



Augmented Reality-Based Interactive Media in Contextual Flipped Classroom to Enhance Elementary Students' Learning Motivation

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Abstract

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Natural and Social Sciences (IPAS) instruction in Indonesian elementary schools frequently employs conventional methods that fail to stimulate student engagement and motivation. This study developed and examined interactive Augmented Reality (AR) integrated media within the Contextual Flipped Group Classroom (CFG) model to enhance elementary students' IPAS learning motivation. Method: Employing Research and Development with the ADDIE model, 224 elementary students participated in experimental and control groups. Data were analyzed using ANCOVA and independent t-tests. Results: AR-based media within CFGC significantly enhanced motivation across all dimensions ($p < 0.05$), with highest improvements in self-efficacy and active learning strategies. AR-CFGC integration represents effective pedagogical innovation for fostering elementary students' learning motivation through contextual, collaborative, and meaningful experiences.

Keywords:

Interactive Media, Educational Technology, Natural and Social Sciences, Science Education

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INTRODUCTION

The Programme for International Student Assessment (PISA) 2022 results demonstrated improvement in Indonesian education, with rankings rising 5 to 6 positions in reading literacy, mathematics, and science compared to 2018 (OECD, 2023). Despite this progress, Natural and Social Sciences (IPAS) instruction in Indonesian elementary schools remains dominated by conventional methods that fail to stimulate active student participation and learning motivation (Metaj-Macula & Bytyqi-Damoni, 2020; Suryawati & Osman, 2018). Elementary students are at a cognitive development stage that requires concrete, engaging, and daily life-relevant learning experiences, yet instruction tends to be abstract and predominantly teacher-centered. This condition necessitates pedagogical innovations that not only deliver content but also stimulate students' enthusiasm, engagement, and self-efficacy (Lee et al., 2021). The development of innovative interactive learning media integrated with creative and contextual pedagogical approaches has therefore become an urgent necessity in 21st-century education, as such media can enhance learning motivation (C. Chen & Jamiat, 2023; C. W. Liao et al., 2019), learning



outcomes (Suriani et al., 2024; Khaltsum et al., 2023; Rahman et al., 2023), and critical thinking abilities (Mughtar et al., 2021).

Augmented Reality (AR) represents a potentially transformative technology for delivering interactive learning experiences. AR enables students to interact with virtual objects within real-world contexts, allowing abstract concepts to be visualized more concretely (C.-H. D. Liao et al., 2024). Various meta-analyses demonstrate that AR can enhance motivation (C. Chen & Jamiat, 2023; Khan et al., 2019) and learning outcomes (Garzón et al., 2020; Prasetya et al., 2024). At the elementary level, this technology is particularly appropriate since children remain in the concrete operational stage, making interactive visualization instrumental in helping them comprehend scientific concepts that are difficult to explain verbally.

The flipped classroom represents another pedagogical innovation proven to enhance student engagement by relocating information acquisition activities outside the classroom and utilizing face-to-face time for discussion, collaboration, and experimentation. Meta-analysis results indicate that flipped classroom provides positive impacts on motivation, satisfaction, and learning achievement (Mengesha et al., 2024; Strelan et al., 2020; Wong et al., 2023). However, flipped classroom implementation at the elementary level remains uncommon, with most studies focusing on secondary and higher education levels (Lo & Hew, 2017; Utami et al., 2023).

When the Contextual Teaching and Learning (CTL) approach—which emphasizes the connection between learning content and students' real-life experiences (Tampubolon & Amri, 2021)—is integrated with the flipped classroom and collaborative group work, the Contextual Flipped Group Classroom (CFGFC) model emerges. This model prioritizes collaboration, contextualization, and more effective use of face-to-face time, where students independently study materials using interactive media prior to classroom sessions (Nasrah et al., 2024). Recent studies confirm that collaborative flipped classroom models improve group awareness, self-efficacy, and learning motivation (Lin et al., 2025). The CFGFC model aligns with 21st-century education by combining technology-assisted learning (Vagg et al., 2020; Elmunsyah et al., 2019) with contextual approaches that foster deeper student engagement (Setiawan & Hendri, 2019).

However, critical research gaps remain. Studies on AR in elementary schools predominantly focus on technological aspects and knowledge outcomes rather than motivation (Garzón & Acevedo, 2019; Arici et al., 2019), and the flipped classroom is more frequently studied in higher education settings (Lo & Hew, 2017). Exploration of AR integration with the CFGFC model, specifically to enhance elementary students' learning motivation, is still limited. This study addresses these gaps by developing and testing the effectiveness of AR-based interactive media within the CFGFC model to improve elementary students' IPAS learning motivation. The theoretical contribution provides an integrated AR-based learning design framework, while the practical contribution offers interactive media and implementation guidelines for teachers.

This study addresses the following research questions: a) How effective is AR-based interactive media within the CFGFC model in enhancing elementary students' science learning motivation? b) Which motivational dimensions show the most significant improvement? c) What are the students' and teachers' perceptions of this pedagogical innovation?

METHODS

The participants of this study were fifth-grade elementary school students in Makassar City, South Sulawesi Province, Indonesia. The research population comprised

all fifth-grade students from 479 elementary schools distributed across four administrative regions of Makassar City: North, East, South, and West.

Sampling Technique. Sample selection was conducted using a *multistage cluster random sampling* technique through three stages:

Regional stratification stage — All elementary schools in Makassar City were stratified based on four geographical regions (North, East, South, and West) to ensure spatial representativeness.

Cluster random sampling stage — From each region, one elementary school was randomly selected, yielding four schools (School A, B, C, and D) as the selected clusters.

Purposive sampling stage — Within each selected school, fifth-grade classes meeting the inclusion criteria were purposively assigned as experimental and control classes.

Inclusion and Exclusion Criteria. Participants meeting the inclusion criteria were students who: (a) were actively enrolled as fifth-grade students during the current academic semester; (b) had access to a smartphone or tablet device supporting the AR application; and (c) agreed to participate with parental/guardian informed consent. Exclusion criteria included: (a) students absent for more than 20% of the learning sessions; and (b) students with special needs requiring individual assistance beyond the scope of this research design.

Assignment to Experimental and Control Groups. Group assignment was conducted at the class level (*intact group*), not at the individual level, consistent with the quasi-experimental design. In each school, one fifth-grade class section was assigned as the experimental group receiving instruction using AR-based interactive media within the CFGC model, while the other class section was assigned as the control group receiving conventional instruction. The determination of which class section served as the experimental or control group was conducted randomly through a lottery draw at each school.

The total number of participants meeting the inclusion criteria was 224 fifth-grade students distributed across four elementary schools as follows:

Table 1. Sample Distribution

No.	School	Experimental Group		Control Group		Total
		Male	Female	Male	Female	
1	School A	9s	18	10	17	54
2	School B	15	8	11	12	46
3	School C	12	15	11	16	54
4	School D	15	20	12	23	70
Total		51	61	44	68	224

Comparison of Demographic Characteristics. The experimental group consisted of 112 students (51 males and 61 females), while the control group comprised 112 students (44 males and 68 females). Participants' ages ranged from 10 to 11 years, consistent with the normative age of fifth-grade elementary school students in Indonesia. To ensure equivalence between both groups prior to treatment, baseline equivalence tests were conducted through:

Normality testing using the Kolmogorov-Smirnov test on pretest learning motivation scores, which indicated normal distribution in both groups (experimental group: Sig. = 0.200; control group: Sig. = 0.200).

Analysis of Covariance (ANCOVA) controlling for pretest scores as a covariate, thereby accounting for initial ability differences between groups in the media effectiveness analysis.

The gender proportion showed that females were slightly more represented (129

students; 57.6%) compared to males (95 students; 42.4%) across both groups. School D contributed the largest sample (70 students; 31.3%), followed by Schools A and C with 54 students each (24.1%), and School B with 46 students (20.5%).

RESULTS & DISCUSSION

This section presents research findings obtained through a series of quantitative and qualitative data analysis stages according to established analytical frameworks. This data analysis evaluates product feasibility, product practicality, and the effectiveness of Interactive Augmented Reality Media within the CFGC Model for enhancing elementary students' motivation in the Makassar region of South Sulawesi Province. The following are the data analysis results obtained from this research:

Augmented Reality (AR) Product Design

The Augmented Reality (AR)-based learning media developed in this study is designed to assist students in enhancing motivation and critical thinking in IPAS learning through interactive three-dimensional visualization. The AR media design consists of pop-up media embedded with barcodes that are scanned using mobile devices. The media displays objects in both 2D and 3D formats that can be rotated, enlarged, and accompanied by text descriptions and simple audio explanations. The developed AR media contains materials on human organ systems, biotic and abiotic environments, the solar system, Indonesia's geographical location, and cultural diversity in Indonesia.

AR Media for Human Organ Systems

This media is designed using Assembler Edu and Canva applications. The Human Organ Systems AR media is developed by integrating pop-ups designed as attractively as possible to align with the CFGC learning model. Consequently, students not only view materials in text and image formats but can also understand, apply, and reflect on learning, making the learning experience more vivid and contextual.

The materials presented in this media consist of human senses, circulatory system, and respiratory system. Each topic is visualized through a combination of pop-up illustrations and 3D objects that appear when scanned using a camera or AR application. This makes the media more interactive and appropriate for 21st-century characteristics that emphasize motivation, collaboration, and critical thinking skills.

AR Media for Biotic and Abiotic Environments

In the biotic and abiotic environment topic, the pop-up media displays images of animals, plants, and abiotic components visualized in interactive folding formats. Students can open these folds to discover brief explanations about each biotic and abiotic environmental component. The presented AR features 3D ecosystem animations that are alive, displaying interactions between biotic and abiotic components. This provides a more engaging experience.

AR Media for Solar System

In the solar system topic, the pop-up is equipped with brightly colored planet illustrations. Students can open folds containing brief information about planets, the sun, and satellites. By accessing QR codes, 3D AR displays of planets appear that can be rotated and enlarged through mobile phone layers. These interactive animations help students understand planetary sequence, size comparisons, and positions within the solar system.

AR Media for Indonesian Cultural Diversity and South Sulawesi Provincial Local Wisdom

This AR media is designed with pop-up visualizations that display traditional dances, traditional clothing, and South Sulawesi provincial local wisdom in 3D using mobile devices. Engaging visual experiences and narratives help students better understand Indonesia's cultural diversity as embodied in the motto "Unity in Diversity" (Bhinneka Tunggal Ika). This media also helps students cultivate pride and tolerance toward the nation's diversity.



Figure 2. Augmented Reality (AR) Media

Learning Management System (LMS) Design

The Learning Management System (LMS) in this research utilizes the Google Classroom application. The LMS presents several online student activities as networking learning in the first syntax of the CFGC model learning. The activities presented include online learning attendance, learning materials, AR media, educational games, and evaluation. For games, researchers developed using Wordwall, while evaluation was developed using the Quizizz application.

Textbook

The textbook was developed to complement learning using AR media within the CFGC learning model. This book is structured according to the latest learning objectives issued by the Ministry of Primary and Secondary Education. The advantage of this book is that it is equipped with AR media barcodes.



Figure 3. Comprehensive Learning Package Supporting AR-CFGC Implementation Validity and Product Analysis

Validity testing was conducted to assess the content, construct, and language of the Interactive Augmented Reality learning media within the CFGC Model and its supporting components. Assessment was performed by three experts using validation instruments and then analyzed using Aiken's V technique. The analysis results can be seen in the following table:

Table 3. Expert Validity Test Analysis Results for AR Products and Supporting Applications

No.	Developed Product	Assessed Aspects	Average Aiken's V Coefficient	Validity Category
1	AR Media	Content appropriateness, media design, AR interactivity and functionality, Deep Learning aspects, alignment with CFGC learning model, language appropriateness, benefits, innovation and accessibility	0.97	Very High
2	IPAS Textbook	Format substance and content, learning construct aspects, language, appearance and document completeness	0.96	Very High
3	Learning Management System (LMS)	Display quality, learning content and features, language, security and accessibility	0.98	Very High
4	Lesson Plan (RPP)	Content appropriateness, RPP construction and systematics, language, appearance and document completeness	0.96	Very High
5	Student Worksheet (LKPD)	Instructions, concept accuracy, concept depth, questions, sentence clarity and language	0.97	Very High
6	Learning Motivation Questionnaire	Instructions, content and language	0.93	Very High
7	Teacher Response	Instructions, content, language	0.98	Very High
8	Student Response	Instructions, content, language	0.88	Very High

From the data presented in Table 3, overall the AR learning media and research support obtained validity values with very high categories in the range of average Aiken's V coefficient values of 0.88-0.98. This indicates that the products are declared valid and appropriate for use in learning.

Media Practicality Analysis

After products were developed and declared valid, the next stage was conducting trials to determine product practicality. Practicality analysis involved teachers and students as direct users through questionnaire distribution. The practicality indicators for student response questionnaires include AR media quality, CFGC learning model alignment with AR media, learning motivation, and critical thinking development. Student response questionnaire data and quantitative response questionnaire analysis results can be seen in Table 4.

Table 4. Student Response Analysis toward AR Media

No.	Indicator	Average Response Percentage	Average Response Percentage	Description
1	Augmented Reality Media Quality	80.06	90.5	Positive
2	CFGF Learning Model Alignment Aspects	78.39	88.5	Positive
3	Learning Motivation Aspects	80.14	87.5	Positive
Average Score		79.53	88.83	Positive

Based on Table 5, student responses toward AR media show all aspects were assessed positively with an average score of 79.93. This indicates that students evaluate the media as easy to use, engaging, and appropriate for student learning needs. Teacher responses toward Augmented Reality-based learning products demonstrate very positive tendencies. The media quality indicator obtained an average score of 79.53, confirming that this media is considered very good in terms of appearance, ease of use, and media attractiveness. Furthermore, the alignment aspect with the CFGF learning model received a score of 88.83, meaning the media aligns with the characteristics of the learning model used in the classroom. From the data results, it can be concluded that the developed Augmented Reality media has a high level of practicality and is well-received by users.

Media Effectiveness Analysis on Learning Motivation

After completing validation and practicality testing stages, the next step is testing the effectiveness of the developed media. Effectiveness analysis is conducted to determine the extent to which AR media can impact the improvement of students' motivation and critical thinking. This test is implemented through application in one class by comparing students' initial and final motivation using a one-group pretest-posttest design. Data are analyzed descriptively and inferentially. Analysis results are used to observe differences in students' learning motivation.

Student Learning Motivation Indicator Analysis

Analysis of student learning motivation improvement was conducted through measurements before (pretest) and after (posttest) implementation of Augmented Reality (AR)-based learning media in experimental and control classes. Five learning motivation indicators—achievement goal, performance goal, science learning value, active learning strategies, and self-efficacy—were used to assess students' cognitive and affective aspects. Comparisons of pretest and posttest results can be seen in the following figure.

The figure above illustrates the comparison of pretest and posttest score percentages between experimental and control classes across five Natural and Social Sciences (IPAS) learning motivation indicators: achievement goal, performance goal, science learning value, active learning strategies, and self-efficacy. The graph demonstrates differences in improvement levels between both groups following the implementation of Augmented Reality (AR)-based learning media in the experimental class.

Generally, both control and experimental classes experienced score increases from pretest to posttest, however, the experimental class showed higher improvements across all indicators. The most notable increases occurred in the self-efficacy and science learning value indicators, indicating that AR media utilization strengthens students'

confidence in learning and enhances the value and meaning of science education from students' perspectives.

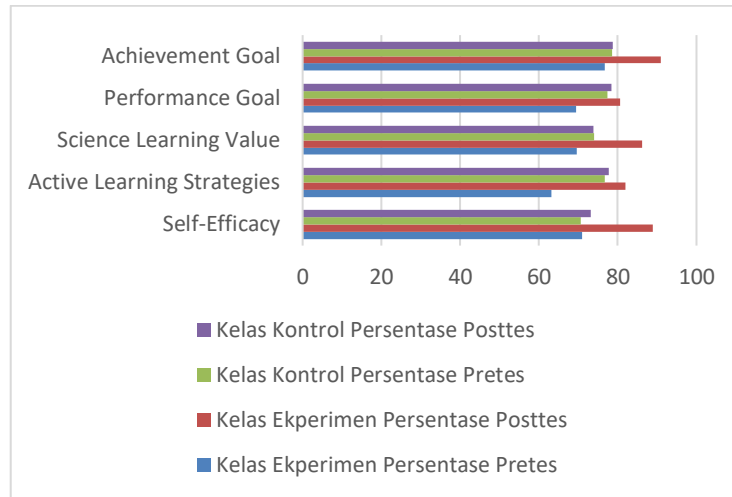


Figure 2. Percentage Values of IPAS Learning Motivation Indicators

The achievement goal and active learning strategies indicators also experienced significant improvements in the experimental class compared to the control class. This indicates that learning with AR media encourages students to be more oriented toward learning achievement and actively manage their learning strategies. Overall, this graph reinforces statistical analysis results that the implementation of Augmented Reality (AR) learning media within the Contextual Flipped Group Classroom (CFGK) learning model provides positive impacts on improving students' learning motivation across achievement goals, active learning strategies, and self-confidence in the learning process.

Normality Analysis

Student motivation data normality testing was conducted using the Kolmogorov-Smirnov test. Analysis results are shown in the following table:

Table 5. Student Learning Motivation Data Normality Analysis

Class	Test	Statistic	df	Sig.
Experimental Class	Pre-test	0.065	112	0.200
	Post-test	0.085	112	0.061
Control Class	Pre-test	0.071	112	0.200
	Post-test	0.069	112	0.200

Based on normality test results in the table above, the significance values (Sig.) for initial motivation tests in the experimental class were 0.200 and for final tests in the experimental class, student motivation was 0.061. Furthermore, initial motivation tests in the control class were 0.200 and for final tests in the control class, student motivation was 0.200. These data are greater than 0.05, indicating that both experimental and control class test data, as well as final tests, are normally distributed.

Independent Sample Test

The Independent Sample Test was conducted after data were declared normal. This test is used to determine whether there are significant differences between initial and final motivation test scores among students in experimental and control classes. The test results can be seen in the following table:

Table 6. Independent Sample Test Analysis

Data	Mean	Mean Difference	Std. Error Difference	t	df	Sig. (2-tailed)
Equal variances assumed	5.45536	-10.661	0.695	-15.339	222	0.001
Equal variances not assumed		-10.661	0.695	-15.339	176.549	0.001

Analysis results using the Independent Samples t-test show that the Levene test value for equality of variances is $F = 32.270$ with a significance level of $0.001 < 0.05$. Therefore, interpretation of t-test results was conducted based on the "Equal variances not assumed" row. Based on t-test results, the t value = -15.339 with degrees of freedom (df) = 176.549 and significance value (Sig. 2-tailed) = 0.001, which is smaller than the 0.05 significance level. This indicates a statistically significant difference between the means of both compared groups. The Mean Difference value = -10.661 signifies that the experimental group's average score is higher than the control group by a difference of 10.661 points. Thus, it can be concluded that the use of Augmented Reality (AR) learning media provides a significant effect on improving student learning outcomes. The substantial mean difference between both groups reinforces findings that AR-based interactive media implementation can enhance learning process effectiveness compared to conventional methods.

ANCOVA Test

To determine the effect of the CFGC learning model using Augmented Reality media on student learning motivation after controlling for pretest scores, Analysis of Covariance (ANCOVA) was conducted. This analysis aims to test whether there are significant differences between learning outcomes (posttest) of students who participated in learning using Augmented Reality (AR) media with the CFGC learning model compared to students who participated in conventional learning, after controlling for the influence of initial ability (pretest). ANCOVA analysis results are displayed in the following table.

Table 7. Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3809.969 ^a	2	1904.985	120.734	.000
Intercept	3995.260	1	3995.260	253.212	.000
Pretest	995.523	1	995.523	63.094	.000
Learning Model	3601.985	1	3601.985	228.287	.000
Error	3487.013	221	15.778		
Total	942550.000	224			
Corrected Total	7296.982	223			

Dependent Variable: Posttest

^a R Squared = .522 (Adjusted R Squared = .518)

Based on analysis results presented in the table above, the F value = 120.734 with a significance level of $0.000 < 0.05$ indicates that the learning model provides a significant effect on student learning outcomes. The pretest component also has a significant effect on the posttest ($F = 63.094$; Sig. = 0.000), meaning students' initial ability influences learning outcomes after treatment.

The Learning Model variable has an F value = 228.287 with Sig. = 0.000, leading to the conclusion that implementation of Augmented Reality (AR) learning media significantly improves student learning outcomes compared to conventional learning. The

R Squared value = 0.522 indicates that 52.2% of variation in student learning outcomes (posttest) can be explained by the learning model and initial ability, while the remaining 47.8% is influenced by other factors outside the studied model. Thus, it can be confirmed that the use of Augmented Reality-based learning media provides significant contribution to improving student learning motivation, while simultaneously strengthening the effectiveness of Contextual Flipped Group Classroom (CFGC) model implementation in the learning process.

Discussion

This research produced a valid interactive AR media based on expert judgment and practical positive user responses that are integrated into the CFGC learning model. Generally, descriptive analysis results demonstrate that average learning motivation scores among experimental class students were higher compared to the control class. This finding indicates that AR integration into contextual and collaborative learning models can create more engaging and meaningful learning experiences for students (Prasetya et al., 2024; Wannapiroon et al., 2021; Waskito et al., 2024).

In per-indicator analysis, motivation improvement appears evenly distributed across five main indicators: achievement goal, performance goal, learning value, active learning strategies, and self-efficacy. Among motivation indicators, the highest improvements occurred in self-efficacy and active learning strategies indicators. This demonstrates that AR-based learning within the CFGC model can cultivate students' self-confidence in understanding material and encourage active participation in learning activities (M. P. Chen et al., 2022; Khan et al., 2019). Three-dimensional visualization in AR media helps students connect IPAS concepts with real phenomena, making them feel more competent and courageous in exploration. This finding aligns with research by Lampropoulos et al. (2022) and Ntoumanis et al. (2021), which confirms that AR usage provides immersive learning experiences and enhances intrinsic motivation through meaningful visual interactions.

Improvements in achievement goal and performance goal indicators also demonstrate that students are motivated to achieve academic success and strive to display their best performance. The CFGC model, which emphasizes pre-class learning through videos and AR-based activities, enables students to prepare themselves before classroom discussions. During group activities, students who already possess foundational understanding become more confident in participating and explaining concepts to their group members. Consequently, achievement motivation and performance orientation increase naturally as learning success results from effort and collaboration. Erbil & Kocabaş (2020) support this by stating that AR-based flipped learning provides independent exploration space that enhances students' sense of responsibility and achievement motivation.

T-test results reinforce these descriptive findings. The t-value of -15.339 with 0.001 significance indicates significant differences between experimental and control groups regarding student learning motivation. Higher average learning motivation scores in the experimental group signify that AR integration in learning effectively creates more engaging, contextual, and challenging learning conditions. Students experience more enjoyable learning because they can directly interact with virtual objects, making them more focused and motivated. These results are consistent with research finding that AR usage in thematic learning increases elementary students' interest and active participation (Angraini et al., 2024; Pratama et al., 2021; Yousef, 2021).

Furthermore, ANCOVA test results demonstrate that learning models using AR media significantly affect learning motivation after controlling pretest scores ($F =$

228.287; $p < 0.001$). The R^2 value of 0.522 indicates that approximately 52.2% of variation in student learning motivation scores is explained by AR media implementation within the CFGC model. This reveals that interactive media contribution is sufficiently strong in enhancing student motivation, even after considering initial abilities. This demonstrates that the AR-CFGC approach not only enriches visual learning displays but also deeply influences students' affective aspects. Similar results have been found, showing that AR integration in flipped classrooms enhances self-efficacy and motivation through active and collaborative learning experiences (Indayati et al., 2024; Schunk & DiBenedetto, 2021; Zander et al., 2018).

From a theoretical perspective, these findings can be explained through Self-Determination Theory (SDT) proposed by Deci and Ryan through meta-analysis results (Howard et al., 2021; Ntoumanis et al., 2021). In this theory, learning motivation increases when three basic psychological needs of students are fulfilled: autonomy, competence, and social connection. The CFGC model enables students to learn independently before class (autonomy), then build understanding and confidence through AR (competence), and collaborate in group discussions (social connection). These three elements mutually reinforce each other, creating learning environments that support intrinsic motivation (Howard et al., 2021). Additionally, these research results are also relevant to Goal Orientation Theory, which explains that students with achievement orientation tend to have high learning effort and more stable motivation (Krou et al., 2021). AR-CFGC-based learning that emphasizes exploration and collaboration processes encourages students to focus on understanding improvement rather than merely final results. Such learning environments cultivate growth mindset, which becomes an important foundation in 21st-century learning (Zander et al., 2018).

These findings demonstrate that AR-based interactive media implementation within the CFGC model not only increases motivation but also confidence and active student engagement. Learning becomes more meaningful because students can connect IPAS concepts with real experiences. From a pedagogical perspective, this approach provides space for students to become active subjects who construct their own knowledge, aligning with the spirit of the Merdeka Belajar curriculum. These research results support the notion that digital learning innovations must focus on creating collaborative, reflective, and real-life context-based learning experiences (AlGerafi et al., 2023; Álvarez-Marín et al., 2023).

Therefore, Augmented Reality media integration within the Contextual Flipped Group Classroom model proves effective in enhancing elementary students' IPAS learning motivation. This media is not merely a visual aid but a tool capable of providing meaningful learning experiences, encouraging social collaboration, and cultivating students' intrinsic motivation and curiosity toward natural and social phenomena around them.

Limitations and Future Directions

Despite the significant findings, several limitations of this study should be acknowledged. First, the sample was limited to urban elementary schools in Makassar City, South Sulawesi Province. Consequently, the generalizability of these findings to rural or remote school settings—where infrastructure, digital literacy, and access to technology may differ substantially—remains constrained. Future research should replicate this study across diverse geographical and socioeconomic contexts, including rural and underdeveloped regions, to examine whether the AR-CFGC model produces comparable motivational outcomes in less resource-equipped environments.

Second, the intervention was implemented within a relatively short timeframe, which limits the ability to determine the long-term sustainability of the observed

motivational improvements. Short-term motivation gains may diminish as the novelty effect of AR technology wears off (Garzón & Acevedo, 2019). Longitudinal studies spanning an entire academic year or multiple semesters are therefore recommended to assess whether the motivational benefits of AR-CFGC integration are sustained over time and whether they translate into improved long-term academic achievement and science literacy.

Third, technical challenges related to device availability and internet connectivity posed practical constraints during implementation. Not all students had equal access to personal smartphones or tablets capable of running the AR application smoothly, and intermittent internet connectivity in certain school locations occasionally disrupted the flipped learning component delivered through Google Classroom. These technological barriers are particularly relevant in the Indonesian educational context, where the digital divide remains a significant concern (AlGerafi et al., 2023). Future implementations should explore offline AR functionality and low-bandwidth alternatives to ensure equitable access for all students.

Fourth, this study did not systematically assess the level of teacher training required for effective AR-CFGC implementation. Although teachers received orientation prior to the intervention, the depth and duration of this training may influence implementation fidelity and, consequently, student outcomes. Subsequent research should investigate optimal teacher professional development models, including the minimum training hours, technical competencies, and pedagogical support needed for teachers to confidently and effectively integrate AR media within the CFGC framework.

Fifth, the quasi-experimental design using intact groups, while practically appropriate for classroom-based research, does not permit the same level of causal inference as true randomized experiments. Although ANCOVA was employed to control for pretest differences, unmeasured confounding variables—such as differences in teacher effectiveness, classroom climate, or students' prior technology exposure—may have influenced the results. Future studies should consider multi-site randomized controlled trials with larger and more diverse samples to strengthen causal claims.

Practical Implications

The findings of this study carry important practical implications for educational stakeholders seeking to implement AR-based interactive media within the CFGC model.

1. Implementation Cost.

Developing AR media requires initial investment in content creation using platforms such as Assembler Edu and Canva, along with the procurement of compatible mobile devices. However, once developed, AR content can be reused across multiple cohorts with minimal additional cost, making it a cost-effective long-term investment. Schools with limited budgets may adopt a shared-device model, where tablets are rotated among classrooms, thereby reducing per-student technology costs. Educational policymakers should consider allocating technology grants or integrating AR media procurement into existing school operational assistance funds (BOS) to support wider adoption.

2. Training Requirements.

Successful implementation of the AR-CFGC model depends on teachers' technological pedagogical content knowledge (TPACK). At minimum, teachers require training in: (a) operating AR applications and troubleshooting common technical issues; (b) designing flipped classroom activities that effectively integrate pre-class AR exploration with in-class collaborative discussions; and (c) facilitating contextual group work that connects AR content to students' real-life experiences. A structured professional development program of at least 16–24 hours, combining hands-on

workshops with ongoing mentoring, is recommended to ensure teachers achieve sufficient confidence and competence.

3. Scalability and Sustainability

For this pedagogical innovation to achieve broader impact, several scalability considerations must be addressed. The AR media developed in this study covers five IPAS topics (human organ systems, biotic and abiotic environments, the solar system, Indonesia's geographical location, and cultural diversity), which represents only a fraction of the elementary IPAS curriculum. Expanding the AR content library to cover additional topics and grade levels would enhance the model's utility and justify the initial development investment. Furthermore, establishing collaborative teacher communities for sharing AR content and best practices would facilitate organic dissemination beyond the initial research context. Integration with the national Merdeka Belajar curriculum platform could further accelerate adoption across Indonesian elementary schools (Nasrah et al., 2024).

CONCLUSION

This study developed and examined the effectiveness of Augmented Reality (AR)-based interactive media integrated within the Contextual Flipped Group Classroom (CFGF) model to enhance elementary students' Natural and Social Sciences (IPAS) learning motivation. The findings demonstrated that the AR-CFGF integration significantly improved students' learning motivation across all five dimensions—achievement goals, performance goals, learning value, active learning strategies, and self-efficacy—with the experimental group consistently outperforming the control group ($p < 0.05$). The most substantial improvements were observed in the self-efficacy and active learning strategies dimensions, confirming that AR-mediated visualization and contextual group collaboration effectively foster students' confidence and active engagement in learning scientific concepts.

Theoretically, this study contributes an integrated pedagogical framework that synthesizes three approaches—Augmented Reality technology, the flipped classroom model, and Contextual Teaching and Learning—into a unified CFGF model grounded in constructivist learning theory. This framework extends existing literature by demonstrating that the synergistic combination of these approaches produces motivational outcomes beyond what each approach achieves independently, particularly at the elementary education level where such integration remains underexplored.

From a practical standpoint, the AR-based interactive media developed through the ADDIE model provides teachers with a ready-to-use, validated instructional tool that transforms abstract IPAS concepts into concrete, interactive learning experiences. The CFGF model optimizes face-to-face classroom time by shifting content acquisition to pre-class AR exploration, enabling teachers to dedicate in-class sessions to collaborative discussion, experimentation, and contextual application. These findings affirm that technology-integrated pedagogical innovation, when thoughtfully designed and contextualized, can serve as an effective strategy for addressing the persistent challenge of low learning motivation in Indonesian elementary science education.

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do so in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

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