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The Role Of Augmented Reality In Enhancing Students' Ability To Translate Scientific Thinking Into Effective Communication

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Abstrak
Success depends not only on having brilliant ideas but also on how those ideas are conveyed. Effective communication is a fundamental prerequisite for success in human interaction. This research is motivated by the understanding that without good communication, all positive desires risk failing to be fully actualized. In the context of science learning, there are two keys to success: critical thinking skills to generate substantial ideas and social communication skills to disseminate them effectively. This research aims to develop Augmented Reality (AR)-based student worksheets (LKPD) to improve elementary school students' critical thinking and social communication skills in science learning. Using the ADDIE model of Research and Development (R&D) with a quasi-experimental design, the research instrument has been tested for validity and reliability. Independent t-test analysis shows a significant difference in achievement between the experimental and control groups, with an effect size (Cohen's d) in the large category. The results of the study are expected to demonstrate that integrating Augmented Reality into education not only sharpens students' logical thinking but also trains them to articulate complex ideas into easily understood messages, thereby balancing intellectual intelligence and social communication skills.

Keywords: *Augmented Reality (AR); Critical Thinking; Student Worksheets; Social Communication.*

1. Introduction

In the increasingly complex dynamics of modern life, technical abilities (hard skills) alone are no longer sufficient to guarantee individual success. A lot of research on professional and social success says that communication skills are one of the most important skills. Communication is more than just passing on information; it's a necessary link between ideas and the real world. (Ennis, 2011; Facione, 2015; Johnson & Johnson, 2014; University of Queensland & Gillies, 2016)Robles (2012) said that business leaders put honesty and communication at the top of the list of traits that make someone successful at work, even more important than technical skills.

In human interactions, however, there is sometimes a paradox: having excellent intentions or great ideas does not always lead to good results. If you do not know how to communicate well, good intentions can get twisted, leading to misunderstandings or failed implementation. Lunenburg (2010) asserts that failures in the communication process are often a major obstacle to organizations and individuals achieving their goals. This means that a clear vision and good intentions require the "vehicle" of competent communication skills to be accepted, understood, and supported by others.

Furthermore, in the context of 21st-century education, communication cannot stand alone; It must go hand in hand with critical thinking skills. Wagner (2008), in his analysis of The Global Achievement Gap, identified that critical thinking and effective oral communication are two of the seven survival skills students must possess. If not expressed well, important ideas that come from deep cognitive processes will stay dormant. On the other hand, eloquence without critical thinking will only lead to empty speech.

So, education is a strategic place where you can learn both of these skills at the same time. Educational institutions are required not only to transfer scientific knowledge but also to create an environment that stimulates students to critically process information and convey it socially. This integration of critical thinking and clarity of delivery is the key to true success, which needs to be systematically trained and developed through appropriate learning interventions in schools.

Students in the 21st century need to learn not only facts but also how to think critically and communicate with others. These are important skills for dealing with the complicated problems and demands of working together in today's world. Students benefit from critical thinking skills. Examine data, assess arguments, and arrive at logical conclusions, while social communication facilitates the sharing

of ideas and cooperative learning (Ennis, 2011; Facione, 2015; Johnson & Johnson, 2014; University of Queensland & Gillies, 2016).

Nonetheless, numerous studies indicate that learning in elementary schools remains predominantly focused on reproductive activities, offering limited opportunities for students to participate in comprehensive discussion, exploration, and reflection. This condition impacts the development of critical thinking skills and social interactions in students in the classroom (OECD, 2023; Slavin, 2015). This condition is reinforced by research findings in elementary schools showing that learning remains dominated by reproductive activities, oriented toward memorization, and with minimal space for discussion and conceptual exploration (Putri dkk., 2022; Sani, 2019). So, students' social interactions in learning are also often passive, with little participation in discussions and the chance to share their thoughts.

Elementary school students' social communication skills also encounter numerous challenges in learning practices, alongside cognitive aspects. Numerous studies indicate that classroom interactions are predominantly characterized by unidirectional communication from teacher to student, whereas students' opportunities for discussion, opinion expression, and active collaboration are relatively limited (Johnson & Johnson, 2014; Slavin, 2015; University of Queensland & Gillies, 2016). In elementary school science classes, students often work alone on worksheets (LKPD), which means they haven't had the chance to learn how to share ideas, listen to what other students have to say, and build a shared understanding (Putri dkk., 2022). However, social communication is an important foundation for cooperative learning and social constructivism, because through interaction and the negotiation of meaning, students can build a more profound understanding (University of Queensland & Gillies, 2016). The limited availability of learning tools designed to facilitate discussion and collaboration is one factor contributing to students' low social communication skills in the classroom.

Previous research has shown that Student Worksheets (LKPD) play a strategic role in guiding student learning activities, particularly when designed based on HOTS and active learning. A number of studies have shown that systematically developed LKPDs can help elementary school students improve their higher-order thinking skills, problem-solving skills, and interest in learning (Hidayati et al., 2021; Prastowo, 2015; Putri et al., 2022). However, the majority of developed LKPDs concentrate on individual cognitive dimensions and have not

been specifically crafted to enhance social interaction and communication among students during the learning process.

As educational technology progresses, numerous studies have commenced the integration of digital media and Augmented Reality (AR) into learning environments to facilitate the visualization of abstract concepts and enhance student engagement (Akçayır & Akçayır, 2017; Garzón dkk., 2019). Nevertheless, the application of augmented reality through digital dioramas directly incorporated into student worksheets (LKPD) as an educational resource remains relatively underexplored in elementary education research. Current research predominantly categorizes digital dioramas as visual aids or demonstration instruments, with limited systematic investigation into their capacity to simultaneously enhance critical thinking and social communication skills.

Consequently, this research holds a strategic significance in advancing the study of LKPD by incorporating Augmented Reality (AR)-based dioramas into structured learning activities, primarily to facilitate the enhancement of critical thinking and social communication skills among elementary school students.

One reason for this problem is that Student Worksheets (LKPD) haven't been designed well enough to get kids to think more deeply and talk to each other. The LKPD commonly used in elementary schools still function as individual worksheets with closed-ended questions and are oriented toward final answers, rather than toward the thinking process, argumentation, and interaction between students (Hidayati dkk., 2021; Prastowo, 2015). But LKPD has a lot of potential as a learning tool that can help with discussions, guide learning activities, and get students to think and interact with each other at the same time.

Augmented Reality (AR) is a new technology that could help with meaningful learning by showing 3D images that are interactive and relevant to the situation. Several studies have shown that Augmented Reality (AR) can improve conceptual understanding, learning engagement, and student motivation, especially in abstract and dynamic materials (Akçayır & Akçayır, 2017; Cheng & Tsai, 2019; Garzón dkk., 2019). Within the framework of multimedia learning theory, Augmented Reality (AR) visualization integrates visual and verbal channels simultaneously, thereby reducing cognitive load and enhancing information processing (Mayer, 2020)

Furthermore, from a social constructivist perspective, Augmented Reality (AR) acts as a shared visual representation that enables students to construct understanding through social interaction,

discussion, and collaborative negotiation of meaning (Ibáñez & Delgado-Kloos, 2018). Meta-review studies indicate that AR has the potential to support higher-order cognitive processing, including analysis and evaluation, when integrated into activity-based and discussion-based learning scenarios, rather than used as a stand-alone visual medium (Dunleavy & Dede, 2014; Radu, 2014).

In this context, the use of Augmented Reality (AR)-based dioramas has specific pedagogical advantages. Augmented Reality (AR) dioramas enable spatial, contextual, and dynamic representations of phenomena, allowing students to observe causal relationships, ask questions, and discuss findings collaboratively. Research shows that digital dioramas can improve the quality of classroom discussions, conceptual understanding, and student social engagement by providing a shared visual object that can serve as a focus for interaction (Chairudin dkk., 2023; Sya'diah dkk., 2024). The selection of the 'Earth is Changing' topic for fifth-grade students is based on the material's characteristics of high abstraction and systemic phenomena, which require dynamic diorama visualization to help students at the concrete operational stage understand natural changes that cannot be directly observed. Thus, Augmented Reality (AR) dioramas function not only as visualization tools but also as learning communication tools that encourage critical thinking and integrated social communication.

But the effectiveness of Augmented Reality (AR) in education is not automatic; it depends a lot on the pedagogical design that goes with it. Prior studies indicate that Augmented Reality (AR) is more effective when incorporated into organized, collaborative learning activities rather than utilized as an isolated visual tool (Dunleavy & Dede, 2014; Gameel & Wilkins, 2019). Therefore, learning tools such as Student Worksheets (LKPD) are needed to systematically integrate Augmented Reality (AR) technology with students' critical thinking and social communication activities.

This research is significant as it aims to aid elementary school teachers in enhancing students' critical thinking and social communication skills through the creation of Augmented Reality (AR)-based Student Worksheets (LKPD). The media and LKPD function as both academic practice instruments and educational tools that methodically direct students to engage in collaborative observations, analyses, discussions, and reflections. For teachers, this LKPD provides concrete pedagogical guidance for facilitating science learning that simultaneously encourages students' cognitive engagement and social interaction, especially with abstract material that requires contextual

visualization. This research aids educators in the implementation of 21st-century learning that prioritizes the cultivation of critical thinking and social communication skills in a cohesive manner.

Based on the description, this study aims to answer the following questions: (1) What is the importance of having good communication skills for students? (2) What is the importance of having sharp critical thinking skills? (3) How does Augmented Reality (AR) based LKPD affect students' critical thinking skills? In addition, (4) How does Augmented Reality (AR) based LKPD affect elementary school students' social communication skills?

2. Method

This research used a research and development (R&D) approach based on the ADDIE model, which includes analysis, design, development, implementation, and evaluation. We chose this model because it lets us develop learning products in a systematic way that meets the needs of users (Borg & Gall, 2003; Branch, 2009).

The quasi-experimental design employed was a pretest-post-test non-equivalent control group design, comprising one experimental group and one control group. This design was selected because of constraints within the school environment, which precluded total randomization of subjects while still enabling systematic comparison of learning outcomes across groups (Shadish dkk., 2002).

The experimental group received learning using a developed Augmented Reality (AR)-based worksheet (LKPD), while the control group received learning using a conventional worksheet commonly used in schools. Both groups were given a pretest before the treatment to obtain an initial overview of their critical thinking and social communication skills, and a post-test after the treatment to assess changes in learning outcomes.

This research design was not intended to draw absolute causal conclusions, but rather to explore differences in learning outcomes between groups in the context of product development implementation. Consequently, the findings must be interpreted judiciously, considering the constraints of the quasi-experimental design, including the possible impact of external variables that cannot be entirely regulated.

To enhance internal validity, initial equivalence between the experimental and control groups was examined through descriptive analysis of pretest scores. Furthermore, the learning process for both groups was conducted with the same allocation of time, materials, and

teachers, so that any differences in results could be more closely linked to differences in LKPD use.

2.1 Research Subjects and Locations

The research was conducted at a public elementary school in Jember Regency during the odd semester of the 2025/2026 academic year. The research subjects consisted of two stages: a limited trial and a field trial. The small trial included 10 fifth-grade students and was meant to test how easy it was to read the instrument and understand the instructions, as well as to do some initial testing of its validity and reliability.

The field trial included 50 fifth-grade students, split into two groups of 25: an experimental group and a control group. Subjects were deliberately chosen due to the similarity of academic traits and the curriculum employed in both classes.

2.2 Development Procedures

This study employs the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation (Borg & Gall, 2003) for the creation of Augmented Reality (AR)-based Student Worksheets (LKPD). We chose this model because it gives us a structured way to make learning tools that meet the needs of users and can be tested all the time.

The analysis stage is done to find out what students need to learn and what problems they are having in the classroom. Activities at this stage include: (1) analysis of the curriculum and basic competencies in the material The Earth is Changing, (2) analysis of the characteristics of fifth grade elementary school students, (3) analysis of teacher and student needs for learning tools, and (4) analysis of learning problems related to students' low critical thinking and social communication skills. The results of the analysis show that individual activities still dominate learning and does not facilitate discussion and exploration of concepts, the available LKPD is still unable to adopt students' needs in learning that focuses on improving students' critical thinking and social communication skills so that LKPD is needed that can encourage visual, analytical, and collaborative activities in an effort to improve these two skills.

In the design stage, the researcher prepared an initial draft of the Augmented Reality (AR)-based LKPD. Activities at this stage include: (1) preparing learning objectives that align with indicators of critical thinking and social communication skills, (2) designing the structure and format of the LKPD, (3) preparing problem-based learning activities and group discussions, (4) designing a digital diorama based on

Augmented Reality (AR) as a supporting visual medium, and (5) preparing assessment instruments and rubrics used to measure students' critical thinking and social communication skills. The LKPD design is designed to encourage active student involvement through observation, analysis, discussion, and reflection.

The development stage involves turning the LKPD design into a product ready for use. Activities carried out at this stage include: (1) creating printed and digital LKPDs, (2) developing Augmented Reality (AR) dioramas using supporting applications, (3) integrating AR diorama content into LKPD activities, and (4) product validation by material experts and media experts. The validation results serve as a basis for revising the product until the LKPD is declared suitable for learning.

The implementation phase was carried out in two forms, namely a limited trial and a field trial. The limited trial involved 10 fifth-grade students and aimed to assess the readability of the worksheets and the clarity of the instructions, and to conduct initial validity and reliability testing of the research instrument. The results of the limited trial were used to refine the worksheets and instruments, and were not used in the primary statistical analysis. The field trial was conducted by applying Augmented Reality (AR)-based worksheets to an experimental group of 25 students, while the control group of 25 students used conventional worksheets. Learning was conducted in 3 meetings, each lasting 2 x 35 minutes (70 minutes), in accordance with the time allocation for the 'Earth is Changing' material in the curriculum. Learning was conducted in several meetings, within the allocated time for the material, with the teacher serving as a learning facilitator.

The evaluation stage was conducted to assess the quality and impact of using Augmented Reality (AR)-based LKPD. The evaluation comprised: (1) formative evaluation informed by expert input and constrained trial outcomes, and (2) summative evaluation via the analysis of disparities in post-test results of critical thinking and social communication skills between the experimental and control groups. The evaluation results showed that Augmented Reality (AR)-based LKPD helps elementary school students learn how to think critically and talk to other people.

2.3 Research Instruments

The research instruments were used to measure the critical thinking and social communication skills of elementary school students and to assess the feasibility of the developed Augmented Reality (AR)-based worksheets. All instruments were developed based on relevant

theoretical studies and adapted to the characteristics of fifth-grade students in the "The Earth is Changing" topic.

2.3.1 Critical Thinking Skills Instrument

The critical thinking ability instrument is a descriptive test consisting of 15 questions. This instrument was developed based on a critical thinking framework that includes analysis, interpretation, explanation, inference, evaluation, and metacognition (Facione, 2015), with a cognitive level at C4-C6 of the revised Bloom's taxonomy. The questions are based on environmental problems that are relevant to students' lives, like how human actions affect climate change. Students must look at cause-and-effect relationships, make sense of data, come up with logical arguments, come up with solutions, and think about how their actions affect the environment for each question. Critical thinking ability assessment is conducted using an analytical rubric on a scale of 1-4, with categories ranging from far from expectations to exceeding expectations. The rubric is compiled in detail for each critical thinking indicator to ensure consistent assessment and reduce assessor subjectivity.

2.3.2 Social Communication Instruments

The social communication instrument is a social communication skills observation sheet used to assess students' communication behavior during the learning process. This instrument was developed based on social skills indicators in cooperative learning and social constructivism (University of Queensland & Gillies, 2016). The aspects assessed include: 1) living and working together (cooperation, tolerance, and social sensitivity), 2) self-control and self-direction (self-control and responsibility), and 3) sharing ideas and experiences with others (sharing opinions and experiences). Each aspect is described in terms of 17 behavioral indicators directly observed during learning. Assessments are conducted using a Likert scale of 1-4 (no, sometimes, often, and always) and are accompanied by explicit descriptions of behavior for each category to maintain the objectivity of observations.

2.3.3 Product Validation Instrument

The product validation instrument consists of an assessment sheet used by material experts and media experts to assess the feasibility of Augmented Reality (AR)-based student worksheets (LKPD). Validation by material experts covers the suitability of content to the curriculum, conceptual accuracy, and integration of learning activities. In contrast, validation by media experts covers aspects of visual appearance, clarity of illustrations, integration of Augmented Reality (AR) dioramas, and ease of use of the LKPD.

2.3.4 Instrument Validity and Reliability Test

The instrument's validity and reliability were assessed in a limited trial phase involving 10 fifth-grade students. We used Cronbach's Alpha to check the instrument's reliability and had experts help us with the validity test. Instrument items that did not meet the validity criteria were eliminated and/or revised to improve measurement accuracy. The results of the reliability test indicate that the critical thinking and social communication skills instrument falls within the reliable range, making it suitable for use in the field trial phase. The data from the limited trial were utilized to enhance the instrument and were excluded from the primary statistical analysis in the field trial phase.

2.4 Data Analysis Techniques

Data analysis in this study was conducted in stages, in accordance with the research objectives and the quasi-experimental design. The analyzed data encompassed students' critical thinking and social communication skill scores derived from pretests and post-tests administered in both the experimental and control groups.

2.4.1 Descriptive Analysis

A descriptive analysis was performed to delineate the initial and final ability profiles of students in both groups. Pretest data were analyzed descriptively to determine the equivalence of initial abilities between the experimental and control groups. We looked at the post-test data to get a general idea of how well people did in critical thinking and social communication after treatment. The descriptive statistics employed encompassed the mean, standard deviation, minimum, and maximum values.

2.4.2 Prerequisite Analysis Test

Prior to inferential analysis, post-test data were tested to ensure they met parametric statistical assumptions. Normality was tested using the Shapiro-Wilk test because the sample size was less than 50. Homogeneity of variance was assessed using the Levene test to ensure equal variances between the experimental and control groups. Data were deemed to meet the analysis requirements if the significance value $(p) > 0.05$.

2.4.3 LKPD Effectiveness Test

Quantitative data analysis was conducted using an independent t-test followed by an effect size test (Cohen's d) to examine the magnitude of the difference in learning outcomes between the experimental and control groups. The use of effect sizes is recommended in educational research to complement statistical

significance tests and provide practical meaning to the differences found (Field, 2018; Kleber et al., 2013). The results of the independent-samples t-test can also demonstrate the effect of using Augmented Reality (AR)-based student worksheets, as measured by differences between groups that use only conventional student worksheets.

Figure 1. Research Flow Diagram

3. Result

3.1 Initial Product Feasibility (Expert Validation)

The developed Augmented Reality (AR)-based student worksheet (LKPD) product was validated by subject matter and media experts to assess its content suitability, visual quality, and structure, as well as its relevance as a learning communication medium. Before the product was used in the trial phase with students, this validation was done to make sure it met quality standards.

The validation results from material experts gave a total score of 74, with an average of 4.63, which is very appropriate. The aspects assessed included the content's suitability to the curriculum, clarity of learning objectives and instructions, the appropriateness of Augmented Reality (AR) media integration, and its potential to support students' critical thinking and social communication activities.

Validation by media experts yielded a total score of 24, with an average of 4.62, also categorized as very appropriate. Aspects assessed included visual appearance, readability, ease of use, and the quality of

visual communication produced by the Augmented Reality (AR) diorama. The validators gave a number of suggestions for how to make things better, such as making the learning objectives clearer, giving students more time to do activities, and making the instructions in the Student Worksheet (LKPD) clearer. All of these suggestions were followed up through product revisions, as summarized in Table 1.

Table 1. Product Revision Details

Before Revision	After Revision
Language Validator	
	
The language used does not meet the criteria for fifth-grade students.	The language has been adjusted to the criteria for fifth-grade elementary school students.
	
The language used does not meet the criteria for fifth-grade students.	The language has been adjusted to the criteria for fifth-grade elementary school students.
Before Revision	After Revision

Before Revision	After Revision
Media Validator	
	
Learning objectives do not yet use the new format.	Learning objectives are now using a new format.
	
There is no time allocation for the work.	Allocations have been provided in the LKPD questions.

3.2 Limited Trial Results (n = 10)

A limited trial was conducted with 10 fifth-grade students to test the instrument's readability, clarity of instructions, and to conduct initial validation and reliability testing of the critical thinking and social communication skills instruments. Data from this stage were used to refine the instrument and were not included in the field-trial statistical analysis.

The validity test results using the Pearson Product-Moment correlation indicated that most items in the critical thinking skills

instrument met the statistical validity criteria. However, two items, namely items 3 and 12, did not meet the validity criteria and were therefore eliminated from further analysis. For the social communication skills instrument, the validity test results showed that most items were in the valid category. However, four statement items (6, 9, 13, and 15) did not meet the criteria and were subsequently eliminated.

The instrument reliability test used Cronbach's Alpha to assess internal consistency. The analysis results showed that the critical thinking skills instrument had a Cronbach's Alpha value of 0.761, while the social communication skills instrument had a value of 0.927. Both values exceeded the minimum limit of 0.70; thus, the instrument was declared to have a good-to-excellent level of reliability and was suitable for use in the field trial phase.

3.3 Descriptive Analysis Results

A descriptive analysis of the pretest data was conducted to characterize students' initial levels of critical thinking and social communication skills in the experimental and control groups. The results of the descriptive pretest analysis indicate that students' critical thinking and social communication skills in the experimental and control groups were relatively equal. The average pretest scores for critical thinking skills in the experimental group were 23.12, and in the control group, 22.40, while the average pretest scores for social communication skills were 28.88 and 28.16, respectively. The similarity in the average values and distributions of scores for these two variables indicates that students' initial abilities in both groups were comparable before the treatment was administered. A summary of the descriptive pretest results for students' critical thinking and social communication skills in the experimental and control groups is presented in Table 2.

Table 2. Descriptive Statistics of the Pretest

Variables	Group	N	Mean	SD	Min	Max
Critical Thinking	Control	25	22,40	2,77	17	28
Skills	Experiment	25	23,12	3,06	18	30
Social	Control	25	28,16	3,92	22	35
Communication	Experiment	25	28,88	3,72	24	35

3.4 Prerequisite Analysis Test Results

Before conducting an inferential analysis to test differences in critical thinking and social communication skills between the experimental and control groups, a preliminary statistical analysis was

conducted. This prerequisite test's goal is to make sure that the data from the post-test scores meet the requirements for using parametric statistical analysis, such as the independent t-test. The data tested at this stage are students' post-test scores on critical thinking and social communication skills, which serve as the primary basis for analyzing differences in learning outcomes between groups. Meanwhile, the pretest data are used solely to provide descriptive information on students' initial abilities and are not included in the prerequisite statistical test.

3.4.1 Normality Test Results

A normality test was conducted to ensure that the post-test scores for critical thinking and social communication skills in the experimental and control groups were normally distributed, as a prerequisite for using parametric statistical analysis. In this study, the normality test was conducted using the Shapiro-Wilk test because the sample size in each group was less than 50 students.

The Shapiro-Wilk test results showed that the significance value for the post-test score on critical thinking skills in the control group was 0.595 (> 0.05), and in the experimental group was 0.681 (> 0.05). Meanwhile, the significance value of the post-test score for social communication skills in the control group was 0.850 > 0.05, and in the experimental group was 0.101 > 0.05. These findings indicate that all post-test data for both variables and both groups were normally distributed. Consequently, the assumption of normality was satisfied, allowing for additional statistical analysis through parametric tests. Table 3 shows the results of the normality test for the post-test data for critical thinking skills and social communication skills in both the experimental and control groups.

Table 3. Results of The Normality Test

Variables	Group	N	Statistic	Sig.	Description
Critical Thinking Skills	Control	25	0,968	0,595	Data is normally distributed
	Experiment	25	0,971	0,681	
Social Communication	Control	25	0,978	0,850	
	Experiment	25	0,933	0,101	

3.4.2 Homogeneity Test Results

A homogeneity of variance test was conducted to ensure that the variances of the post-test scores for critical thinking and social communication skills were equal across the experimental and control

groups, as a prerequisite for using parametric statistical tests. In this study, the homogeneity test was conducted using Levene's Test.

The results of Levene's test showed that the p-values for the post-test scores on critical thinking skills (0.107) and social communication skills (0.768) were not significant. Both significance values were greater than 0.05, indicating that the data variance between groups is homogeneous. Thus, the assumption of homogeneity of variance was met, and the analysis of differences in abilities between the experimental and control groups can proceed using an independent t-test. The results of the homogeneity-of-variance test for the post-test data on critical thinking skills and social communication skills in the experimental and control groups are presented in Table 4.

Table 4. Results of The Homogeneity Test

Variables	Levene Statistic	df1	df2	Sig
Critical Thinking Skills	2,697	1	48	0,107
Social Communication	0,088	1	48	0,768

3.5 Results of the LKPD Effectiveness Test

The effectiveness test of Augmented Reality (AR)-based LKPD was conducted to determine the differences in critical thinking skills and social communication skills between students who learned using Augmented Reality (AR)-based LKPD (experimental group) and students who learned using conventional LKPD (control group). Analysis was conducted on post-test scores because these data represent students' achievement after the treatment was administered and meet the assumptions of normality and homogeneity of variance.

To determine the differences in critical thinking and social communication skills between the experimental and control groups after treatment, an independent t-test was conducted on the post-test scores. The results of the independent t-test are presented in Table 5.

Table 5. T-Test Results

Variables	Experimental Mean	Mean Control	t	df	Sig. (2-tailed)
Critical Thinking Skills	33,80	28,08	-6.087	48	.000
Social Communication	45,40	37,00	-8.471	48	.000

Note: Sig. < 0.05 indicates a significant difference.

Based on Table 5, the independent t-test results indicate a significant difference between the experimental and control groups in post-test scores for critical thinking skills ($p < 0.05$) and social communication skills ($p < 0.05$). The average score in the experimental group was higher than that in the control group for both variables.

Meanwhile, to determine the practical significance of the observed differences, an effect size (Cohen's d) was calculated. The results of the calculation are presented in Table 6.

Table 6. Effect Size (Cohen's d) of Learning Using AR-Based Student Worksheets

Variables	Mean Eksperimen	Mean Kontrol	Cohen's d	Effect Category
Critical Thinking Skills	33,80	28,08	1,72	Large
Social Communication	45,40	37,00	2,39	Large

The results of the effect size calculations indicate that Cohen's d values for critical thinking and social communication skills are in the large effect size category. This finding indicates that the differences between the experimental and control groups are not only statistically significant but also practically meaningful in the context of learning.

The independent t-test and effect size show that Augmented Reality (AR)-based LKPD is better than regular LKPD at helping elementary school students improve their critical thinking and social communication skills in the learning context studied.

Table 7 summarizes the key findings of this study by comparing students' critical thinking and social communication outcomes between the experimental and control groups.

Table 7. Summary of Research Findings Based on Learning Variables

Variable	Group	Mean Post-Test	Effect Size (Cohen's d)	Interpretation
Critical Thinking	Experimental	33.80	1.72	Large effect
Critical Thinking	Control	28.08	-	Lower achievement
Social Communication	Experimental	45.40	2.39	Large effect

Variable	Group	Mean Post-Test	Effect Size (Cohen's d)	Interpretation
Social Communication	Control	37.00	-	Lower achievement

4. Discussion

This discussion seeks to conceptually analyze the research findings by connecting them to theoretical frameworks and prior studies, as well as to address methodological constraints that affect the interpretation of the results. This discussion centers on the significance of proficient communication skills, the necessity for students to cultivate robust critical thinking abilities, and the disparities in critical thinking and social communication skills between students utilizing Augmented Reality (AR)-based worksheets and those employing traditional worksheets. The first thing we will talk about is what we learned about how important it is to have good communication and critical thinking skills in this century.

The first section we will discuss is the findings on the importance of mastering strong communication and critical thinking skills in this century. Various empirical studies have shown that mastery of technical (hard) skills alone is not sufficient to guarantee career sustainability. Deming (2017), in his economic research at Harvard University, found that from 1980 to 2012, jobs requiring high social skills (including communication) grew by 24%, while jobs relying solely on technical/mathematical abilities stagnated.
This is reinforced by a survey by the National Association of Colleges and Employers (NACE). In the 2021 Job Outlook report, communication skills (both verbal and written) consistently ranked among the top attributes sought by employers, surpassing quantitative analysis skills (NACE, 2021). Robles (2012), in a study of business executives, also concluded that integrity and communication are two key predictors of employability. Without communication skills, an individual with a brilliant idea will struggle to gain the social buy-in necessary to execute it.
Future success depends heavily on collaboration skills. Research by Morreale and Pearson (2008) emphasized that communication incompetence is often a major cause of failure in academic and professional life. They stated that communication competence is a prerequisite for effective functioning in society.
In this context, the phenomenon of "failed good intentions" can be explained scientifically. Miscommunication creates cognitive

distortions in the recipient. Someone may have an altruistic leadership vision (good intentions), but if it is conveyed with an aggressive or ambiguous communication style, that vision will be rejected. A study by the Project Management Institute (2013) found that ineffective communication is a major factor in project failure (56% of the risk), resulting in significant financial losses. This proves that a good idea without a proper narrative is a wasted investment. Specifically in the context of science education and students' futures, communication is inseparable from critical thinking. The two have a reciprocal relationship. Hashemi et al. (2010) found that social communication skills are positively correlated with critical thinking skills. Students who have been taught how to express their thoughts are encouraged to make arguments that are logical, clear, and based on facts. Because of this, modern education uses the 21st Century Skills framework, which includes critical thinking, communication, collaboration, and creativity. Trilling and Fadel (2009) contend that in the 21st century, knowledge has transitioned from a static to a dynamic state. Students who can get information, think critically about it, and share it with others to solve hard problems are the ones who do well in school.

The research indicated that students utilizing Augmented Reality (AR)-integrated worksheets exhibited superior critical thinking abilities compared to those employing traditional worksheets. This finding corroborates prior research indicating that Augmented Reality (AR) enhances students' cognitive engagement and conceptual comprehension, particularly with abstract content (Akçayır & Akçayır, 2017; Cheng & Tsai, 2019; Garzón dkk., 2019). However, this study extends these findings by showing that improvements in critical thinking skills are influenced not only by the use of AR as a visual medium but also by its systematic integration into worksheets that guide students' analysis, evaluation, and reflection.

One of the main obstacles to critical thinking is students' inability to visualize problems. Good intentions to solve problems often fail due to a lack of in-depth understanding of the object of study.

Wu et al. (2013), in their thorough review, say that AR makes it possible to see abstract ideas that would otherwise be hidden. When students use AR to move around 3D science objects, like turning a molecular structure or looking at the layers of the Earth, they aren't just memorizing anymore. They are observing, analyzing, and drawing conclusions, which are all parts of critical thinking. AR provides concrete "visual evidence" for students to construct logical arguments,

making the ideas they generate more substantial and data-based, rather than mere assumptions.

The enhancement of critical thinking skills in the experimental group can be attributed to the student worksheet design, which integrates AR diorama visualization with problem-based tasks and discussions. Three-dimensional visualizations enable students to perceive natural phenomena of change in a spatial and dynamic manner, thereby facilitating the identification of causal relationships and the development of logical arguments. These results are consistent with constructivist learning theory, which emphasizes that knowledge is developed through active engagement between students and their learning environment (Facione, 2015; Ibáñez & Delgado-Kloos, 2018). Consequently, the AR-based student worksheets employed in this study serve as pedagogical scaffolds that promote higher-order thinking processes, rather than merely providing visual assistance.

Regarding social communication skills, the results showed that students in the experimental group also achieved higher scores than those in the control group. This finding corresponds with the studies conducted by the (Johnson & Johnson, 2014; University of Queensland & Gillies, 2016), which assert that social interaction and cooperation are essential elements of cooperative learning. This study demonstrates that AR-based dioramas can serve as collective visual representations that promote student discussion, opinion exchange, and the construction of shared understanding, in contrast to several prior studies that employed AR in isolation. When students observe the same object through an AR diorama, social interaction occurs naturally as part of the learning process.

The differences in the results of this study compared to some previous studies can be explained by several factors. First, this study integrates Augmented Reality (AR) directly into the Student Worksheet (LKPD) as a structured learning tool rather than merely a supporting visual medium. Second, the research participants were fifth-grade elementary school students at the concrete operational stage, so the visual and contextual nature of the AR diorama was more effective in helping them understand abstract science concepts. Third, the learning was designed to be group-based, so the use of AR contributed not only to individual cognitive understanding but also to improved social communication through discussion and collaboration. These factors distinguish this research from previous studies that generally focused solely on AR's individual visualization aspects or on learning motivation.

Dunleavy et al. (2009) found that AR-based learning naturally encourages high levels of social interaction. When a group of students observes the same virtual object through their devices, a "shared visual context" is created. This reduces ambiguity in communication.

In the context of the "good intentions require good communication" philosophy:

Shared Context: AR ensures that the sender (student A) and the recipient (student B) see the same object. This minimizes message distortion.

Discussion Trigger: The interactive nature of AR triggers curiosity, prompting students to ask questions, debate, and explain their findings to their teammates (Cheng & Tsai, 2013). This is where students practice phrasing their critical ideas so that their teammates can understand them.

The effect size (Cohen's d) values in the large category for both variables indicate that the difference in achievement between the experimental and control groups is not only statistically significant but also practically meaningful. In the context of educational research, reporting effect sizes provides a more comprehensive picture of the strength of a learning intervention's impact (Field, 2018; Kleber dkk., 2013). Thus, the results of this study indicate that Augmented Reality (AR)-based student worksheets have strong potential for application in science learning in elementary schools.

However, the results of this study should be interpreted with caution. The study design was a quasi-experimental study without complete randomization, so there is still the possibility of uncontrolled influences, such as student learning motivation or the effect of technological novelty. However, control efforts were made by matching the teaching staff, materials, and learning time allocation for both groups, so that differences in results could be more closely attributed to the use of Augmented Reality (AR)-based worksheets.

Overall, this study provides both theoretical and practical contributions. Theoretically, this study enriches the study of technology-based learning by demonstrating that integrating student worksheets (LKPD) with Augmented Reality (AR)-based dioramas can simultaneously support the development of critical thinking and social communication skills within a social constructivist framework. In practice, this study provides elementary school teachers with alternative learning tools to design more interactive, collaborative, and meaningful science lessons. These findings confirm that the effectiveness of learning

technology is determined not only by the sophistication of the media but primarily by the accompanying pedagogical design.

To clarify the relationship among the use of Augmented Reality (AR)-based LKPD, structured learning activities, and students' critical thinking and social communication skills, a conceptual diagram summarizing the findings of this study is presented in Figure 2.

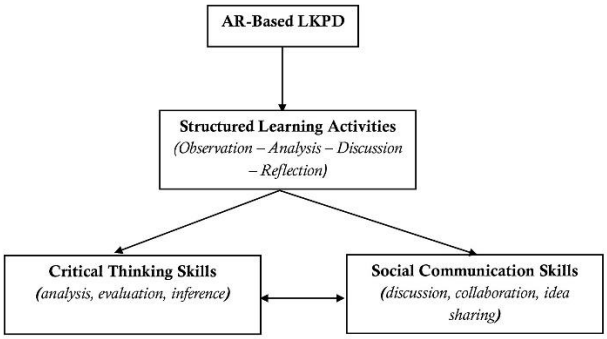

Figure 2. Conceptual Relationship between AR-Based LKPD, Learning Activities, Critical Thinking, and Social Communication

To clarify the relationships among the use of Augmented Reality (AR)-based worksheets, facilitated learning activities, and students' critical thinking and social communication achievement, the conceptual relationships among the findings of this study are summarized in Figure

Figure 3. Integration of Findings from the Use of Augmented Reality (AR) Diorama-Based LKPD

To synthesize the relationships among AR-based LKPD, structured learning activities, and students' critical thinking and social

communication skills identified in this study, a conceptual diagram is presented in Figure 2. Furthermore, to clarify how these relationships are manifested through the learning process and to illustrate the pedagogical mechanism underlying the observed outcomes, the flow of learning activities facilitated by the AR-based LKPD is illustrated in Figure 4.

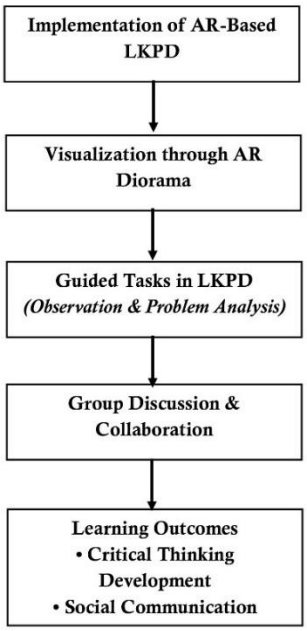

Figure 4. Learning Process Flow of AR-Based LKPD Implementation

Ultimately, AR serves as a scaffolding that unites ideas and words. Akçayır and Akçayır (2017) concluded that AR increases motivation and learning satisfaction, which are positively correlated with student participation in class discussions.

With the help of AR, students have powerful material to think about (Critical Thinking) and engaging media to discuss (Communication). Education through AR teaches students to be more than just passive consumers of information. It teaches them to be active science communicators who can clearly and convincingly explain difficult concepts, which is an important skill for future success.

5 Conclusion

Communication is the bridge that transforms potential into achievement. No matter how good a person's intentions or ideas are,

they will have no positive impact if they are not communicated effectively. Effective communication prevents meaning distortion and ensures that ideas are accepted and supported by the social environment.

On the other hand, critical thinking is the foundation of substance. It enables students to filter information, solve complex problems, and generate quality ideas. Without critical thinking, communication becomes nothing more than empty, directionless rhetoric.

Education should not be limited to the transmission of academic knowledge. Schools and other educational institutions have a strategic responsibility to be places where both of these skills can grow at the same time. Schools must be places where students learn how to sharpen their minds (by processing ideas) and expand their influence (by conveying ideas) through the right kinds of learning. This will help them become well-rounded people who are ready to face the challenges of the times.

Based on the results of the development and testing conducted, the Augmented Reality (AR)-based Student Worksheet (LKPD) is suitable as a learning tool, as evidenced by expert validation and readability tests. The results of the quasi-experimental test showed a significant difference in the acquisition of critical thinking and social communication skills between students who used the AR-based Student Worksheet and the conventional group. This finding is supported by the effect size (Cohen's d), which falls in the large category, indicating that the use of AR has strong practical significance in improving students' critical thinking and social communication skills in science materials.

However, these findings cannot be interpreted as absolute causality, given the quasi-experimental design without complete randomization. The success of this intervention is also influenced by external variables such as student motivation and the teacher's role as a facilitator. Teachers can effectively implement this worksheet by using guided discussion strategies and forming heterogeneous small groups. This is crucial so that the AR diorama can function as a shared visual representation that optimally stimulates negotiation of meaning and collaboration among students in the classroom.

As a follow-up, further research is recommended to use a pure experimental design (True Experimental Design) with complete randomization to strengthen internal validity and causal inference. In addition, it is recommended to extend the intervention duration (longitudinal study) to control for the novelty effect and to integrate

more specific measurement instruments, such as metacognition observation sheets or long-term retention tests, to better understand the impact of AR technology on students' mindsets.

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