How to Cite (APA Style):
Sulianto, J., Buchori, A., & Rahmawati, N. D. (2025). Development of Augmented Reality-Based Mathematics Textbooks to Foster Critical and Creative Thinking Skills. *Jurnal Ilmiah Pendidikan Dasar*, *12* (2), 228-250. http://dx.doi.org/10.30659/pendas.12.2.228-250

JURNAL ILMIAH PENDIDIKAN DASAR
p-ISSN: 2354-9580
e-ISSN: 2685-211X

Development of augmented reality-based mathematics textbooks to foster critical and creative thinking skills

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Submitted: June 13th, 2025 **DOI: 10.30659/pendas.12.2.228-250**
Revised: July 30th, 2025
Accepted: July 31st, 2025

Keywords:
development; thematic textbook; augmented reality

Abstract

The implementation of three-dimensional textbooks in both public and private elementary schools within the Semarang city area remains limited with most institutions still relying on conventional printed versions. However, AR-based mathematics textbooks—already adopted in parts of Indonesia—offer interactive visual experiences that can enhance students' critical and creative thinking. This study employed a Research and Development (R&D) approach using the Multimedia Development Life Cycle (MDLC) model developed by Luther-Sutopo, which includes six phases: concept development, design, material collection, assembly, testing, and distribution. A limited trial was conducted at SDN Sawah Besar 01 Semarang. The outcomes of the study are as follows: (1) The development of the 2nd grade thematic AR textbook linked to the Pancasila Student Profile, featuring engaging and interactive AR content; (2) high validation scores from experts—89 (material) and 87.75 (media)—indicating strong suitability for use in thematic learning at the second-grade level; (3) Multivariate Analysis of Variance (MANOVA) results demonstrated a statistically significant improvement ($p < 0.05$) in critical and creative thinking among students using the AR textbook compared to the control group. These results suggest that AR-enhanced thematic textbooks are both effective and viable for wider adoption in elementary schools across Semarang.

INTRODUCTION

Background of the Study

Thematic learning in elementary schools is not only learning that has been delivered, but elementary school students must really master the material correctly and students enjoy participating in learning in class, then based on observations at SD Pedurungan Tengah 01 Semarang and SD Islam Harapan Bunda Semarang in 2022 showed that 80% of elementary school students in grade I in thematic learning really need a touch of technology in their learning in class, especially elementary school mathematics material for grade 2 which is linked to the independent curriculum which is very difficult for students and teachers, this needs to be innovated because elementary school thematic learning is comprehensive learning between subject matter with a minimum of 2 to 4 subject matter that are packaged continuously (Nugraha et al., 2021). Meanwhile, in classroom learning, students are only directed to memorize information, remembering without understanding the information obtained in daily life activities. Most teachers are fixated on textbooks as a source of learning. Over time, technological developments, and research, many references have emerged to make thematic learning fun, but they are not necessarily suitable for the conditions in the classroom being taught, especially in relation to the profile of Pancasila students. In addition to creating interesting learning media, a teacher must be able to choose a learning approach that suits the characteristics of the students, one of the approaches used is the Pancasila student profile approach, with the hope that students will have more nationalism and reliable human resource capabilities, then with the application of thematic elementary school textbooks based on augmented reality, it can improve the critical and creative thinking skills of elementary school students to be better. (Mahmud & Cempaka, 2022). With the existence of thematic elementary school textbooks based on augmented reality, it is very much hoped that it will form a profile of Pancasila students who think critically and creatively by using this augmented reality-based textbook, here specifically thematic elementary school mathematics textbooks for grade 2 are made covering 5 essential materials in grade 2 elementary school.

In this research, it is adjusted to the 2017-2045 national research master plan with a focus on social, humanities, arts, culture and education research, which includes aspects of education and culture, which develops participatory technology research to build national identity with a focus on character and competitive education Shabrilia, Maheswari & Adhiatma, (2022), by creating a design for thematic

elementary school textbooks based on augmented reality, with the hope that elementary school teachers and students in the Semarang city area have competitiveness in presenting interesting and enjoyable thematic elementary school learning, then adjusted to the LPPM Semarang PGRI University strategic plan, one of which focuses on developing learning media to improve the professionalism of educators and education personnel.

The Problem of The Study

Based on the conditions in schools and relevant research, the following problems can be formulated: 1) How to design thematic elementary school textbooks, especially grade 2 mathematics based on augmented reality that support the Pancasila student profile?, 2) Can thematic elementary school textbooks, especially grade 2 mathematics based on augmented reality, improve students' critical and creative reasoning skills?

Research's State of the Art

Table 1. State of Art Penelitian

Previous research:	1. Animal Recognition Learning Media for Elementary School Students Using Android-Based Augmented Reality is able to improve student learning outcomes. Reynaldo, Suprianto, & Indahyani (2022) 2. The development of interactive Kuraru media based on augmented reality in elementary school thematic learning can increase students' learning motivation (Nisa, Hudha,& Husamah. (2023) 3. With Local Wisdom Values in E-LKS Based on Wayang Sukuraga, it is able to increase the Realization of Student Profiles (Andhini, Nurasiah, & Nurmeta, 2022)
Current developments	Thematic learning media for learning to pray using augmented reality has been used for elementary schools which is able to increase students' understanding. siswa (Fitriyanti et al., 2023). Then, mentoring and introduction of interactive teaching methods with augmented reality can improve students' critical reasoning in thematic learning in grade 2 of elementary school (Idham Rusdi, Prasti, & Rais, 2021).
Gap Analysis	1. The development of MAR (Augmented Reality Mathematics) exploration with character strengthening in elementary school spatial geometry material shows that there is a negative effect, namely that weak students need to be taught the material again. (Rachmawati, Wijayanti, & Putri Anugraini, 2020) 2. in contrast to the development of augmented reality-based picture story books that greatly accommodate Generation Z (Lubis & Dasopang, 2020)

Research conducted	AR-based thematic textbooks will be created for elementary school grade 2, the media of which will be created using the latest Unity 3D to support the profile of Pancasila students who think critically and creatively (Wahyuddin & Hasnawati (2023)

Novelty, Research Gap, & Objective

Novelty In this study, it is supported by research from outside the research team and previous research from the research team regarding the feasibility analysis of millennial textbooks based on augmented reality (AR) as a learning medium for procedural texts in Magelang which is very suitable for use by millennial children. (Hapsari & Wulandari, 2020) and strengthened by research on Digital Media which is able to Empower Children's Critical Thinking Skills in Science Learning in Elementary Schools (Hasanah, Astra, & Sumantri(2023), then the research that has been carried out by the research team related to the design of technology applications in the form of AR-based elementary school mathematics textbooks specifically for grade 2 of elementary school is as follows:

Table 2. Novelty dan Research Gap

2026 to 2027	Distribution: Marketing of AR-based thematic elementary school textbook products, especially for grade 2 elementary school mathematics throughout Indonesia.
2025 to 2026	Testing : Testing of AR-based elementary school mathematics textbook products for grade 2 elementary school. by the Ministry of Education and Culture
2025	Assembly: In assembling AR-based elementary school mathematics textbooks, it was carried out at PGRI Semarang University with partner lab facilities and the UPGRIS campus.
2024	Collection of materials needed to develop AR-based elementary mathematics textbooks for all grade levels.
2023	1. Study (Asyaroh, Buchori, Wardani, & Wijayanto, 2023). about the Development of Augmented Reality-Based Fraction Number Educational Games as a Medium for Learning Mathematics for Grade III Elementary Schools shows that AR-based educational games can improve student learning outcomes. 2. Study (Fitrianingsih, Akhyar, & Efendi, A, 2023) About Developing character building learning model using mobile AR media with 3D visualization and interactive gameplay effectively enhances elementary students' understanding of solid geometry concepts. 3. Study (Nafisa, & Nuvitalia (2023). About the profile of children's stories and hand puppet media in the character-based storytelling method for elementary school students shows that elementary school children like to learn and play with media Determining the concept and design of good and suitable AR-

based elementary school thematic textbooks for grade 2.

METHOD

Type and Design

This research method uses the Luther-Sutopo version of the Multimedia Development Life Cycle (MDLC) research and development model through six stages, namely concept, design, material collection, assembly, testing, and distribution (Widiati, Murhadi, & Saputro(2023)) , with the research stages for 1 year as follows:

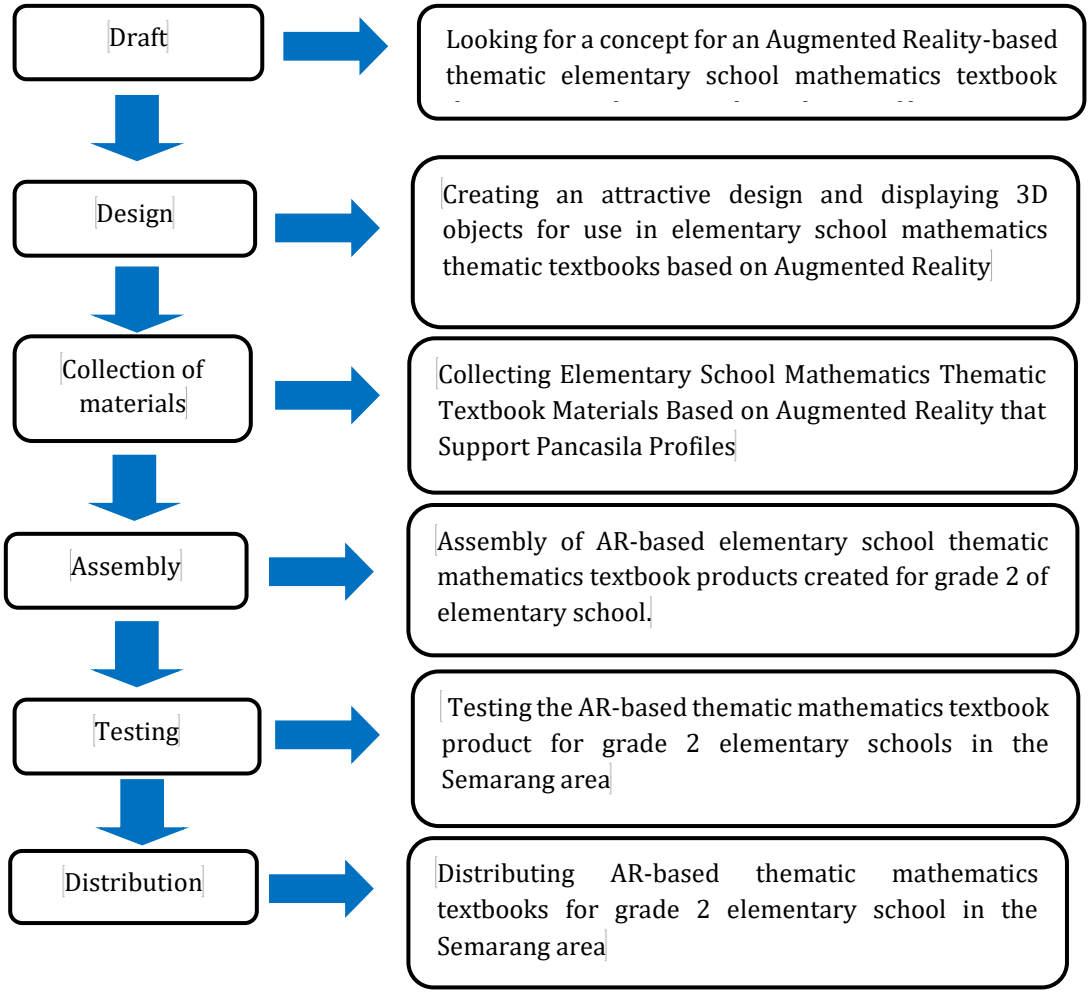


Figure 1. Method MDL

Data and Data Sources

This research was conducted at SDN Sawah Besar 01 Semarang, This research was conducted in January - September 2024, Academic Year 2024/2025. The subjects in this study were all students of class II of SDN Sawah Besar 01 Semarang consisting of two classes, namely class II A (28 people) as the control class by implementing the conventional learning model and class II B (28 people) as the experimental class by implementing the AR Book Thematic.

Data Collection Technique

In this study, data collection was carried out using questionnaires and tests given to validators and students at SDN Sawah Besar 02 Semarang, the questionnaire used a Likert scale and the test used descriptive test questions in answering questions related to elementary school mathematics for grade 2 thematically with other subjects.

Data Analysis

In this research on the development of the Elementary School Mathematics AR Book, quantitative analysis was used by conducting t-tests and manova tests, which were previously tested for normality and homogeneity.

RESULTS

In this study, the design of an elementary school mathematics textbook based on augmented reality is by using the Multimedia Development Life Cycle (MDLC) model, Luther-Sutopo version, through six stages, namely concept, design, collection of materials, assembly, testing, and distribution. (Roedavan, Pudjoatmodjo, & Putri Sujana, 2022).

Stage 1 : Draft

In making the concept adjusted to the learning conditions at SDN Sawah Besar 01 Semarang, especially thematic material for grade 2 of elementary school, especially elementary school mathematics, covering 5 chapters of material, this is because based on the grade 2 elementary school teacher, it shows that children are still confused about the material on comparison of value and inverse value, so it is necessary to make an approach so that students understand the comparison material better and students do not get bored following mathematics learning, one of the breakthroughs so that students are interested in following mathematics learning is to make mathematics textbooks more interesting with the presence of augmented reality with a three-dimensional media display accompanied by interesting music and animations.

Stage 2 : Design

In making the design of the AR Book of Elementary School Mathematics for grade 2, this was done by first making a design related to the addition and subtraction material using Corel Draw with attractive color gradations, then the structure of the material that will be delivered in the AR Book of addition and subtraction material was made which includes learning activities, material descriptions, sample questions equipped with augmented reality in each sample question with an AR Barcode that appears with a three-dimensional animation that comes out of the book and music and animation come out, so that it is interesting for students and teachers who use it, the following is the design of the AR Book of Elementary School Addition and Subtraction Material that has been made:

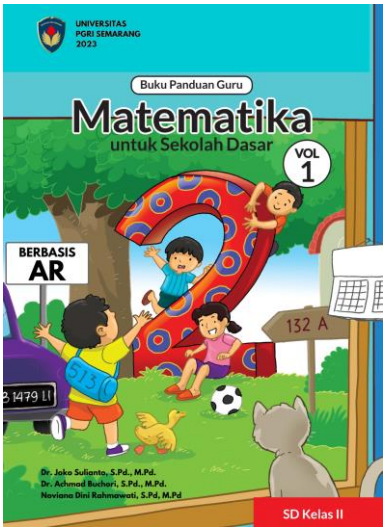


Figure 2. Cover Design for Ggrade 2 Eelementary School Mathematic Material

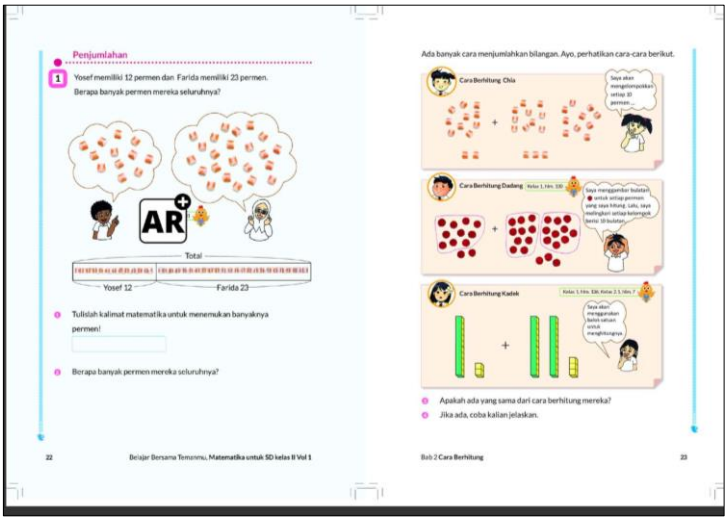


Figure 3. Application of AR Barcode in Elementary School Grade 2 Mathematics Material

Stage 3: Collection of Mmaterials

In collecting materials to create this AR Book for Elementary School Mathematics for Class 2, various methods were used, namely (1) selecting material from elementary school mathematics teaching books from various publishers from within and outside the country related to the independent curriculum, (2) selecting addition and subtraction material and looking for examples of contextual questions that could be made into augmented reality markers, (3) looking for software that is relevant to the AR Book for Elementary School Mathematics, namely Unity 3D software, Vuforia development, Blender software which can finally be used as a tool to create the AR Book Math application for Elementary School that is ready to be used in class.

Stage 4 : Assembly

In the assembly of the AR Book Math SD, it is done simultaneously and systematically by selecting the appropriate addition and subtraction material seen from its grammar, example questions and practice questions along with the answer keys are packaged well and AR Barcodes are added to each example question, so that when using this AR Book Math SD, teachers and students can immediately see the augmented reality that comes out of the AR barcode in each example question by first installing the application on their smartphone or tablet.

Stage 5: Testing

In the testing of the AR Book Math SD product, it was carried out at SDN Sawah Besar 01 Semarang in collaboration with teachers and students during several meetings to determine the effectiveness of using the AR Book Math SD based on the independent curriculum in mathematics learning in the classroom, then before the product was tested on a limited basis, expert validation was carried out first by material experts and learning media experts who were competent in their fields.

Figure 4. Validation of AR Book Mathematics SD Product by Eexpert Judgment

Table 3. Results of Eexpert Vvalidation of the AR Book Math SD Pproduct

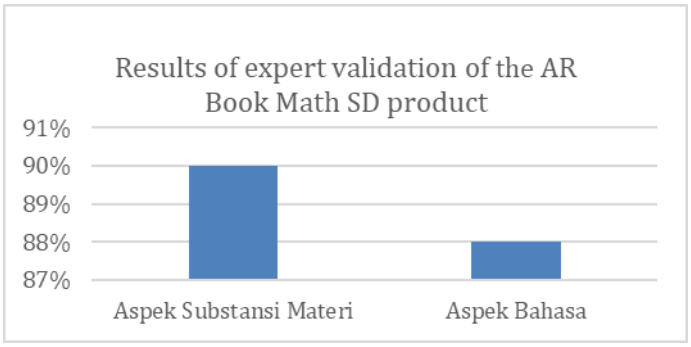
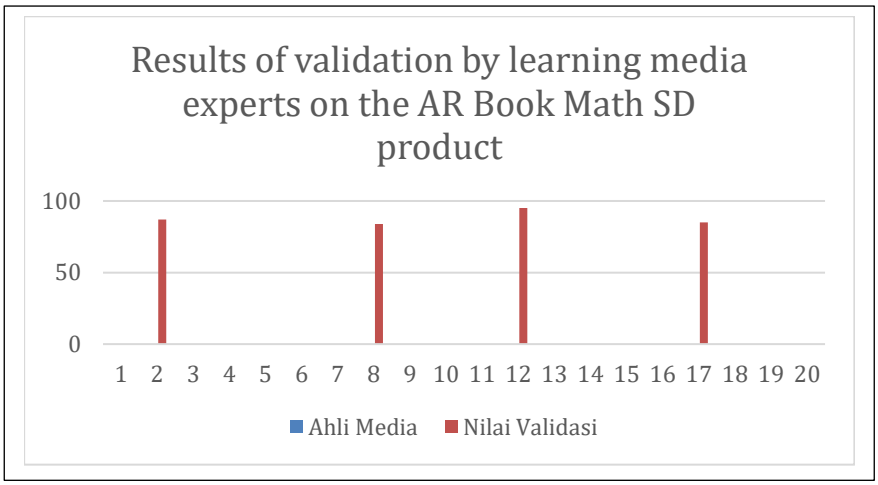


Table 3 shows that the material substance aspect obtained a score of 90 and the language aspect obtained a score of 88, meaning that the average score obtained from material experts was 89%, this shows that the AR Book Math SD product is very suitable for use in mathematics learning in grade 2 of elementary school based on the independent curriculum, then continued with validation by learning media experts assessed by ICT lecturers at UPGRIS by obtaining the following scores:

Table 4. Results of Validation by Llearning Mmedia Eexperts on the AR Book Math SD Product



From table 4 it shows that the application aspect obtained a score of 87, the creative aspect obtained a score of 84, the innovative aspect obtained a score of 95 and the visual communication aspect obtained a score of 85, meaning that the average validation score for learning media was 87.75%, meaning that the AR Book Math product for grade 2 elementary school is very suitable for use in mathematics learning in elementary school.

After expert validation was carried out, the product was improved and a limited

test was conducted at SDN Sawah Besar 01 Semarang with the following details: (1) students and teachers were asked to install the AR Book Math SD application on addition material, (2) then students and teachers practiced by directing the AR Book Math application to the marker in the AR Book Math SD textbook until the music and augmented reality appeared, (3) then the teacher explained the addition and subtraction material conventionally and continued practicing using AR Book Math to help students understand the addition and subtraction material, (4) students provided input related to the use of AR Book Math SD in writing and orally, (5) students completed a post-test related to the addition and subtraction material.

Figure 5. Limited Test of AR Book Math SD Products at SDN Sawah Besar 01 Semarang

Figure 6. The Eenthusiasm of Teachers and Eelementary Sschool Sstudents at SDN Sawah Besar 01 Semarang using AR Book Math SD

The following are the results of research data after students were given treatment with AR Book Math SD and conventional classes related to its influence on students' critical and creative thinking skills.

From the processing of critical thinking data, students obtained data:

Table 5. Normality Test

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Kelas	Statistic	df	Sig.	Statistic	df	Sig.
Nilai	Eksperimen Class	.467	24	.076	.528	24	.079
	Control Class	.225	24	.093	.837	24	.091

From the Test of Normality table in Shapiro-Wilk above, the significant value of critical thinking in the experimental class is 0.079 = 7.9% and the significant value of critical thinking in the control class is 0.091 = 9.1%. Because 7.9% > 5% and 9.1% > 5%, then based on the H0 criteria it is accepted. This means that the samples in the critical thinking of the experimental class and the critical thinking of the control class are normally distributed.

Table 6. Test of Homogeneity of Variances

Score

Levene Statistic	df1	df2	Sig.
2.645	1	46	.111

From the Test of Homogeneity of Variances table above, the significant value is 0.111 = 11.1%. Because 11.1% > 5%, then based on the H0 criteria it is accepted. This means that the variance of the experimental class population and the control class are the same (homogeneous).

Table 7. T-Test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Grade	Equal variances assumed	2.645	.111	3.245	46	.000	17.500	5.392	6.646	28.354
	Equal variances not assumed			3.245	43.855	.000	17.500	5.392	6.632	28.368

From the Independent Samples Test table in the t-test for Equality of Means table above, the significant value is 0.000 = 0%. Because 0% <5%, then H0 is rejected. This means that we accept H1, which means that the results of critical thinking in mathematics using elementary school mathematics textbooks based on augmented reality to support the profile of Pancasila students are better than conventional learning models.

To determine which class between the experimental class and the control class has a higher average value, Group Statistics analysis is used which can be seen in the table below.

Table 8. Group Statistics

	Class	N	Mean	Std. Deviation	Std Error Mean
Grade	Critical thinking	24	92.50	16.485	3.365
	Eexperimental class	24	75.00	20.642	4.214

By looking at the average literacy in the mean column, the Group Statistics table shows that the average of the experimental class is 92.50 while the average of the control class is 75.00. These results indicate that the critical thinking of mathematics in the experimental class is better than that of the control class.

From the data processing of students' creative thinking scores, data was obtained:

Table 9. Normality test

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Grade	Critical thinking experimental class	.437	24	.104	.563	24	.108
	Critical thinking control class	.212	24	.097	.873	24	.096

From the Test of Normality table in Shapiro-Wilk above, the significant value of creative thinking in the experimental class is 0.108 = 10.8% and the significant value of creative thinking in the control class is 0.096 = 9.6%. Because 10.8% > 5% and 9.6% > 5%, then based on the criteria H0 is accepted. This means that the samples in the creative thinking of the experimental class and the creative thinking of the control class are normally distributed.

Table 10. Test of Homogeneity of Variances

Grade				
Levene Statistic	df1	df2	Sig.	Sig.
9.884	1	46	.193	.111

From the Test of Homogeneity of Variances table above, the significant value is 0.193 = 19.3%. Because 19.3% > 5%, then based on the H0 criteria it is accepted. This means that the variance of the experimental class population and the control class are the same (homogeneous).

Table 11. Independent Sampels T-Test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Grade	Equal variances assumed	9.884	.193	3.303	46	.000	9.583	2.901	3.744	15.423
	Equal variances not assumed			3.303	39.285	.000	9.583	2.901	3.717	15.450

From the Independent Samples Test table in the t-test for Equality of Means table above, the significant value is 0.000 = 0%. Because 0% <5%, then H0 is rejected. This means that we accept H1, which means that the results of creative mathematical thinking using elementary school mathematics textbooks based on augmented reality to support the profile of Pancasila students are better than conventional learning models.

To determine which class between the experimental class and the control class has a higher average value, Group Statistics analysis is used which can be seen in the table below.

Table 12. Group Statistics

Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Grade	Experimental class	24	86.25	7.697	1.571
	Control class	24	76.67	11.948	2.439

By looking at the average numeracy in the mean column, the Group Statistics table shows that the average for the experimental class is 86.25 while the average for the control class is 76.67. These results indicate that the creative thinking in mathematics of the experimental class is better than that of the control class.

Table 13. The Results of the Manova Critical and Creative Thinking Test

Descriptive Statistics				
	Class	Mean	Std. Deviation	N
Critical thinking	Experiment	92.50	16.485	24
	control	75.00	20.642	24
	total	83.75	20.486	48
Creative thinking	Experiment	86.25	7.697	24
	control	76.67	11.948	24
	total	81.46	11.059	48

From the descriptive table above, it is obtained that the average critical thinking in the experimental class is 92.50, the control class 75.00. While for creative thinking in the experimental class is 86.25, the control class 76.67. This means that the critical thinking and creative thinking of the experimental class are better than the control class. This proves that the use of elementary school mathematics textbooks based on augmented reality to support the profile of Pancasila students has a significant impact on learning.

Table 14. The Results of the Manova Critical and Creative Thinking Test

Multivariate Tests[a]								
Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[c]
Intercept	Pillai's Trace	.993	3143.849[b]	2.000	45.000	.000	6287.699	1.000
	Wilks' Lambda	.007	3143.849[b]	2.000	45.000	.000	6287.699	1.000
	Hotelling's Trace	139.727	3143.849[b]	2.000	45.000	.000	6287.699	1.000
	Roy's Largest Root	139.727	3143.849[b]	2.000	45.000	.000	6287.699	1.000
Kelas	Pillai's Trace	.195	5.448[b]	2.000	45.000	.008	10.896	.823
	Wilks' Lambda	.805	5.448[b]	2.000	45.000	.008	10.896	.823

Hotelling's Trace	.242	5.448[b]	2.000	45.000	.008	10.896	.823
Roy's Largest Root	.242	5.448[b]	2.000	45.000	.008	10.896	.823

a. Design: Intercept + Kelas
b. Exact statistic
c. Computed using alpha = ,05

The multivariate test table explains that the comparison test is taken from the average of critical thinking and creative thinking variables with treatments (experimental and conventional). The results obtained from each Pillai's Trace, Wilks' Lambda, Hotelling Trace, Roy's Largest Root Sig. values overall 0.000 <0.05. This is in accordance with the criteria that there is an influence of independent variables on the dependent variable. After seeing the influence, it is continued with the Lavene's Test. The Lavene's Test table is used to test the homogeneity of variance univariately. This test is intended to test the similarity of variance between data groups. In the Lavene's test table, the criteria used are if Sig. <0.05 then the variance of the data group is different, and if Sig >0.05 then the variance of the data group is the same. The output results are as follows. Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Table 15. Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
Critical Thinking	2.645	1	46	.111
Creative Thinking	9.884	1	46	.193

Table 16. Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[c]
Corrected Model	Critical Thinking	3675.000[a]	1	3675.000	10.533	.000	10.533	.888
	Creative Thinking	1102.083[b]	1	1102.083	10.912	.000	10.912	.899

Intercept	Critical Thinking	336675.000	1	336675.000	964.925	.000	964.925	1.000
	Creative Thinking	318502.083	1	318502.083	3153.599	.000	3153.599	1.000
Class	Critical Thinking	3675.000	1	3675.000	10.533	.000	10.533	.888
	Creative Thinking	1102.083	1	1102.083	10.912	.000	10.912	.899
Error	Critical Thinking	16050.000	46	348.913				
	Creative Thinking	4645.833	46	100.996				
Total	Critical Thinking	356400.000	48					
	Creative Thinking	324250.000	48					
Corrected Total	Critical Thinking	19725.000	47					
	Creative Thinking	5747.917	47					

a. R Squared = .186 (Adjusted R Squared = .169)

b. R Squared = .192 (Adjusted R Squared = .174)

c. Computed using alpha = ,05

The results obtained from the Lavene's test procedure obtained that the Sig. value of both variables is 0.111 and 0.193 where the Sig. value is > 0.05, so that according to the criteria meaning that the covariance of all data groups is the same. Next, a test of between subjects is carried out, for the output results as follows. Based on the table, it is obtained that overall on the critical thinking variable the Sig. value is 0.000 < 0.05, it can be concluded that there is an influence and on the creative thinking ability the Sig. value is 0.000 < 0.05, it can be concluded that there is an influence of the independent variable on the dependent variable.

Based on the table, it is obtained that overall on the critical thinking ability variable, the Sig. value is 0.000 <0.05, it can be concluded that there is an influence and on the creative thinking ability, the Sig. value is 0.000 <0.05, it can be concluded that there is an influence of the independent variable on the dependent variable.

The results of statistical processing show that using the AR Book Math SD media can improve students' critical and creative thinking skills compared to conventional classes that are not treated with the AR Book Math SD media for addition and subtraction material.

Stage 6: Distribution

The AR Book Math product for addition and subtraction material has been given to teachers and students of SDN Sawah Besar 01 Semarang to be used as a supplement to learning media in class or outside the classroom, this is because the application is mobile in nature and can be used anytime and anywhere, then the e-book has also been given so that there is no need to print the book, just open the book on a cellphone or computer and direct the AR Book, then the augmented reality will automatically appear.

DISCUSSIONS

In the development research with the Multimedia Development Life Cycle (MDLC) model version of Luther-Sutopo through six stages, namely concept, design, material collection, assembly, testing, and distribution have been carried out simultaneously, in the use of this MDLC model several very important findings were obtained in the development of the Elementary School Mathematics AR Book as follows:

1. In the concept step, it was found that the Elementary School Mathematics AR Book is still weak in the concept of addition and subtraction, especially the depth of the concept of addition and subtraction material where the majority of students still use finger arithmetic. Students should be taught with concrete objects that are adjusted to Bruner's iconic, enactive and symbolic theory, so that students really understand the essence of mathematics in everyday life, and this can be helped by augmented reality in clarifying students' understanding of the concept.
2. In the design step, it was found that the SD Mathematics AR Book was still not optimal in its image design, the design with Canva was still not smooth, especially related to the image design displayed with augmented reality, it was necessary to refine the three-dimensional appearance of this SD Mathematics AR Book product so that students really enter the 3D world that explains addition and subtraction material in an interesting and enjoyable way.
3. In the material collection step, it was found that the Elementary School Mathematics AR Book had problems with the materials in the form of assets

displayed in this AR Book. The majority of the assets in AR are paid for, so skills are needed in creating AR with Unity 3D or Vuforia development simultaneously.

4. In the assembly step, it was found that the Elementary School Mathematics AR Book still lacks the pro Unity 3D software so that it is easy to use during assembly, while the Unity 3D used still uses the old Unity 3D software so that the animation product is not optimal.
5. In the testing step, it was found that the Elementary School Mathematics AR Book experienced obstacles, namely that not all students had smartphones that supported AR, so they had to join students whose cellphones supported it to access the AR barcode on each page in this Elementary School Mathematics AR Book, then the sound in the AR Book did not run smoothly because not all students had an internet quota, so that the video tutorial on addition and subtraction material could not be accessed optimally on the AR Barcode.
6. In the distribution step, it was found that the Elementary School Mathematics AR Book had been distributed at SDN Sawah Besar 01 Semarang by being distributed to each class so that it could be used as a supplement to the textbooks in grade 2 of elementary school, however, the obstacle was that when using this Elementary School Mathematics AR Book, students were not yet accustomed to using it so that they were still constrained by supporting equipment in the form of smartphones that were able to access the AR Code on each page.

The results of this study show that the use of the thematic AR Book for elementary school makes students more enthusiastic about learning both in and outside the classroom. This is because students are attracted to the augmented reality features embedded in the thematic AR Book. These findings are in line with the research conducted by Hariyastuti, A. (2024), which showed that learning effectiveness using this media exceeded the standard learning outcomes. Similarly, the study by Kusuma, N. (2024) indicated that interactive learning media strongly support classroom learning activities. Based on the findings of Jupriyanto, Nuhyal, and Yuni (2024), technology-integrated instruction significantly contributes to enhancing students' comprehension quality and learning outcomes. Similarly, Ismiyanti and Permatasari (2021) demonstrated that the use of picture story media has a statistically significant impact on improving students' critical thinking skills, as evidenced by t-test analysis. Sari, Jupriyanto, and Kusumadewi (2025) further confirmed that interactive multimedia grounded in scientific inquiry approaches is effective in fostering critical thinking among elementary school students. Moreover,

Primasari, Ulia, and Yustiana (2021) concluded that technology-based instructional materials are both feasible and effective in supporting the success of creative learning programs in schools. Wahyuningsih and Izzah (2023) also reported that interactive media plays a crucial role in enhancing both creative and critical thinking skills among Indonesian elementary students.

CONCLUSION

Based on the findings of this study, several key outcomes have been achieved that contribute to the enhancement of mathematics learning for Grade 2 students in elementary schools within the Semarang city area. A product titled *AR Book Math SD* has been successfully developed, focusing on addition and subtraction materials for Grade 2 students. The product integrates augmented reality (AR) technology and aligns with the Pancasila Student Profile, resulting in an engaging and interactive learning experience. Validation results from subject matter experts and instructional media experts yielded scores of 89 and 87.75, respectively. These scores indicate that the *AR Book Math SD* is highly appropriate and effective for use in mathematics instruction at the targeted educational level. Statistical analysis using MANOVA demonstrated that students who utilized the *AR Book Math SD* exhibited significantly higher levels of critical and creative thinking compared to those in the control group who did not use the AR-based media. These findings suggest that the integration of augmented reality in early mathematics education can support both cognitive skill development and student engagement.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.