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The Effectiveness of Collaborative Learning with BIM-AR in Improving Design Skills and Higher-Level Thinking Skills

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ABSTRACT

The Indonesian government prioritizes technology-based integrated learning through its current research policy. One aspect of the review that is focused on is learning in vocational education. Effective and efficient learning is needed to optimize existing resources, one of which is the application of technology through Building Information Modeling-Augmented Reality (BIM-AR) media for building construction. This research aims to determine the effectiveness of collaborative learning with BIM-AR in improving design and higher-level thinking skills in the building construction design. This research is experimental research through pretest and post-test designs. This research involved 58 students from the Department of Civil Engineering Education, UNY, who were divided into two classes: 29 students in the control class and 29 students in the experimental class. The effectiveness measured is the ability to design and high-level thinking skills in building construction design learning materials. The data were collected using observations, tests, and portfolios of building construction design results using BIM-AR (building information modelling-augmented reality) media. The data were tabulated and analyzed using a t-test. Analysis of the findings of the research shows that collaborative learning with BIM-AR media in building construction design learning materials can effectively improve design skills and higher-order thinking skills through t-test results (sig<0.05). High-level thinking skills are obtained through analyzing BIM-AR simulation results on building construction design examples. Meanwhile, design skills can be obtained through design experiments from BIM-AR simulation results.

1. Introduction

The Industrial Revolution 4.0 policy in Indonesia faces several opportunities and challenges. Indonesia is predicted to get a demographic bonus, with a large population with many productive ages. Adriani and Yustini [1] said that Indonesia has a demographic advantage, with most of the

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productive age population through the implementation of competency-based training and education and supportive policies that can drive economic growth and create jobs, one of which is in the construction industry sector. The abundance of productive population in Indonesia has potential as well as a challenge for the Indonesian government. Human resources and technology are the benchmarks and indicators of readiness, so it is hoped that through the optimization of integrated learning through the use of digital media such as augmented reality (AR) and Building Information Modelling (BIM) in the construction industry sector, it can improve the quality of learning outcomes and be able to provide competent prospective workers by Pratama *et al.,* [2]. The demographic bonus in Indonesia in 2030 is predicted to increase economic growth. Still, a *blueprint* for capacity building in the high-quality education sector is needed to prepare a productive and competitive workforce, according to Azizah *et al.,* [3].

Technological advances in learning have led to the ability to learn in real life, which, in this case, is associated with *an online* learning environment. This learning environment is expected to accommodate students' interests in observing, doing, and interacting. This effort can be carried out through the ability to interact and recognize subjects and learning objects. Technology with this kind of ability can overcome the limitations of time and place, according to Pratama *et al.,* [4]. Therefore, technology is needed to overcome the learning experience of the artificial world in a real environment, such as using augmented reality, virtual reality, and AI.

The growth of the construction industry sector in Indonesia within ten years is very rapid; on average, no less than 8 million workers are absorbed in the industrial sector every year, according to Pratama *et al.*, [5]. This encourages the government through universities to innovate with the industry through a joint research program (matching fund) to improve high-level thinking skills and design skills and produce prospective workers in the construction industry who are competent, superior, and competitive. Software such as BIM has been applied in designing and calculating building construction in recent years. Not only that but through the combination of the use of BIM-AR with collaborative learning, it is hoped that it can improve higher-level thinking and design skills.

1.1 Collaborative learning

Collaborative learning was chosen because it followed the characteristics of learning in higher education and vocational, namely learning output in the form of projects/final projects. The majority of the implementation of education and training in the construction sector uses collaborative learning approaches such as the ability to design 2D/3D drawings, the ability to design construction work in accordance with construction standards, the ability to calculate budget and cost needs, and construction managerial skills. Students acquire these skills through discussion activities, problem-solving, project completion, and product creation. Collaborative learning can encourage students to work together to solve problems, complete projects, or create products, thus encouraging learning as a natural social action, according to Tam [6]. It was also conducted by Gokhale [7], who mentioned that collaborative learning encourages critical thinking by encouraging the active exchange of ideas in small groups, leading to higher levels of thinking. This is realized through discussions between students to design 2D/3D drawings and design activities on construction work per construction standards. Through cooperative learning activities, it can encourage students to communicate both between students and with teachers actively. Clear assignment of projects is one of the keys to the success of effective collaborative learning implementation, and the resulting projects are centered on students' creativity, according to Gillies [8].

The implementation of the use of BIM-AR simulation media during collaborative learning is expected to improve design skills in construction work. Laal *et al.,* [9] said that collaborative learning involves participants working together in groups and can increase interaction through individual and group discussions and presentations. Classroom conditions when implementing collaborative learning offline and online show evidence of active collaboration between participants, but this condition is more optimal when carried out offline (face-to-face). Collaboration in collaborative learning is defined as an ongoing effort to outline the "common problem" of a project/task representation that must be solved, as presented by Baker [10]. Another research by Jamaludin *et al.,* [11] said that students are more interested in practical learning and produce products through collaborative learning. In addition, the implementation of collaborative learning in Electronic Systems courses during the pandemic through online mode is also influenced by student motivation, according to Johari *et al.,* [12]. Research on the implementation of collaborative learning has been developed, one of which is in the field of construction, which is process- and result-oriented, but there is very little development using simulation media, one of which is through BIM-AR, according to Le *et al.,* [13].

1.2 Design skills

Design skills are the ability to create concepts and visuals that meet certain needs; in this case, in the construction field, it can be realized through drawing design. These skills include various aspects, such as aesthetics, functionality, and accuracy. Design skills can be applied to complex social and technical problems that require organizational management and innovation, according to Brown *et al.,* [14].

Based on the characteristics of collaborative learning in the field of construction, there are several important components in design skills by Kleinsmann *et al.,* [15] including: 1) creativity: the ability to generate new and original ideas; 2) technical knowledge: understand the tools and software used in the design process, in this case using Building Information Modelling and augmented reality (BIM-AR); 3) understanding of design principles: know the basic principles of design such as balance, contrast, alignment, proportion, and accuracy; 4) Communication skills: able to convey messages or information accurately; 5) Problem solving: able to find creative solutions to design problems at hand; 6) Understanding of trends: knowing the latest design trends and how to apply them in work; 7) collaboration: work closely with the team to achieve the desired design goals; 8) Time management: manage time well to meet project deadlines; 9) Criticism and feedback: Able to receive and give constructive criticism to improve design results; and 10) Detail-oriented: Pay attention to small details that can affect the overall design. Design skills through collaborative learning can continue to improve along with independent and group learning experiences and improve collaborative design performance.

The ability to design that involves problem-solving, such as in construction design projects, can improve the cognitive domain of students who focus on problem-solving, creativity, and alternative solutions, according to Cross [16]. BIM-AR simulation media are expected to improve the learning experience by developing psychomotor domains. This is because, through simulation activities, students can carry out trial activities in construction designs according to the characteristics of the project obtained. This research will measure the success of improving design skills through the following components: creativity, technical knowledge, understanding of design principles, communication skills, collaboration, and time management. This component is considered very important because it is in accordance with the characteristics of project-based learning in the construction field.

Design skills require a systematic approach that considers technical and non-technical aspects and blends cognitive and psychomotor domains, according to Mourtos [17]. This study's results show

how effective collaborative learning can improve design skills by using BIM-AR simulation media. This research contributes to the use of simulation media to improve design skills through collaborative learning.

1.3 High-level thinking

High-level thinking skills are thinking skills that involve analysis, creation, and creation. These skills allow a person to understand complex concepts, solve problems, and make decisions based on critical thinking. Using appropriate learning models, media, and assessments can effectively improve higher-level thinking skills in students by Shalikhah *et al.,* [18]. Using simulation media based on several research results effectively stimulates and develops higher-level thinking skills by several authors [19-20].

Important components in higher-order thinking skills that are the focus of this study include: 1) analysis, which is the ability to decipher information into more detailed parts and understand how these parts are interconnected, for example, in the application of building construction design; 2) evaluation, which is the ability to assess the quality or validity of project results; 3) synthesis, which is the ability to combine information from various sources or ideas to form new concepts or solutions, at the same age as the characteristics of the project through creativity and innovation; 4) problem-solving, which is the ability to find solutions to complex problems using logic, creativity, and a systematic (detailed) approach; and 5) decision making, which is the ability to make choices based on in-depth analysis and evaluation of various options, this includes the ability to consider the long-term and short-term consequences of each option in order to complete the project.

High-level thinking skills are very important in construction work, and this is because incorrect construction design will fail the construction of a building, bridge, toll road, and others. Hence, the ability to analyze, evaluate, synthesize, solve problems, and make decisions is very necessary. This ability can be increased if, in their learning, students can do simulations. Therefore, the use of simulation media is very important, namely through BIM-AR simulation media. The results of this study will be a reference by researchers in the field of training and education in the construction industry sector to improve critical thinking skills relevant to the characteristics of the project.

Based on previous theories and research, it can be described that collaborative learning encourages critical thinking through the active exchange of ideas in groups, but this has not been proven optimal when using auxiliary media in the form of simulations. In addition, the success of implementing collaborative learning in the form of projects is based on students' creativity. However, this has not been proven for projects that are designed, such as in the projects designing building construction. There is a gap: How effectively can collaborative learning through simulation media in building construction improve design and high-level thinking skills? Therefore, in-depth and comprehensive research is needed to determine the effectiveness of collaborative learning when reviewed for the field of building construction, which in this case uses BIM-AR.

2. Methodology

This study is quantitative research with an experimental approach through pretest and post-test design. The experiment was used to determine how effective the use of Building Information BIM-AR simulation media was on learning in the construction field by combining collaborative learning as one of the learning methods used when students completed projects. The project completed by the students is to produce a building construction design, including drawings, cost budget calculations, and time schedules.

This study involved 58 students from Civil Engineering Education and Planning, Faculty of Engineering, Yogyakarta State University (UNY), divided into two groups/classes. The division of students into two groups/classes aims to determine how effective the use of BIM-AR simulation media is in learning in the construction field between the control group/class and the experimental group/class. The initial design of each group/class is carried out by giving a pretest. The pretest presented includes components of design skills consisting of 1) creativity, 2) technical knowledge, 3) understanding of design principles, 4) communication skills, 5) collaboration, and 6) time management. Meanwhile, the components of higher-level thinking skills measured include 1) the ability to analyze, 2) evaluate, 3) synthesize, 4) solve problems, 5) and make decisions. The pretest results in control groups/classes and experiments will be used as a baseline to plan the next learning design using BIM-AR simulation media.

The control class will apply collaborative learning to solve projects conventionally. In contrast, the experimental class will use BIM-AR simulation media to apply collaborative learning. During the learning process, observations will be made to determine the process of improving design skills and high-level thinking skills in students through independent and group performance. After that, at the end of the learning activities in the two groups/classes, a post-test will be carried out to measure how much the design and high-level thinking skills have improved to produce building construction design designs. In general, the learning process is integrated with the use of BIM-AR simulation media so that the process of increasing students' design and high-level thinking skills will be obtained, where at the end of the learning obtained project results in the form of portfolios that will be used as further studies in the future when illustrated as in Figure 1 below.

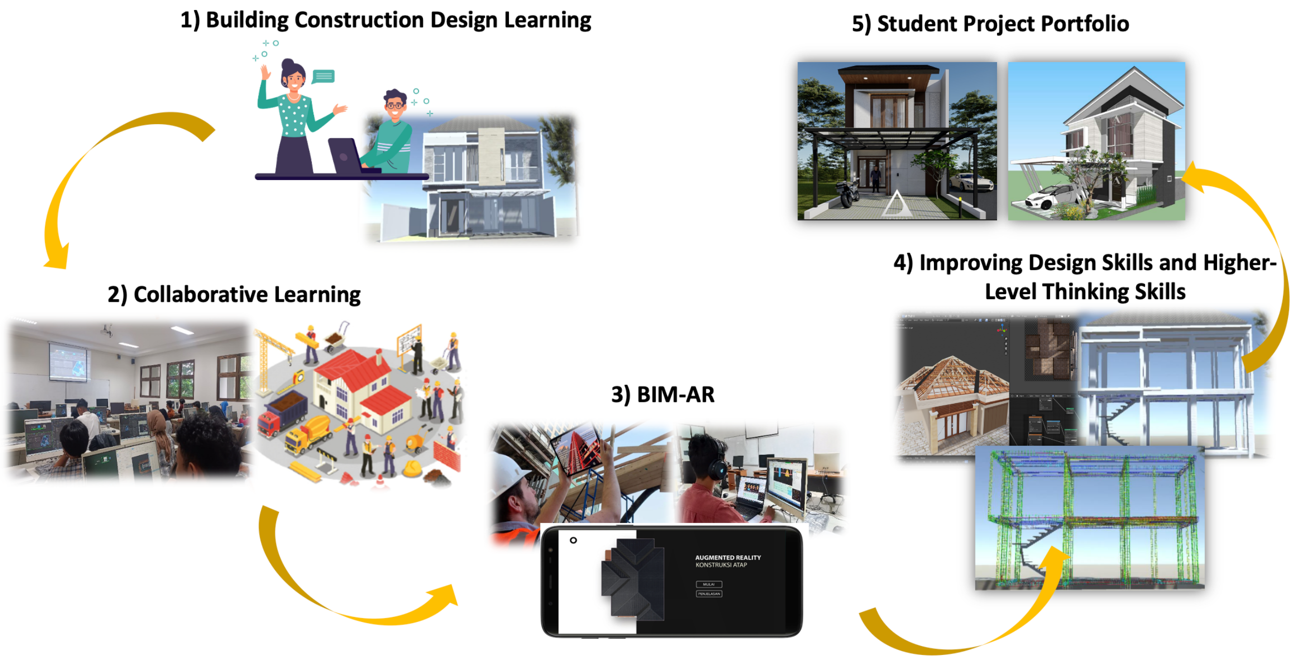

Fig. 1. Collaborative Learning Scheme using BIM-AR

In addition, learning results in the form of projects, including drawings, cost budget calculations, and time schedules, will be used as portfolio material from the experiments' results. All test results through pretest and post-test, as well as observation results during the learning process until the portfolio of learning projects, will be tabulated and analyzed using a t-test.

Table 1
Classification of control and experiment classes

Class	Information	Numb. of Students
1	Control	29
2	Experiments	29

3. Results

To determine the effectiveness of implementing collaborative learning through BIM-AR simulation media on building construction design learning materials to improve design and high-level thinking skills, pre-tests were conducted in the control and experimental classes first. This pre-test is carried out through the initial task delivery technique to measure the understanding and skills of building construction design, including drawings, cost budget calculations, and time schedules. Through the pre-test, a description of the students' initial abilities in the components of design skills was obtained, including creativity, technical knowledge, understanding of design principles, communication skills, collaboration, and time management, as well as higher-order thinking skills, including the ability to analyze, evaluate, synthesize, solve problems and make decisions. The data results obtained through the pre-test were descriptive analyses to determine the mean, median, minimum, and maximum scores for design and high-level thinking skills, as shown in Table 2.

Based on the table, it can be explained that the design skill obtained a mean score = 36.45; the maximum score = 47 from the ideal maximum score of 90. Meanwhile, high-level thinking skills obtained a mean score = of 32.14 and a maximum score = of 42 from the ideal maximum score of 80. When calculated, the percentage of pre-test achievement for design skills is 52.22%, and high-level thinking skills is 52.50%, which means that the level of understanding and skills in building construction design, including drawings, cost budget calculations, and time schedules owned by students at the beginning is very low. This encourages experiments with treatment using collaborative learning through BIM-AR simulation media in the experimental class to improve design and high-level thinking skills by several authors [4] [9]. Before the post-test, the data from the pre-test was pre-tested first through a normality test (Kolmogorov-Smirnov) and a homogeneity test.

Table 2
Data description result

Name	Description	Statistic
Design skills	Mean	36,45
	Median	36,50
	Variance	18,638
	Std. Deviation	4,317
	Minimum	27
	Maximum	47
High-level thinking skills	Mean	32,14
	Median	32
	Variance	9,910
	Std. Deviation	3,148
	Minimum	26
	Maximum	42

The normality test was carried out to determine whether the initial data in design skills and high-level thinking skills were normally distributed. The data can be normally distributed if the test result value > 0.05 (Sig. > 0.05). Based on the analysis results, it was found that the components of design skills and high-level thinking skills were normally distributed, namely 0.200 > 0.05 and 0.150 > 0.05, as shown in the table below.

Furthermore, the data were subjected to a homogeneity test to determine whether the data in the control and experimental classes were homogeneous. The data is said to be homogeneous if the test result value > 0.05 (Sig. > 0.05). Based on the analysis results, which can be seen in Table 3 below, it was found that the components of design skills and high-level thinking skills in the control and experimental classes were homogeneous, with a value of 0.368 > 0.05. After the data was declared to be normally distributed and homogeneous, the implementation of collaborative learning was observed through BIM-AR simulation media in the experimental class.

Table 3
Data normality test result

Name	Valid		Kolmogorov-Smirnov		
	N	Percent	Stat.	df	Sig.
Design skills	58	100,0%	,089	58	,200
High-level thinking skills	58	100,0%	,101	58	,150

3.1 Design skills

The components measured in designing skills are creativity, technical knowledge, understanding of design principles, communication skills, collaboration, and time management. Through the implementation of collaborative learning with BIM-AR simulation media, observations were made in the experimental class. This observation aims to discover how the process of improving each component in design skills produces a building construction design. The use of BIM-AR simulation media was chosen because students can see the components in the construction of the building in more detail, and there are more comprehensive simulations, so students can increase their motivation to learn and come up with new ideas in designing. In addition, the advantages of BIM-AR simulation media can be trial-and-error many times so that students get more learning experience compared to designing using auto-CAD media. Auto-CAD media use in building construction has been widely used, but it takes a long time to create a 3D design. In addition, the use of VR technology to design building construction is considered more expensive than AR. Therefore, using BIM-AR simulation media in this study is considered more appropriate according to learning characteristics. Based on the observation results, the results of the increase in the activity of participants in the collaborative learning process by using BIM-AR simulation media are shown in Table 4 below.

Based on the results of the observation in Table 4 below, it was found that there was an increase in each component of the student's design skills when the collaborative learning process was carried out. In addition, BIM-AR simulation media stimulates students to be more active, creative, and effective in completing projects. This finding aligns with research conducted by Pratama *et al*., [4] that using simulation media will make it easier for students to form cognitive domains, and experiments carried out through simulation media can stimulate the formation of psychomotor domains by several authors. Using collaborative learning stimulates students to actively collaborate and effectively develop plans for completing projects. This finding is in line with research conducted by several authors [2] [21] [22], which states that collaborative learning will encourage students to be active in independent and group learning through collaboration so that the understanding obtained is more complex.

Table 4
Observations on design skills

No	Component	Description
1	Creativity	Through the use of BIM-AR simulation media, all students conducted a trial observation of the design of building construction samples. Furthermore, each group comes up with creative ideas to solve problems through discussion and experimentation. The results of these creative ideas were presented by each group and received input from all members, and the final design was obtained which was used for the final project/project of the group. **There was an increase in** the creativity component of students through the process of discussion, trials, and presentations after the use of BIM-AR simulation media.
2	Technical Knowledge	Through collaborative learning, all students engage in active discussions, **this activity increases** students' understanding of the initial knowledge of the project being worked on. Students exchanged opinions and actively discussed during the presentation.
3	Understanding of design principles	The understanding of design principles in building construction was observed to have **improved**, this process was carried out through discussions and exchanges of opinions between students. In addition, the students' understanding of design principles also increased through answers to questions submitted by other groups.
4	Communication skills	Through the use of BIM-AR simulation media, all students tested building construction design samples. Furthermore, all students in the group actively communicate through the submission of ideas and ideas. **There was an increase in the components of** students' communication skills through the discussion and presentation process through the use of BIM-AR simulation media.
5	Collaboration	Through collaborative learning, all students carried out active discussions, **this activity increased** students' participation to collaborate with each other to complete projects. In addition, students' collaboration abilities improved through the completion of construction designs and when making presentations.
6	Time Management	The time managerial ability of students when completing projects using BIM-AR simulation media can be completed appropriately, students can estimate the time needed when conducting discussions to presentations. In addition, through BIM-AR simulation media, students can design time schedules used in completing projects, so that **there is an increase in the component** of students' time managerial abilities through the use of BIM-AR simulation media.

3.2 High-level thinking skills

Components measured in high-level thinking skills include the ability to analyze, evaluate, synthesize, solve problems, and make decisions. Observations were made in the experimental class by implementing collaborative learning using BIM-AR simulation media. This observation aims to determine how to improve each component in terms of high-level thinking skills to produce building construction design designs. Based on the observation results, an increase was obtained in the form of activeness and high-level thinking of students during the learning process using BIM-AR simulation media.

Based on the results of the observation below in Table 5, it was found that there was an increase in each component of the students' high-level thinking skills when the collaborative learning process was carried out. In addition, BIM-AR simulation media stimulates students to be more active, fast, and precise when completing projects. This finding aligns with research conducted by Oliveira et al. that using simulation media will make it easier for students to understand new material quickly, make it easier to conduct trials and minimize the risk of failure Shiratuddin *et al.,* [23]. Another research by Yeh, *et al.,* [24] can be explained that through collaborative learning and constructivism, learners' abilities can be developed holistically according to 21st-century skills. In addition, previous research can explain that collaborative learning stimulates students to actively collaborate and think critically through high-level thinking by identifying all risks that will be faced so as to minimize mistakes conveyed by several authors [22] [25].

During the observation process, there was an increase in the student's ability for design skills and higher-level thinking skills. The observation results describe the implementation of collaborative learning with BIM-AR simulation media to help students improve these skills. The process of improvement efforts that occur in the classroom has been described in detail for each component. This is a new finding, so it can be a reference and development for further research in the field of training and education in the construction industry sector. The results of this finding will also be carried out by a follow-up survey regarding the long-term impact on students after participating in building construction design learning materials using BIM-AR simulation media. The goal is to see the implications of using BIM-AR in teaching materials afterwards, which can improve design skills and high-level thinking skills in students. This survey effort is carried out by observing the results of the final learning product so that learning products are obtained through the use of BIM-AR simulation media in the form of a product portfolio that can be used for career development.

Table 5
Observation of high-level thinking skills

No	Component	Description
1	Analyze	Through the use of BIM-AR simulation media, all students conducted a trial observation of the design of building construction samples. Furthermore, each students completed the project and analyzed the success through trials. The results of the trial were then discussed in groups and presented to get input. **There was an increase** in the analysis component in all students through the discussion process and post-trial use of BIM-AR simulation media.
2	Evaluate	When the learning process takes place, students are active in exchanging opinions, this is done to get good and correct project results. This process **improves** the evaluation ability of students through questions and answers in group discussions, so that group discussion activities become more active and critical.
3	Synthesis	Students During the group discussion process, they were seen as active in expressing their opinions after conducting a simulation using BIM-AR media. This activity **encourages** students to synthesize the results of the discussion in each group, so that all inputs after the presentation activity become effective to support the completion of their projects.
4	Problem solving	Through collaborative learning, all students solve problems according to the theme of each group's project. The problem-

No	Component	Description
		solving process appears through the results of trials, analysis and exchange of opinions (question-and-answer). **This activity increases** the participation of students to dare to have opinions to solve problems in the group, then discuss together and end with a presentation.
5	Taking decisions	Through the use of BIM-AR simulation media, students are more confident in determining the final design to be used. This learning process **increases** the courage of students to be able to make decisions on the ideas/ideas presented in the final report. The learning experience through the use of BIM-AR simulation media makes it easier for students to achieve the project targets that have been set.

The results obtained during the observation process, in addition to improving students' abilities, were carried out in a differential test analysis (t-test) in the control class, and then the experiment was carried out post-test. This post-test aims to determine whether implementing collaborative learning using BIM-AR simulation media in building construction design learning materials can effectively improve design skills and high-level thinking skills.

Based on Table 6 below, the results of the analysis of the differential test (t-test) in the control class and the experiment can explain that implementing collaborative learning using BIM-AR simulation media in building construction design learning materials can effectively improve design skills and high-level thinking skills. These results were obtained through pre-post-test analysis for control and experimental classes. The results of the differential test (t-test) in the control class showed significant results, namely 0.000 (sig<0.05) and t-table> count (22.245 > 2.0595), according to Creswell [26]. In addition, the results of the differential test (t-test) in the experimental class also showed significant results, namely 0.000 (sig<0.05) and t-table > (42.174 > 2.0595) [23].

Table 6
Result of differential test analysis (t)

Name		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre – Post Control	-30,931	7,488	1,390	-33,779	-28,083	-22,245	28	,000
Pair 2	Pre - Post Experiment	-68,517	8,749	1,625	-71,845	-65,189	-42,174	28	,000

When viewed from the percentage improvement in the control and experimental classes during the pre-post test for high-level design skills and thinking skills is illustrated in the graph below. The graph in Figure 1 below shows that implementing collaborative learning using BIM-AR simulation media in the experimental class can increase design skills by 41.53%. In contrast, in Figure 2, it can increase high-level thinking skills by 46.25%. The findings of this study are very interesting because, based on the analysis of the differential test (t-test), the description of the learning process and the percentage of improvement in design skills and high-level thinking skills support each other.

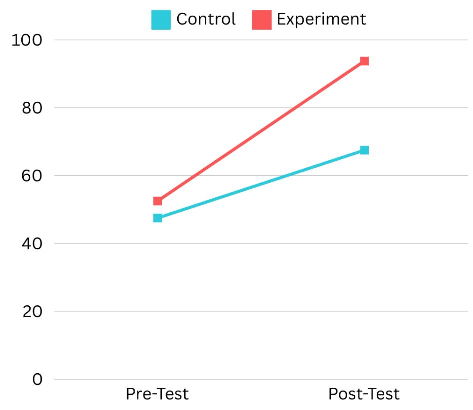

Fig. 2. Percentage Improvement in Control and Experiment Classes for Design Skills

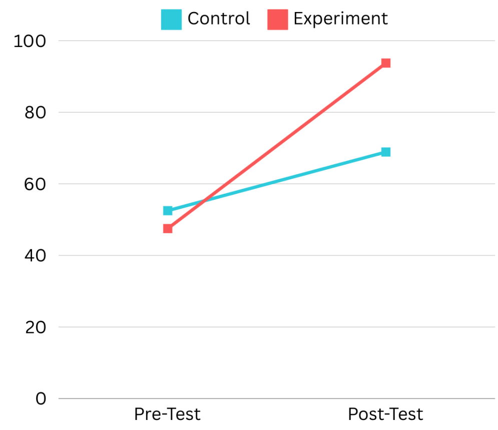

Fig. 3. Percentage Increase in Control and Experiment Classes for High-Level Thinking Skills

This research also supports the research conducted by several authors [22] [25]., which states that collaborative learning will encourage students to be active in independent and group learning through collaboration so that the understanding obtained is more complex. Meanwhile, the use of simulation media will provide more experience for students to conduct experiments, think critically, and synthesize to form cognitive and psychomotor domains by several authors [2] [4] [23].

4. Conclusions

The analysis of the findings shows that collaborative learning using BIM-AR simulation media in building construction design learning materials can effectively improve design and high-level thinking skills. The results of the t-test in the experimental class showed significant results, namely 0.000 (sig<0.05) and t-table > count (42.174 > 2.0595).

High-level thinking skills are obtained through BIM-AR simulation results analysis activities on building construction design examples. In contrast, design skills can be obtained through design experiments from BIM-AR simulation results. The results of this research will contribute to the use of simulation media combined with collaborative learning can stimulate a person's cognitive and psychomotor domains, and the development of this research is very useful to be adopted in project-based learning and problem-based learning.

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