstract science concepts such as photosynthesis. This approach draws on prior research by integrating augmented reality and dioramas within a project-based learning framework. As highlighted by Zhang and Ma (2023), integrating instructional media into project-based learning is essential for enhancing instructional effectiveness, while careful selection of appropriate sample groups remains particularly important when teaching abstract science concepts.

This study presents novelty by investigating the full integration of AR-based diorama media with the complete project-based learning syntax in elementary-level natural and social sciences at Kalibanteng Kidul 01 Elementary School. Prior studies have largely examined the use of project-based learning or digital media separately, leaving the full integration of AR-based and tangible instructional media across the entire project-based learning syntax underexplored, especially in elementary-level contexts involving abstract science concepts such as photosynthesis. Addressing this gap, the present research aims to examine the effect of AR-based diorama-assisted project-based learning on fourth-grade students' understanding of photosynthesis and their learning outcomes. The findings of this study are expected to contribute to education in Indonesia by providing empirical evidence for integrating

student-centred learning models and digital learning media in elementary science classrooms, in line with 21st-century learning requirements.

### Methods

The primary aim of this study is to examine the effects of AR-based diorama-assisted project-based learning on Grade 4 students' understanding of photosynthesis and learning outcomes at Kalibanteng Kidul 01 Elementary School. A quasi-experimental non-equivalent control group design was adopted in this study, as it allowed the use of pretest and posttest measures across both experimental and control groups to address the study's objectives (Krass, 2016; Whitney, 2000). Similar designs have been extensively used in educational research involving student subjects in natural science learning, as employed by Nawangsari et al. (2022), Pangestu et al. (2024), and Pebriani (2017). Quasi-experimental research commonly includes two designs: the non-equivalent control group design with pretests and posttests in both groups, and the one-group pretest–posttest design. The former provides a comparison group and stronger internal validity, whereas the latter is weaker due to the absence of a control group, making causal attribution more difficult. Therefore, the present research employed the former design to enable a more concrete evaluation of the intervention's effect on students' learning outcomes (Marsden & Torgerson, 2012; Stratton, 2019). A non-equivalent control group design was used, with the experimental group receiving the treatment and the control group serving as a comparison group (Krishnan, 2019; Sørli & Ogden, 2014). The key difference lay in the selection of the groups, which were not chosen randomly (Sugiyono, 2016). Table 1 below illustrates the non-equivalent control group design.

**Table 1.** Study Design

| Group              | Pretest | Treatment | Posttest |
|--------------------|---------|-----------|----------|
| Experimental group | $O_1$   | X         | $O_2$    |
| Control group      | $O_3$   | -         | $O_4$    |

Legend:

- $O_1$  &  $O_3$  : Both groups completed the same pretest prior to the treatment to determine students' initial levels of understanding.
- X : The experimental group received the treatment
- $O_2$  : The experimental group completed a posttest after the treatment to examine students' learning outcomes.
- $O_4$  : The control group completed a posttest after the treatment to examine students' learning outcomes.

The study population comprised Grade 4 and 5 students enrolled at Kalibanteng Kidul 01 Elementary School across classes IV-B, -C, and V-A. This study involved 90 students in the 2025/2026 academic year, organised into three class-based groups of 30 participants each. Saturated sampling was employed due to the small population size; consequently, all participants were included to minimise sampling error and enhance the representativeness of the findings. The study stages began with (1) an introduction of the initial conditions through interviews and observations of teachers and school principals; (2) preparation of facilities and supporting materials required for implementing an AR-based photosynthesis diorama; (3) conducting the initial test (pretest); (4) providing the learning treatment; (5) conducting the final test (posttest); and (6) processing and analysing the study data. Based on the methodological explanation, sampling, and stages as explained previously, the study hypotheses were:

- $H_o$  : The results showed no significant effect of the treatment on the Natural and Social Sciences learning outcomes of Grade 4 students at Kalibanteng Kidul 01 Elementary School.
- $H_a$  : The results showed a significant effect of the treatment on the Natural and Social Sciences learning outcomes of Grade 4 students at Kalibanteng Kidul 01 Elementary School.

This study employed the following data collection techniques: initial observations, interviews with teachers in Grade 4 classes, interviews with other involved parties, student tests, including pretests and posttests, and documentation. Data analysis began with validity and reliability testing to ensure the

suitability of the test instruments used. Validity and reliability tests were conducted at Kalibanteng Kidul 01 Elementary School, with a sample of 30 students per class. Meanwhile, the prerequisite analysis tests were performed, including normality and homogeneity tests based on the Kolmogorov Smirnov method. Once all prerequisite tests were met, a parametric statistical analysis was conducted using the independent-samples t-test. Additionally, the N-Gain test was used to assess students' learning gains. All data processing was performed using SPSS version 25.

## Results and Discussion

### Results

As mentioned earlier, data collection did not involve Grade 4 classes but was limited to IV-B, serving as the experimental group, and IV-C, serving as the control group. Grade 5 from class V-A, however, only served as the preliminary testing group. IV-B received treatment through AR-based diorama-assisted project-based learning, whereas IV-C underwent traditional learning methods commonly practised by teachers. Data collection was conducted across three sessions per class, including the pretest, treatment, and posttest. The results obtained from the pretest and posttest, together with the normality and homogeneity analyses, are presented below.

#### 1. Results of the Trial Test

A preliminary test was conducted with V-A students to determine the research instrument's validity and reliability and to confirm its suitability for examining the target variables.

##### a) Item Validity Test of the Trial Questions

Item validity was examined using a two-tailed Pearson product-moment correlation at the 0.05 significance level. The instrument trial was conducted with 30 students from V-A ( $n = 30$ ). Based on this sample size, the critical  $r$ -table value was 0.361. An item was qualified as valid when its calculated correlation coefficient ( $r$ ) was greater than the  $r$ -table value. The validity test results indicated that 32 test items met the validity criteria.

##### b) Item Reliability Test of the Trial Questions

Instrument reliability was examined after the validity test to ensure the consistency of the measurement items in assessing the intended construct. A predetermined reliability threshold was used as the evaluation criterion. The reliability test was conducted on all 50 trial items prior to item selection, and the results yielded a Cronbach's Alpha coefficient of 0.871. This value suggests that the research's instrument demonstrates high reliability and meets the reliability criteria. Table 2 below summarises the reliability test results.

Table 2. Reliability Test Item

| Reliability Statistics |            |
|------------------------|------------|
| Cronbach's Alpha       | N of Items |
| 0.871                  | 50         |

A trial test was conducted with 30 students from V-A using 50 questions. As seen in Table 2, the results were examined through validity and reliability tests, and the analysis determined that 20 questions were selected for use as the research instrument. The selection was based on item validity, indicated by correlation coefficients  $\geq 0.361$ , and on the proportional reliability of the items. The finalised instrument was subsequently used as the pretest and posttest in the main study.

#### 2. Initial Data Analysis Results

The pretest results showed that students in the IV-B experimental group scored between 27.16 and 87.65. In the IV-C control group, pretest scores ranged from 23.45 to 86.41. These results indicate that both groups demonstrated varied pre-treatment abilities.

##### a) Normality Test of Pretest Initial Data

The Kolmogorov-Smirnov test was used to assess the normality of the pretest data at the 0.05 significance level. A significance value (Sig.) greater than 0.05 indicates that the data are normally distributed, as determined by the test. As shown in Table 3, the pretest normality test results

indicated that the IV-C had a significance value of 0.200, while the IV-B had a significance value of 0.124. Since both values exceed 0.05, the pretest data for both groups are normally distributed.

**Table 3.** Pretest Data Normality Test Results

| Class                             | Kolmogorov-Smirnov <sup>a</sup> |    |       |
|-----------------------------------|---------------------------------|----|-------|
|                                   | Statistics                      | df | Sig.  |
| Pretest A<br>(Control class)      | 0.101                           | 30 | .200  |
| Pretest B<br>(Experimental class) | 0.142                           | 30 | 0.124 |

**b) Pretest Initial Data Homogeneity Test**

**Table 4.** Pretest Data Homogeneity Test Results

|               | Levene Statistics | df1 | df2 | Sig.  |
|---------------|-------------------|-----|-----|-------|
| Based on Mean | 1.443             | 1   | 58  | 0.235 |

Levene's test was used to examine the homogeneity of the pretest data. A significance value (Sig.) greater than 0.05 indicates that the data are homogeneous, as determined by the test. As shown in Table 4, the significance value based on the mean was 0.235. Since this value exceeds 0.05, the pretest learning outcomes of both groups are considered homogeneous and were comparable prior to the intervention. Following the completion of all prerequisite tests on the initial data, the study proceeded to the treatment stage. The treatment was applied to IV-B through the implementation of project-based learning, using an AR-based diorama as the instructional medium for photosynthesis.

**3. Final Data Analysis Results**

Based on the posttest data from the IV-B experimental group, students' scores ranged from 71.60 to 100, with a mean score of 87.73. These results indicate that students achieved a high level of understanding and learning outcomes in photosynthesis after participating in project-based learning assisted by an AR-based diorama. Meanwhile, the IV-C control group's posttest scores ranged from 51.85 to 92.59, with a mean score of 75.03. These suggest that students in the control group also improved in learning outcomes, though achievement varied, with some students attaining lower scores while others performed at higher levels.

**a) Normality Test of Posttest Final Data**

The Kolmogorov–Smirnov test was used to examine the normality of the posttest data for both groups, with a significance level of 0.05. A significance value (Sig.) greater than 0.05 indicates that the data are normally distributed, as determined by the test. As shown in Table 5, the significance value for the IV-B was 0.200, while the IV-C obtained a significance value of 0.193. Since both values exceed 0.05, the posttest data for both groups are normally distributed.

**Table 5.** Posttest Data Normality Test Results

| Class                              | Kolmogorov-Smirnov <sup>a</sup> |    |       |
|------------------------------------|---------------------------------|----|-------|
|                                    | Statistics                      | df | Sig.  |
| Posttest A<br>(Control class)      | 0.132                           | 30 | 0.193 |
| Posttest B<br>(Experimental class) | 0.105                           | 30 | .200  |

**b) Final Posttest Data Homogeneity Test**

**Table 6.** Posttest Data Homogeneity Test Results

|               | Levene Statistics | df1 | df2 | Sig.  |
|---------------|-------------------|-----|-----|-------|
| Based on Mean | 2.358             | 1   | 58  | 0.130 |

Levene's test was used to examine the homogeneity of the posttest data. A significance value (Sig.) greater than 0.05 indicates that the data are homogeneous, as determined by the test. As shown in Table 6, the significance value based on the mean was 0.130. Since this value exceeds 0.05, the posttest learning outcomes of both groups are considered homogeneous.

Based on the results of the normality and homogeneity tests conducted on the posttest data, the data from both groups were found to be normally distributed and homoscedastic. As the assumptions of normality and homogeneity were met, an independent-samples t-test was subsequently conducted for further analysis.

#### 4. Hypothesis Testing

**Table 7.** Results of the Independent Sample T-test on Learning Outcomes

|       |                         | <b>F</b> | <b>Sig.</b> | <b>t</b> | <b>df</b> | <b>Sig. (2-tailed)</b> | <b>Mean differences</b> |
|-------|-------------------------|----------|-------------|----------|-----------|------------------------|-------------------------|
| Value | Equal variances assumed | 2.358    | 0.130       | -5.088   | 58        | 0.000                  | -12.69500               |

The results of the independent sample t-test on students' learning outcomes are presented in Table 7. Based on the analysis assuming equal variances, the obtained t-value was -5.088, while the critical t-table value at a significance level of 0.05 with 58 degrees of freedom was 2.001. In addition, the two-tailed significance value was 0.000, which is less than 0.05. Therefore, the null hypothesis ( $H_0$ ) was rejected, and the alternative hypothesis ( $H_1$ ) was accepted.

These results indicate a statistically significant difference in learning outcomes between students in the IV-B who were taught using project-based learning assisted by an AR-based diorama and students in the IV-C who were taught using traditional instructional methods.

#### 5. N-Gain Test

The N-Gain test was conducted to examine improvements in students' learning outcomes. The gain score was calculated as the difference between the pretest and posttest scores. The analysis used the differences between the mean pretest and posttest scores of both groups to compute the N-Gain index. The results of the n-gain calculation are presented in Table 8.

**Table 8.** N-Gain Results

| <b>Type of Class</b>    | <b>Mean Score</b> |                 | <b>Average differences</b> | <b>N-Gain %</b> | <b>Criteria</b> |
|-------------------------|-------------------|-----------------|----------------------------|-----------------|-----------------|
|                         | <b>Pretest</b>    | <b>Posttest</b> |                            |                 |                 |
| IV-C Control Class      | 56.02             | 75.03           | 19.01                      | 41.00%          | Low             |
| IV-B Experimental Class | 54.92             | 87.73           | 32.82                      | 72.35%          | High            |

Based on the data presented in Table 8, the analysis showed that the IV-C had an N-Gain score of 41.00%, which is categorised as low. In contrast, the IV-B achieved an N-Gain of 72.35%, which is categorised as high. Overall, these findings indicate that the improvement in learning outcomes in the experimental group was greater than that in the control group.

#### Discussion

Based on the initial data analysis, the students' initial abilities in the IV-B experimental group and the IV-C control group were comparable. This is reflected in the pretest results, where the IV-B obtained a mean score of 54.92 (range: 27.16-87.65), while the IV-C achieved a mean score of 56.02 (range: 23.45-86.41). The normality test using the Kolmogorov-Smirnov method indicated that the pretest data for both groups were normally distributed, as evidenced by p-values of 0.124 for the IV-B and 0.200 for the IV-C. Furthermore, the homogeneity test yielded a significance value of 0.235, which exceeds the 0.05 threshold, indicating that the variances between the two groups were homogeneous. The variation in pretest scores may reflect differences in students' prior knowledge of natural and social sciences concepts, levels of engagement during previous science lessons, and individual motivation to learn abstract topics such as photosynthesis, which aligns with studies showing that elementary students often struggle with conceptualising biological processes (Apriani et al., 2025; Puspita et al., 2025). With the assumptions of normality and homogeneity satisfied, further statistical analysis could be validly conducted.

Following the treatment, the IV-B experimental group, which received the project-based learning assisted by AR-based photosynthesis diorama, demonstrated higher learning outcomes than the IV-C control group, which underwent traditional instruction. Descriptively, the posttest scores of the IV-B

ranged from 71.60 to 100, with a mean score of 87.73. In comparison, the posttest scores of the IV-C ranged from 51.85 to 92.59, with a mean score of 75.03. These findings indicate that the treatment was effective in enhancing students' understanding of photosynthesis material. This effectiveness can be attributed to the combined impact of active engagement in project creation and interactive AR visualisations, which facilitated deeper cognitive processing, improved conceptual understanding, and increased motivation and collaboration among students. The results of the posttest normality test using the Kolmogorov-Smirnov method indicated that the posttest data for both groups were normally distributed, with p-values of 0.200 and 0.193, respectively. Furthermore, the posttest homogeneity test yielded a p-value of 0.130 ( $> 0.05$ ), indicating that the data met the assumptions required for a parametric hypothesis test.

Based on these prerequisite tests, a further hypothesis test was conducted using an independent-samples t-test. The analysis revealed that students in the IV-B experimental group achieved higher learning outcomes than those in the IV-C. The independent-samples t-test produced a t-value of  $-5.088$  and a significance value of  $0.000$  ( $< 0.05$ ). The negative sign of the t-value indicates the direction of the mean difference, namely that the mean posttest score of the experimental class was higher than that of the control class. Since the significance value was less than  $0.05$ , the null hypothesis ( $H_0$ ) was rejected, and the alternative hypothesis ( $H_a$ ) was accepted. These results indicate a statistically significant difference in learning outcomes between the two groups.

The n-gain analysis further supported these findings. The IV-B experimental group obtained an N-Gain value of  $72.35\%$ , falling into the high category, while the IV-C control class achieved an N-Gain value of  $41.00\%$ , categorised as low. This substantial  $31\%$  disparity in N-Gain reflects the cognitive limitations of conventional instructional methods when addressing abstract concepts like photosynthesis. These limitations are effectively bridged by AR visualisations, which allow students to comprehend the microscopic complexity of plant metabolism that is otherwise inaccessible through traditional verbal or two-dimensional explanations. Overall, the experimental group demonstrated greater improvement in learning outcomes than the control group. This finding shows that the research objective of improving students' learning outcomes and engagement in natural and social sciences, particularly in understanding photosynthesis, through the implementation of AR-assisted project-based learning, has been successfully achieved. Therefore, it can be concluded that the implementation is effective in facilitating students' learning of natural and social sciences material. Figure 1 shows students from IV-B collaborating on group projects during the learning process.



**Figure 1.** Student Activities in Working on Projects

The project-based learning syntax was fully implemented in this study, including identifying essential questions, planning the project, organising the schedule, supervising project implementation, assessing the results, and reflecting on the learning process (Maulidia & Istiqomah, 2023; Pratiwi, 2021; Rukmi et al., 2025). Thus, students in the experimental group actively engaged with an AR-based photosynthesis diorama rather than passively receiving learning materials like those in the control group. They actively engaged in group-based project activities involving collaborative planning, task division, and product creation, during which students exchanged ideas, expressed opinions, and cooperated in utilising the diorama. These activities not only strengthened students' conceptual understanding but also enhanced teamwork, communication, and responsibility. Specifically, the 'creating the product' stage emerged as the most critical contributor to the significant posttest gains. For fourth-grade students, who are still transitioning from concrete to formal operational thinking, this stage is crucial because it

transforms abstract theoretical knowledge into a tangible, physical manifestation. By physically constructing the diorama and layering it with AR tools, students move beyond surface learning to a state of ‘learning by making,’ which strengthens their mental models of the photosynthesis process. Project-based learning facilitates the exploration of students’ potential by engaging them in creative, innovative project-based tasks. When integrated with an AR-based photosynthesis diorama, it actively involves students from planning to implementation (Dewi, 2022; Satria et al., 2025; Sinambela et al., 2022), as shown in Figure 2, which presents the students’ AR-based photosynthesis diorama project.



**Figure 2.** Results of the Photosynthesis Diorama Project Based on Augmented Reality

The project results indicate that students collaboratively completed an AR-based photosynthesis diorama according to the planned stages. Each student's group successfully presented the photosynthesis process perfectly using the AR-based diorama. Throughout the project, students actively engaged in discussion, task distribution, and collaboration, which supported the achievement of learning objectives. This activity enhanced students’ motivation, creativity, problem-solving skills, teamwork, and communication, while also training them to manage learning resources effectively. These collaborative and hands-on activities likely contributed to deeper cognitive processing, as students were not only observing but also constructing and explaining the photosynthesis process, which reinforced conceptual understanding and retention, resulting in a more meaningful learning experience and improved learning outcomes.

The positive learning outcomes and enhanced engagement observed in this study are consistent with the findings of Hunaepi et al. (2023) and Irmade et al. (2022), which reported that the use of augmented reality in learning has a significant positive effect on students’ academic achievement, motivation, comprehension, and engagement across various educational contexts. However, the present study extends these findings by demonstrating greater learning gains from the full integration of project-based learning syntax with AR-based diorama media. While Hunaepi et al. (2023) focused on the independent effect of AR and reported an average posttest improvement of approximately 15%, the current study achieved a substantially higher learning gain of 31% based on N-Gain analysis. This difference suggests that combining AR with a fully implemented project-based learning cycle amplifies instructional effectiveness beyond the use of AR alone. On the other hand, Irmade et al. (2022) focused on perceptual engagement in early childhood education rather than posttest outcomes in elementary science, thus highlighting the contextual novelty and added rigor of this study. The increased effectiveness can be attributed to several distinctive features of the present study, including the complete implementation of project-based learning syntax, the integration of collaborative project work with AR-based diorama media, and the focus on photosynthesis, an abstract topic that poses cognitive challenges for fourth-grade students. Overall, these findings support Piaget’s constructivist theory, which emphasises active, contextual, and hands-on learning, facilitated through project-based and collaborative learning (Dennick, 2016; Fahrezi et al., 2020; Kumari, 2022; Salaman et al., 2023). Student activities for observing the photosynthesis process using AR-based photosynthesis diorama media are shown in Figure 3.



**Figure 3.** Student Activities: Observing the Photosynthesis Process

Previous studies have highlighted that project-based learning enhances conceptual understanding through active inquiry, collaboration, and reflection (Fahrezi et al., 2020; Rehman et al., 2024; Salaman et al., 2023; Wang et al., 2025; Zhang & Ma, 2023), while other research has shown that augmented reality facilitates three-dimensional visualisation of abstract scientific concepts (Alfitriani et al., 2021; Kristanto, 2016). The present study synthesises these two approaches by fully integrating AR into the full project-based learning framework, allowing students not only to observe but also to construct and explain the photosynthesis process. This integration promotes deeper cognitive processing and meaningful learning, which likely explains the higher learning gains observed in this study.

An AR-based photosynthesis diorama presents abstract concepts, such as photosynthesis, through interactive three-dimensional visualisations. These visualisations provide perspectives that conventional explanations cannot, thereby making it easier for students to understand scientific material. This effectiveness stems from AR's ability to bridge the gap between macro-level observations (simply seeing a plant) and micro-level biological processes, such as the chemical reactions occurring within the leaf. By externalising these invisible processes, AR significantly reduces students' cognitive load, as they no longer need to mentally visualise complex, unseen stages of metabolism. Diorama, on the other hand, helps students visualise the photosynthesis process in plants more concretely (Apriani et al., 2025). Such media, however, is not novel, as studies have shown that AR-based diorama media can enhance comprehension, improve learning performance, and foster interest and critical thinking in students (Puspita et al., 2025; Wahyuningtyas et al., 2023; Wijaya & Purwati, 2024). Integrating project-based learning with an AR-based photosynthesis diorama not only improves learning outcomes but also enriches the overall quality of the learning experience, making it more contextual, interactive, and meaningful. Consequently, this approach effectively enhances the learning outcomes of fourth-grade students at Kalibanteng Kidul 01 Elementary School, particularly in the natural and social sciences subject.

### **Conclusion**

Based on the overall results of the prerequisite tests, hypothesis testing, and N-Gain analysis, it can be concluded that students in the IV-B experimental group experienced a substantially greater improvement in learning outcomes than those in the IV-C control group. This conclusion is supported by the higher posttest mean score for IV-B ( $M = 87.73$ ) compared to IV-C ( $M = 75.03$ ), as well as by the independent-samples t-test, which showed a statistically significant difference between the two groups ( $t = -5.088$ ,  $p < 0.05$ ). Furthermore, the N-Gain analysis revealed that the IV-B achieved a high gain score of 72.35%, while the IV-C obtained a low gain score of 41.00%. These statistical findings indicate that the implementation of project-based learning assisted by an AR-based photosynthesis diorama was more effective than traditional instruction in improving students' understanding of photosynthesis and provide a strong empirical basis for discussing the instructional effectiveness and pedagogical implications of integrating such treatments in natural and social sciences.

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