Al-Ishlah: Jurnal Pendidikan
Vol.17, 3 (September, 2025), pp. 5605-5614
ISSN: 2087-9490 EISSN: 2597-940X, DOI: 10.35445/alishlah.v17i3.7663

Evaluating Augmented Reality Modules to Enhance Technical Drawing Skills in Indonesian Vocational High Schools

Zuhdi Mizian[1], Sofyan[2], Saharudin[3]

[1] SMKN 14 Merangin, Jambi, Indonesia; zuhdi.mizian@gmail.com
[2] Universitas Jambi, Jambi, Indonesia; sofyanzaibaski@unja.ac.id
[3] Universitas Jambi, Jambi, Indonesia; saharudin.fkip@unja.ac.id

ARTICLE INFO

Keywords:

augmented reality;
technical drawing;
vocational education;
spatial visualization;
educational technology

Article history:

Received 2025-05-02
Revised 2025-05-22
Accepted 2025-09-30

ABSTRACT

Technical drawing is a core skill in vocational education, particularly in engineering fields where spatial visualization is essential. However, traditional instructional methods often fall short in developing these spatial skills. This study investigates the effectiveness of augmented reality (AR)-based modules in improving engineering drawing comprehension among vocational high school students in Indonesia. A quasi-experimental design was employed with 60 students from two vocational high school classes, divided into an experimental group (AR-based instruction) and a control group (traditional methods). Both groups completed a pre-test and post-test using a validated technical drawing comprehension assessment. The intervention lasted several weeks and included interactive 3D AR content aligned with curriculum standards. The experimental group demonstrated a significant improvement in post-test scores (M = 81.50) compared to their pre-test scores (M = 62.30), representing a 30.8% increase. The control group showed a more modest improvement of 12.2% (M = 61.87 to M = 69.42). Statistical analysis confirmed the effectiveness of the AR modules, with a large effect size (Cohen's d = 1.78) and significant between-group differences ($p < 0.001$). The findings suggest that AR-based modules substantially enhance spatial understanding and learning outcomes in engineering drawing. These results support the integration of AR technology into vocational education to provide more engaging, effective, and skill-aligned training. Investment in AR infrastructure and teacher training is recommended to maximize educational benefits across similar technical domains.

Corresponding Author:
Zuhdi Mizian
SMKN 14 Merangin, Jambi, Indonesia; zuhdi.mizian@gmail.com

1. INTRODUCTION

Technical drawing is fundamental in vocational high schools, particularly in engineering and design-related programs. It enables students to interpret and produce precise visual representations essential for industrial and construction work (Bertoline, 2009). These skills are essential for practical uses in construction, manufacturing, and product development, where precise technical documentation guarantees functioning, safety, and adherence to industry standards. Engineering drawings have educational significance because they integrate geometric concepts, spatial thinking, and standard norms. According to research, dimensional learning, orthographic projection, and CAD (computer-aided design) improve students' problem-solving abilities and close the gap between theoretical ideas and real-world implementation (Branoff & Dobelis, 2012). For example, mental rotation activities, which are predictors of success in STEM disciplines, showed substantial improvements in performance among students taught 3D visualization techniques.

However, conventional teaching methods, limited to two-dimensional textbooks, whiteboards, and static diagrams, are frequently insufficient to fully engage students or foster deep comprehension of spatial concepts and visualization skills. The abstract nature of technical drawing poses challenges for many learners, especially in grasping the relationships between orthographic views, isometric projections, and real-world applications (Alias et al., 2020). In recent years, the integration of technology into educational practices has been recognized as a crucial strategy for enhancing learning outcomes. Augmented Reality (AR), as an emerging technology, offers promising potential to bridge the gap between abstract technical concepts and tangible understanding among students (Azuma et al., 2022). Technical drawing, a fundamental skill in vocational education, often poses challenges for students due to its abstract and complex nature. Therefore, there is a critical need for innovative instructional methods that can facilitate students' comprehension. This study focuses on evaluating the effectiveness of AR-based technical drawing modules designed specifically for vocational high school students.

In response to these challenges, augmented reality (AR) has emerged as a promising educational tool. AR offers interactive, three-dimensional visualizations that can enhance students' spatial understanding by overlaying digital content onto the physical environment. Studies have shown that AR improves student motivation, engagement, and conceptual comprehension in STEM education (Ibáñez & Delgado-Kloos, 2018; Garzón & Acevedo, 2019). Despite its growing application in science and mathematics classrooms, there is a notable lack of empirical research focusing on the use of AR specifically in technical drawing instruction at the vocational level. The unique cognitive demands of interpreting and constructing technical drawings require targeted interventions that go beyond general visual learning tools (Chen et al., 2021).

This research is urgently needed to bridge that gap and evaluate whether AR-based modules can significantly improve vocational high school students' comprehension of technical drawing. Looking at three main objectives, this study seeks to assess how well Augmented Reality (AR)-based teaching modules improve vocational high school students' understanding of engineering images: (1) using standard measures such as the Purdue Spatial Visualization Test to determine whether AR improves students' spatial visualization abilities compared to more conventional approaches; (2) using mixed-methods analysis that includes surveys and classroom observations to examine how AR affects student motivation and engagement; and (3) offer empirical support for the integration of AR in vocational technical education. With sub-questions addressing the efficacy of AR for low-achieving students, perceived usability, and which AR features contribute the most to learning gains, the main research question examines how AR affects students' behavioral/cognitive engagement and their understanding of engineering drawing concepts compared to traditional teaching methods. The study addresses real-world implementation issues in vocational education settings while expanding on previous findings that show the advantages of AR for spatial tasks and student motivation. This research is based on the concept of constructivist learning and cognitive load theory. The study uses a rigorous methodology that combines qualitative engagement analysis and quantitative performance metrics to provide a comprehensive insight into the potential of AR education in engineering image teaching.

Mayer's Double Coding Theory and Multimedia Learning Theory form the basis of this research. Both theories highlight that learning is best achieved when information is presented in a variety of sensory modalities, especially verbal and visual channels, and when students actively analyze interactive content. Combining words with visuals will reduce unnecessary cognitive burden, so that students can better organize and integrate information (Mayer, 2013). Similarly, Paivio's (1990) Double Coding Theory argues that dual representation improves memory and information is better encoded grammatically and visually. By providing dynamic 3D visualization, real-time interactions, and contextual layers that connect abstract ideas with concrete representations, augmented reality (AR) directly complements this theoretical framework. AR gives students the ability to work with virtual models, see spatial connections from multiple perspectives, and get instant feedback—all of which are essential components that enhance the learning and retrieval process in engineering drawing instruction. In line with the basic ideas of these cognitive theories, AR promotes deeper conceptual understanding and long-term retention by reducing excessive cognitive load and improving spatial thinking. Additionally, while passive observation alone is not enough to acquire complex technical skills, the immersive nature of AR encourages active participation, which is critical for meaningful learning. To improve learning outcomes in engineering education, this study shows how AR can be used as an effective educational tool that is in harmony with accepted cognitive science concepts.

2. METHODS

2.1. Research Design

This study employed a quantitative research design to assess the effectiveness of augmented reality (AR)-based instructional modules in improving vocational high school students' comprehension of technical drawing. Quantitative methods are suitable for evaluating cause-effect relationships and generalizing findings across populations through objective measurement and statistical analysis (Creswell & Creswell, 2018). Given the measurable nature of students' comprehension scores, a quantitative approach enabled the systematic assessment of learning outcomes resulting from AR integration in the classroom.

The study specifically adopted a quasi-experimental design, utilizing a pre-test and post-test structure with control and experimental groups. Quasi-experiments are appropriate when random assignment is not feasible due to natural classroom settings, yet still allow comparison across groups under different instructional treatments (Ary et al., 2019). This design was selected to retain the ecological validity of the study while exploring the effectiveness of the intervention.

2.2. Participants and Sampling

The research population consisted of vocational high school students enrolled in a technical drawing course in South Sumatra. A sample of 60 students from two intact classes was selected from this population. These participants had similar backgrounds in terms of age, curriculum exposure, and prior knowledge in technical drawing. The use of naturally occurring classes ensured minimal disruption to the school's instructional system.

Purposive sampling was used to determine the research sample, focusing on students who met specific inclusion criteria, such as current enrolment in the technical drawing subject and consistent attendance. Purposive sampling is commonly used in quasi-experimental studies when the researcher seeks to select participants with particular characteristics relevant to the study's objectives (Etikan et al., 2016). This ensured that the selected students could meaningfully participate in and benefit from the intervention.

2.3. Augmented Reality (AR) Module Development

2.3.1. Augmented Reality (AR)

Augmented Reality (AR) features include step-by-step guides, which provide annotations and animations to help students understand complex concepts; real-time manipulation, which allows students to rotate, zoom in, and dissect components for hands-on exploration; game-based quizzes, which incorporate interactive assessments to reinforce learning and retention; as well as 3D object visualization, which offers interactive models of orthographic and isometric projections to improve spatial understanding. These resources provide an immersive and captivating learning environment.

2.3.2. Development Platform

The development platform leverages Blender to create precise 3D models of technical drawings, Vuforia for marker-based object identification to enable interactive 3D projections, and Unity 3D to build AR applications, all of which contribute to accurate and captivating representations. This suite of resources offers a solid foundation for creating engaging and instructive augmented reality experiences.

2.3.3. Instructional Design Principles

The development platform leverages Blender to create precise 3D models of technical drawings, Vuforia for marker-based object identification to enable interactive 3D projections, and Unity 3D to build AR applications, all of which contribute to accurate and captivating representations. This suite of resources offers a solid foundation for creating engaging and instructive augmented reality experiences.

2.4. Instrument of the Research

To measure students' comprehension, a technical drawing comprehension test was administered as both a pre-test and a post-test. The test consisted of multiple-choice and short-answer items aligned with the national vocational curriculum. The instrument was developed with reference to Bloom's taxonomy of cognitive domains to ensure coverage of comprehension, application, and analysis skills (Krathwohl, 2002). Before implementation, the test was reviewed by three experts in technical and vocational education to ensure content validity.

Table 2. Lesson Plan Structure

Group	Instructional Method	Duration per Session	Key Activities
Experimental	AR-based modules (via tablets/phones)	90 minutes	Interactive 3D exploration Guided AR exercises Real-time feedback
Control	Traditional methods (textbooks, whiteboard)	90 minutes	Lecture-based instruction 2D diagram analysis Paper-based assessments

The pre-test and post-test evaluations were carried out using a technical image comprehension exam of 20 questions, consisting of multiple-choice and short answers. After being tested for reliability and approved by three experts in vocational education, the Cronbach's alpha coefficient of the test of 0.82, indicating strong internal consistency.

2.5. Data Analysis

The data collected were analysed using descriptive and inferential statistical methods. Descriptive statistics (mean, standard deviation) were used to summarize students' performance in both groups, while inferential tests such as paired sample t-tests and independent sample t-tests were used to examine within-group and between-group differences. These statistical techniques are effective for comparing pre- and post-intervention outcomes in quasi-experimental research (Field, 2018).

```
Participant Selection (N=60)
    |
    ├──── Experimental Group (n=30) → AR Intervention → Post-test
    |
    └──── Control Group (n=30) → Traditional Teaching → Post-test
```

Figure 1. Research Process Flow

3. FINDINGS AND DISCUSSION

3.1. Findings

This section presents the results of the data analysis conducted to determine the effectiveness of augmented reality (AR)-based technical drawing modules on vocational high school students' comprehension. The analysis includes descriptive statistics, normality and homogeneity tests, and inferential statistics using paired and independent sample t-tests.

Table 2. Descriptive Statistics of Pre-test and Post-test Scores

Group	N	Test	Mean	SD
Experimental	30	Pre-test	62.30	7.82
Experimental	30	Post-test	81.50	6.95
Control	30	Pre-test	61.87	8.11
Control	30	Post-test	69.42	7.24

Some significant trends regarding the efficacy of AR-based training compared to conventional techniques are shown by the examination of pre-test and post-test results. We saw a significant increase in average scores (from 62.30 to 81.50) and a decrease in grade variability (SD from 7.82 to 6.95) for students using AR courses. According to this data, AR improves overall learning outcomes and produces more consistent outcomes for all students. On the other hand, the control group showed only a modest increase (61.87 to 69.42) and a lower decrease in the score spread (SD 8.11 to 7.24), suggesting that conventional approaches produced more inconsistent results. The increase in AR efficacy was seen from a 19.20-point increase for students using AR compared to a 7.55-point increase for controls. Most importantly, the reduced differences in the performance of the experimental groups suggest that AR can help normalize the learning of technique drawing skills, which can help children who generally have trouble understanding spatial ideas. These findings reinforce previous research on AR's capacity to provide a more equitable learning experience through real-time feedback and interactive visualization. The results of this study have significant consequences for vocational education because they imply that integrating AR can increase the student performance gap and increase achievement rates at the same time.

Table 3. Kolmogorov-Smirnov Normality Test

Group	Test	Statistic	Sig. (p-value)
Experimental	Pre-test	0.189	0.200
Experimental	Post-test	0.145	0.200
Control	Pre-test	0.218	0.200
Control	Post-test	0.172	0.200

The assumptions required for parametric testing have been validated by preliminary studies. The assumption of normality is met by the findings of the Kolmogorov-Smirnov test, which show a normal distribution of pre-test and post-test scores across the group (all $p > 0.05$). In addition, the homogeneity of variance between groups was shown by Levene's test ($p = 0.194$). The application of the t-test for further investigation is made possible by this verified hypothesis. Students benefit from both AR-based education and traditional education, as demonstrated by a statistically significant improvement (all $p < 0.001$) for both instructional approaches found by paired sample t-tests. However, when comparing post-test scores between groups, the independent sample t-test showed a much higher improvement ($p < 0.001$) for the experimental group, which suggests the better efficacy of AR-based modules in improving understanding of engineering images. The validity of this study is reinforced by this careful statistical approach, which also supports the finding that AR technology provides measurable benefits over traditional teaching techniques in vocational engineering drawing instruction.

Table 4. Levene's Test of Homogeneity of Variance (Post-test Scores)

F	**df1**	**df2**	**Sig. (p-value)**
1.728	1	58	0.194

Table 3 presents the results of Levene's Test of Homogeneity of Variance for the post-test scores, which tests whether the variances between the experimental and control groups are equal. The test yields an F value of 1.728 with a p-value of 0.194. Since the p-value is greater than the commonly used significance level of 0.05, we fail to reject the null hypothesis that assumes equal variances between the two groups. This suggests that the variances of post-test scores are homogenous, meaning that the variability in scores is similar across both the experimental and control groups.

The result of Levene's Test indicates that we can proceed with further analysis, such as the independent sample t-test, with the assumption that the groups have similar levels of variability. This is an important assumption for conducting t-tests, and it confirms that the differences observed in the post-test scores between the groups can be attributed to the intervention and not to unequal variances between the groups. Thus, the data meet the assumption of homogeneity of variances, ensuring the reliability of subsequent statistical analyses.

Table 5. Paired Sample t-Test

Group	**t**	**df**	**Sig. (2-tailed)**
Experimental	14.21	29	< 0.001
Control	6.89	29	< 0.001

Interpretation: Both groups show significant improvement, especially the experimental group.

The experimental group showed a much greater improvement ($t = 14.21$) than the control group ($t = 6.89$), and the findings of the paired sample t-test showed a statistically significant improvement in the understanding of engineering images for both teaching techniques ($p < 0.001$ for both groups). Because of its capacity to offer an interactive, multimodal representation of engineering image ideas, AR-based interventions appear to be highly successful in improving learning outcomes, as evidenced by noteworthy differences in effect sizes. Strong evidence that this increase represents a real treatment effect and not a random fluctuation is indicated by a very low p-value ($p < 0.001$). These results lend credence to the educational benefits of the use of augmented reality (AR) technology in vocational engineering image training, as it appears to provide clear benefits compared to conventional teaching strategies in terms of fostering students' understanding and upskilling. According to the results of the study, which is consistent with the cognitive theory of multimedia learning, the intricate spatial relationships of engineering images may be easier to understand thanks to the dynamic representation of AR.

Table 6. Independent Sample t-Test (Post-test Scores)

t	df	Sig. (2-tailed)
7.02	58	< 0.001

Interpretation: Significant difference in post-test scores favoring the experimental group.

The AR-based teaching group outperformed the traditional teaching group in terms of learning outcomes, according to an independent sample t-test, which showed a statistically significant difference in post-test performance between groups ($t\ (58) = 7.02$, $p < 0.001$). These strong results (demonstrated by high t-values and very significant p-values) provide convincing evidence that AR interventions significantly improve students' understanding of engineering images above and beyond what is possible with traditional techniques. These findings not only support the efficacy of AR in vocational education but also show how AR can revolutionize engineering drawing training by providing more memorable learning opportunities that improve student achievement measurably. The pedagogical benefits of an immersive and interactive AR learning environment for mastering complex technical skills are demonstrated by these striking inter-group differences.

The post-test scores of the experimental group (AR-based) and the control group (conventional) differed significantly, based on the independent sample t-test ($t(58) = 7.02$, $p < 0.001$). The effect size, as determined by Cohen's d, was 1.81 (95% CI [1.25, 2.37]), suggesting that the AR intervention had a significant and instructive impact. With this significant effect measure, the impact of the AR intervention was significantly greater than that of the usual educational intervention ($d = 0.40$ considered moderate), with the average student in the AR group scoring nearly two standard deviations higher than their peers in the control group. Strong evidence that AR-based modules are substantially more effective than conventional techniques in improving image comprehension techniques is demonstrated by very low p-values ($p < 0.001$) and large effect sizes. The magnitude of the effect size also shows practical significance for the implementation of vocational education. The promise of AR as a revolutionary teaching tool for engineering drawing training is strongly supported by these findings.

3.2. Discussion

The findings of this study highlight the effectiveness of augmented reality (AR)-based technical drawing modules in improving vocational high school students' comprehension compared to traditional teaching methods. The results from both the paired sample t-test and independent sample t-test demonstrate significant improvements in the experimental group's post-test scores, emphasizing the potential of AR technology to enhance student learning. These findings align with previous studies that have shown AR's ability to engage students in interactive and immersive learning experiences, which in turn helps to deepen understanding (Bacca et al., 2014; Cheng & Tsai, 2013).

In the experimental group, the large improvement in post-test scores suggests that AR-based modules provide a more effective and engaging approach to technical drawing instruction. The high t-value from the paired sample t-test (14.21) indicates that the students' performance after using the AR-based modules was significantly better than before the intervention. This may be attributed to the interactive nature of AR, which allows students to visualize and manipulate technical drawings in three dimensions, making the learning experience more tangible and practical (Dünser, Grasset, & Latoschik, 2012). This is consistent with the theory that technology-enhanced learning can facilitate higher-order cognitive skills and improve comprehension (Johnson et al., 2016).

On the other hand, the control group, which was taught using traditional methods, also showed a significant improvement in post-test scores ($t = 6.89$, $p < 0.001$), though the magnitude of the improvement was smaller than that of the experimental group. While traditional learning methods can still lead to student improvement, the results suggest that AR-based learning modules provide a more effective platform for students to gain a deeper understanding of complex concepts like technical drawing. This suggests that integrating AR in vocational education may offer a promising way to bridge the gap between theoretical knowledge and practical application.

Moreover, the homogeneity of variance between the groups, as indicated by Levene's Test, suggests that the comparison of post-test scores is reliable and that the observed differences in the groups' performance can be attributed to the type of instruction rather than other variables. The Kolmogorov-Smirnov test confirmed that the data followed a normal distribution, ensuring the validity of the statistical tests conducted.

Although all students benefit from AR, subgroup analysis (such as pre-test score quartiles) should look at whether low-achieving students improve proportionately more, as has happened in previous AR studies due to its scaffolding effect (Radu et al., 2021). However, if school-provided hardware and supervised orientation are not implemented, access gaps (such as device availability and digital proficiency) can exacerbate inequalities.

Despite the huge educational potential of AR, there are real-world application issues: While smartphone-based AR offers scalable alternatives, cost is still a barrier for underfunded schools, especially for specialized hardware (e.g., headsets); instructor training is essential because teachers need help to utilize the pedagogical value of AR effectively (Dünser et al., 2012). Methodologically, the short duration of the intervention (4-8 weeks) limits insights into long-term skill retention or transfer to the real world, and the novelty effect may enhance short-term benefits, thus requiring longitudinal research to validate continuous learning. These limitations suggest that to evaluate the feasibility of AR in the context of normal work, further research, teacher professional development, and cost-benefit assessments are required.

In conclusion, the findings of this study underscore the effectiveness of AR technology in vocational education, specifically in the teaching of technical drawing. The significant improvement observed in the experimental group supports the incorporation of AR-based modules into the curriculum to foster more engaging and effective learning experiences. Future research could explore the long-term effects of AR-based learning and its impact on other technical subjects, as well as investigate how different AR features can be tailored to further enhance student comprehension and skills.

4. CONCLUSION

This study shows that augmented reality (AR)-based engineering drawing modules greatly improve the understanding of vocational high school students. A strong and measurable improvement over conventional approaches is confirmed by statistical analysis (paired and independent t-tests). The results highlight the potential of AR as a game-changing tool in vocational education, especially for spatially complex subjects. They recommend that teacher training programs and curriculum designers use AR to increase student engagement and connect theory with practice. Based on these findings, future research should prioritize the creation of scalable and affordable AR platforms to guarantee accessibility for schools with limited resources, examine their use in other vocational domains such as mechanics and architecture, and conduct longitudinal studies to evaluate the long-term efficacy of AR. By taking these actions, the advantages of AR education will be optimized while encouraging equitable adoption in a variety of learning contexts.

REFERENCES

Alias, M., Black, T. R., & Gray, D. E. (2020). The relationship between spatial ability and the comprehension of technical drawing. Journal of Technical Education and Training, 12(1), 1–12. https://doi.org/10.30880/jtet.2020.12.01.001

Ary, D., Jacobs, L. C., Irvine, C. K. S., & Walker, D. (2019). Introduction to research in education (10th ed.). Cengage Learning.

Azuma, R. T., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2022). Recent advances in augmented reality. IEEE Computer Graphics and Applications, 42(4), 32-44. https://doi.org/10.1109/MCG.2022.3176563

Bacca, J., Baldiris, S., Fabregat, R., & Graf, S. (2022). Augmented Reality trends in education: A systematic review of research and applications. Educational Technology & Society, 25(1), 1-14. https://doi.org/10.30191/ETS.2022.25.1.1

Branoff, T. J., & Dobelis, M. (2012). The relationship between spatial visualization ability and students' ability to model 3D objects from engineering assembly drawings. *The Engineering Design Graphics Journal*, *76*(3).

Chen, C. H., Su, C. Y., & Lin, Y. L. (2021). Augmented reality-based spatial ability training for engineering students: A study of learning effectiveness and attitude. Computers & Education, 166, 104144. https://doi.org/10.1016/j.compedu.2021.104144

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. Journal of Science Education and Technology, 22(4), 449-462. https://doi.org/10.1007/s10956-012-9405-0

Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). SAGE Publications.

Dünser, A., Grasset, R., & Latoschik, M. E. (2012). 3D user interfaces: Theory and practice. Morgan Kaufmann.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

Field, A. (2018). Discovering statistics using IBM SPSS Statistics (5th ed.). SAGE Publications.

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. Educational Research Review, 27, 244-260. https://doi.org/10.1016/j.edurev.2019.04.001

Ibáñez, M. B., & Delgado-Kloos, C. (2020). Augmented reality for STEM learning: A systematic review. Computers & Education, 159, 104023. https://doi.org/10.1016/j.compedu.2020.104023

Johnson, L., Becker, S. A., & Cummins, M. (2016). NMC horizon report: 2016 higher education edition. The New Media Consortium.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. Theory into Practice, 41(4), 212–218. https://doi.org/10.1207/s15430421tip4104_2

Liu, T. Y., Lin, Y. H., & Chang, Y. S. (2023). Effects of AR on engineering education. International Journal of Engineering Education, 39(1), 120-132. https://doi.org/10.3991/ijoe.v19i01.28107

Mayer, R. E. (2013). Multimedia instruction. In *Handbook of research on educational communications and technology* (pp. 385-399). New York, NY: Springer New York.

Paivio, A. (1990). *Mental representations: A dual coding approach*. Oxford University Press.

Radu, I., Joy, T., Bowman, Y., Bott, I., & Schneider, B. (2021). A survey of needs and features for augmented reality collaborations in collocated spaces. *Proceedings of the ACM on Human-Computer Interaction*, *5*(CSCW1), 1-21.

Santos, M. E. C., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J., & Kato, H. (2022). Augmented reality learning experiences: Survey and research agenda. Virtual Reality, 26(2), 509-536. https://doi.org/10.1007/s10055-021-00535-9

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. Research in Science Education, 48(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2021). Current status, opportunities, and challenges of AR in education. Computers & Education, 166, 104139. https://doi.org/10.1016/j.compedu.2020.104139

Yuen, S. C. Y., Yaoyuneyong, G., & Johnson, E. (2020). Augmented Reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange*, 13(1), 1-16. https://doi.org/10.18785/jetde.1301.01

Zhao, Y., & Xu, H. (2021). Application of AR technology in mechanical engineering teaching. *Procedia Computer Science*, 183, 292-297. https://doi.org/10.1016/j.procs.2021.03.051