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Development of Autograph-Assisted Teaching Materials to Enhance Students' Numeracy Skills in Phase D

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ABSTRACT

The numeracy skills of Phase D students in Indonesia remain relatively low, as evidenced by the 2018 PISA survey, which ranked Indonesia 72nd out of 79 countries. Transformational geometry is one of the topics that demands high numeracy, often posing challenges due to the need for spatial visualization and logical reasoning. While previous studies have shown the potential of Autograph in HOTS-based learning, research on the development of Autograph-assisted teaching materials explicitly designed to enhance numeracy remains limited. This study introduces a novel approach by integrating Autograph into numeracy-oriented materials for transformational geometry, aiming to provide a validated and practical resource for classroom use. The research employed an R&D design with the ADDIE model, involving 36 ninth-grade students and a mathematics teacher at UPT SMP Negeri 4 Siak Hulu. Data were collected using validation sheets, response questionnaires, and pretest–posttest numeracy tests, and analyzed through Aiken's V, practicality percentage, N-gain, paired t-test, and Cohen's d. The results indicated high validity (0.88), high practicality (84.6%), and strong effectiveness (N-gain = 0.78, Cohen's d = 2.7), with significant improvement from pretest to posttest. The findings highlight the novelty of employing Autograph to foster numeracy development in middle school mathematics, offering new insights into technology-supported instructional design. However, the absence of a control group suggests the need for further studies using more rigorous experimental designs.

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Introduction

The numeracy skills of Indonesian students remain a serious concern. According to the Programme for International Student Assessment (PISA) 2018 report released by the OECD (2019), the average mathematics score of Indonesian students was 379, far below the OECD average of 489, placing Indonesia 72nd out of 79 participating countries. This result indicates that the majority of Indonesian students struggle to solve problems requiring mathematical reasoning. Although the 2022 PISA results show a slight improvement, Indonesia's achievement remains below the international average (OECD, 2022). National data from the Minimum Competency Assessment (AKM) further reinforces this finding, with more than half of junior high school students performing only at the basic to intermediate numeracy levels (Nabilah et al., 2023).

Internationally, numeracy is not merely understood as computational ability but as the capacity to formulate, employ, and interpret mathematics in diverse personal, social, and scientific contexts (OECD, 2019). Neumann et al. (2013) also emphasize that numeracy is a form of mathematical competence encompassing modeling, reasoning, representation, and mathematical communication. In the Indonesian context, numeracy serves as an essential foundation for mastering more complex mathematical concepts (Ezkowati et al., 2019; Salvina et al., 2022).

One mathematical topic that requires high numeracy is transformational geometry. This topic involves translation, rotation, reflection, and dilation, which demand spatial visualization, coordinate use, and logical reasoning. However, studies indicate that students frequently encounter difficulties with this topic, such as understanding the relationship between the original and transformed objects or predicting the effects of rotations and dilations (Rukman & Zulfikar, 2023). Interviews with junior high school teachers further revealed students' low interest in studying transformation, largely because instruction is still conducted manually and seldom incorporates technology. To address these challenges, teaching materials need to be systematic, contextual, and supported by interactive learning media. Autograph, as one of the Dynamic Geometry Software (DGS), enables dynamic and interactive visualization of transformational geometry concepts, thereby facilitating student comprehension. Previous research has shown that using Autograph can enhance higher-order thinking skills (Rangkuti et al., 2021) and promote mathematical exploration through animated visualization (Irfianti & Maarif, 2019; Simanjuntak et al., 2024). Nevertheless, empirical evidence on the effectiveness of Autograph in the context of developing numeracy-oriented teaching materials in Indonesia remains limited.

This study thus addresses a clear research gap. A prior study by Luthfiralda et al. (2024) focused on developing Challenge-Based Learning (CBL) worksheets with Autograph assistance in linear programming to support student numeracy. However, no studies have been found that specifically develop Autograph-assisted teaching materials for transformational geometry to improve numeracy skills among Phase D students. Therefore, this research contributes novelty by integrating Autograph technology into teaching materials to enhance junior high school students' numeracy in transformational geometry.

Method

Type of Research

This study employed a Research and Development (R&D) method using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Molenda, 2003). The ADDIE model was chosen because it is systematic, flexible,

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and suitable for the development of technology-based teaching materials, compared to other models such as 4D or Borg & Gall, which are more complex to implement in schools. According to Eny et al. (2021), the ADDIE model (comprising Analysis, Design, Development, Implementation, and Evaluation) provides a structured framework that guides instructional designers in creating effective learning experiences and achieving optimal outcomes.

Subjects and Sampling Technique

The research subjects consisted of 36 ninth-grade students from Class IX-4 at SMP Negeri 4 Siak Hulu in the 2024/2025 academic year and one mathematics teacher. The subjects were selected through purposive sampling based on school recommendations and the researcher's accessibility. The inclusion criteria were active students who participated in the entire learning sequence on transformational geometry, while students absent in any stage of testing were excluded. Three experts served as validators, including two mathematics education lecturers and one senior mathematics teacher, each holding at least a master's degree and with more than five years of teaching experience. The ADDIE stages were carried out systematically, beginning with an analysis of the Phase D curriculum, a needs analysis through teacher interviews, and a literature review on students' difficulties in transformational geometry and the potential of Autograph. The design stage involved structuring the teaching materials by defining objectives, determining the format, organizing numeracy-based activities, and creating layouts integrated with Autograph. In the development stage, the materials were produced, validated by experts using validation sheets, and revised based on feedback. The implementation stage was conducted through a limited trial in Class IX-4, where the teacher acted as facilitator. Finally, the evaluation stage analyzed the validity, practicality, and effectiveness of the developed teaching materials.

Instruments

This study employed several instruments, including a teaching material validation questionnaire, a teacher practicality questionnaire, a student practicality questionnaire, and numeracy pretest–posttest assessments. Prior to use, all instruments were validated by expert validators. The blueprint of the teaching material validation sheet is presented in Table 1.

Table 1. Blueprint of the Teaching Material Validation Sheet

Type of Validity	Assessment Indicators	Number of Items
Content Validity	Accuracy	3
	Material recency	2
	Alignment of material with learning outcomes	1
	Presentation technique	5
	Numeracy competence	3
	Communicative quality	2
	Writing clarity	4
Display Validity	Size of teaching materials	1
	Cover design	4
	Content layout	1

Procedures

To examine the feasibility and effectiveness of the teaching materials, data were collected through validity, practicality, and effectiveness tests. The feasibility test employed questionnaires consisting of validation sheets and response surveys. The validation sheets were used to validate the developed teaching materials, while the suggestions and feedback provided by the validators served as a basis for revising both the materials and the instruments. The response questionnaires were administered to teachers and students as part of the practicality assessment of the developed teaching materials. For the effectiveness test, essay-type test items were administered with the aim of evaluating the effectiveness of the teaching materials in improving student learning outcomes, particularly focusing on the enhancement of students' numeracy skills.

Analysis

The data analysis technique in this study employed quantitative descriptive analysis. The analysis was conducted to assess the validity, practicality, and effectiveness of the Autograph-assisted teaching materials. The content validity of the teaching materials and the test instruments was evaluated by three validators. The validity index was calculated using Aiken's formula (Utami et al., 2024) with the following equation:

$$V = \frac{\sum S}{n(C-1)}$$

With $S = R - L_0$
V = Aiken's V index
S = score given by the rater minus the lowest category scorekategori
R = score assigned by the rater
L_0 = lowest score in the rating scale (1)
C = highest score in the rating scale (4)
n = number of validators (raters)

The criteria for the validity level of the teaching materials were determined using Aiken's V formula (Febriandi et al., 2019), as shown in Table 2.

Table 2. Criteria for Aiken's V Coefficient

Coefficient Range	Validity Interpretation
> 0.80	High
0.60 ≤ V < 0.80	Fairly High
0.40 ≤ V < 0.60	Moderate
0 ≤ V < 0.40	Poor

The practicality data were analyzed using the percentage scores obtained from teacher and student questionnaires. To determine the level of practicality, the formula proposed by Yanto (2019) was applied as follows:

$$P = \frac{\sum f}{N} \times 100\%$$

Notes:
P = Practicality percentage
f = Obtained score
N = Maximum expected score

The criteria for the practicality level of teaching materials according to Yanto (2019) are presented in Table 3.

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Table 3. Criteria for Practicality Level

Percentage (%)	Practicality Level
81 – 100	Very Practical
61 – 80	Practical
41 – 60	Fairly Practical
21 – 40	Less Practical
≤ 20	Not Practical

Effectiveness was analyzed by comparing pretest and posttest scores using the N-gain test and a paired t-test to examine the significance of improvement. In addition, Cohen's d effect size was calculated to estimate the strength of the influence of the teaching materials. The research design employed was a One-Group Pretest–Posttest Design, in which the dependent variable is measured in a single group both before (pretest) and after (posttest) a treatment is administered (William & Hita, 2019). A limitation of this design is the absence of a control group; therefore, the results regarding effectiveness should be interpreted with caution. The formula used to calculate the normalized gain (N-gain) was adapted from Juniyanti & Susila (2022).

$$N\ Gain = \frac{S_{posttest} - S_{pretest}}{S_{ideal} - S_{pretest}}$$

Notes:
N Gain = normalized gain value
$S_{posttest}$ = posttest score
$S_{pretest}$ = pretest score
S_{ideal} = ideal maximum score

The effectiveness criteria were determined based on the normalized gain values as interpreted from Novita et al. (2019), as shown in Table 4.

Table 4. Criteria for Effectiveness Score Levels

Normalized Gain Value (%)	Category
$0.70 \leq n \leq 1.00$	High
$0.30 \leq n < 0.70$	Medium
$0.00 \leq n < 0.30$	Low

The formula used to measure the effect size of the teaching materials (Cohen's d) was adopted from Fatmawati & Utari (2015) and is presented as follows:

$$d = \frac{M_{post} - M_{pre}}{SD_{pooled}}$$

With:

$$SD_{pooled} = \sqrt{\frac{\left(SD^2{}_{pre} + SD^2{}_{post}\right)}{2}}$$

Notes:
d = Cohen's d (effect size)
M_{post} = mean of posttest scores
M_{pre} = mean of pretest scores
SD_{pre}= standard deviation of pretest scores
SD_{post}= standard deviation of posttest scores
SD_{pooled} = pooled standard deviation

The interpretation of Cohen's d values is presented in Table 5 (Becker, 2000) as follows:

Table 5. Criteria for the Interpretation of Cohen's d Effect Size

Cohen's d Effect Size	Category
d ≥ 2,1	Very High
0,8 ≤ d ≤ 2,0	High
0,5 ≤ d ≤ 0,79	Medium
0,2 ≤ d ≤ 0,49	Low
0,0 ≤ d ≤ 0,19	Very Low

Results

The development research was carried out through five stages, namely analysis, design, development, implementation, and evaluation. In the first stage, analysis, the researcher conducted a needs analysis, material analysis, and student characteristics analysis. The needs analysis aimed to identify the problems experienced by students, the material analysis was intended to determine the content to be used in the study, and the student analysis was carried out to adjust the teaching materials to students' age and characteristics. The analysis data were obtained through unstructured interviews with the mathematics teacher at UPT SMP Negeri 4 Siak Hulu. The interviews revealed that one of the main challenges was students' low interest in learning mathematics. In addition, mathematics learning at the school was still conducted manually, with minimal use of technology such as mobile phones and computers.

In the second stage, design, the researcher created an initial draft of the teaching materials, starting with format selection, media selection, and research instrument development. For the format, the researcher designed a cover page, table of contents, concept maps, transformational geometry materials, worked examples, alternative solutions, visualizations using Autograph, practice exercises, summaries, and related components. In media selection, the researcher employed visual media in the form of illustrations and printed teaching materials. For the research instruments, the researcher developed tools to assess the validity, practicality, and effectiveness of the teaching materials. The validation sheet was used to evaluate the developed materials, followed by the design of practicality sheets in the form of teacher and student response questionnaires, and finally, the construction of a numeracy test consisting of essay-type questions based on numeracy skill indicators. The cover format of the developed teaching materials is shown in Figure 1

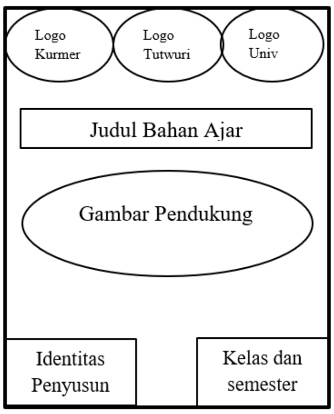

Figure 1. Cover Format of the Teaching Materials

In the third stage, development, the researcher elaborated on the draft created in the previous stage. The developed version of the cover design can be seen in Figure 2.

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Figure 2. Cover of the Teaching Materials

After developing the teaching materials, the researcher conducted validation with three expert validators. The results of the validation analysis using Aiken's V index are presented in Table 6.

Table 6. Results of Aiken's V Index Analysis

Item	V Value	Conclusion	Item	V Value	Conclusion
1	0.888889	High	15	1.000000	High
2	0.666667	Fairly High	16	0.888889	High
3	0.666667	Fairly High	17	0.888889	High
4	0.888889	High	18	0.777778	Fairly High
5	0.888889	High	19	0.888889	High
6	0.888889	High	20	0.888889	High
7	1.000000	High	21	0.888889	High
8	0.888889	High	22	0.666667	Fairly High
9	0.888889	High	23	0.888889	High
10	0.777778	Fairly High	24	0.777778	Fairly High
11	0.777778	Fairly High	25	1.000000	High
12	0.777778	Fairly High	26	1.000000	High
13	0.666667	Fairly High	27	0.777778	Fairly High
14	0.777778	Fairly High			

To further examine the face validity of the teaching materials, the following statistical hypotheses were formulated:

H_0: The validators provide consistent (uniform) judgments.

H_1: The validators provide inconsistent (non-uniform) judgments.

To test the uniformity of the face validity results, the Q-Cochran statistical test was applied. The testing criteria were: accept H_0 if the Asymp. Sig value is greater than α=0.05; otherwise, reject H_0. The results of the Q-Cochran statistical test are presented in Table 7.

Table 7. Test of Face Validity Uniformity of the Teaching Materials

N	27
Cochran's Q	1.923[a]
Df	1
Asymp. Sig.	.166

Table 7 shows that the Asymp. Sig value = 0.166, which is greater than α= 0.05. Therefore, H_0 is accepted and H_1 is rejected, indicating that the validators provided consistent judgments regarding the face validity of the developed teaching materials. This means that the language used in the teaching materials has met the criteria of effectiveness, and the next step is to examine the content validity of the materials.

In the fourth stage, implementation, the researcher conducted a trial of the teaching materials with students. The trial was carried out with Class IX-4 students at UPT SMP Negeri 4 Siak Hulu in the 2024/2025 academic year. This trial aimed to determine the practicality level of the teaching materials used. In addition to the product trial, students were also given a pretest before using the teaching materials and a posttest after using them. The pretest and posttest were administered to measure the effectiveness of the teaching materials. In the fifth stage, evaluation, the researcher assessed the teacher response questionnaire, student response questionnaire, and the results of the pretest and posttest. The practicality results based on teacher and student response questionnaires toward the developed teaching materials are presented in Table 8.

Table 8. Average Practicality Scores

Teacher Response Questionnaire (%)	Student Response Questionnaire (%)	Overall Practicality Result
86.97% Very Practical	82.23% Very Practical	84.6% Very Practical

Teacher and student responses to the teaching materials indicated that the materials were categorized as very practical. Furthermore, the effectiveness of the teaching materials was evaluated based on the results of the pretest and posttest, as presented in Table 9.

Table 9. Results of the Effectiveness Assessment

Mean Pretest Score	Mean Posttest Score	Mean N-Gain	Category
45.48%	86.8%	0.78	High

Based on the average N-gain score of 0.78, which falls within the high category, it can be concluded that the developed teaching materials were effective for classroom use. The detailed results of the effectiveness assessment of the teaching materials are shown in Table 10.

Table 10. Results of Effectiveness Assessment

t-Test: Paired Two Sample for Means	*Pretest*	*Posttest*
Mean	45,48	86,80
Variance	327,25	140,12
Observations	36	36
Pearson Correlation		0,60514211
Hypothesized Mean Difference		0
df		35
t Stat		-17,1812847
P(T<=t) one-tail		6,18
t Critical one-tail		1,68
P(T<=t) two-tail		1,23
t Critical two-tail		2,03

Based on the paired sample t-test (one-tailed), the calculated value was |t|=17.1813, which exceeded the critical value t=1.6896 at the significance level of α =0.05 with 35 degrees of freedom. Since $t_{calculated} > t_{critical}$ (17.1813 > 1.6896), H_0 was rejected and H_1 was accepted. This result indicates a significant difference between the pretest and posttest scores,

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with the posttest scores being higher than the pretest scores. To further demonstrate the magnitude of this difference, the effect size (Cohen's d) was calculated, as shown in Table 11.

Table 11. Results of Effect Size Analysis

Statistic	Value
Mean Pretest	45.48
Mean Posttest	86.80
SD Pooled	15.28
Cohen's d	2.7
Category	Very High

Discussion

The findings showed that the Autograph-assisted teaching materials developed in this study achieved an Aiken's V validity index of 0.88, categorized as highly valid. This high validity was attributed to the alignment of the content with the Phase D curriculum, the clarity of learning objectives, and the use of dynamic visualization that facilitated the representation of transformational geometry concepts. The validators also noted that the structure of the teaching materials was systematic and consistent with the PISA 2018 numeracy framework, ensuring that the assessment instruments were aligned with the targeted competencies. These results are consistent with Rangkuti et al. (2021) and Irfianti & Maarif (2019), who reported that the integration of Dynamic Geometry Software (DGS) tends to produce teaching materials with high validity. Similarly, Zetriuslita et al. (2025), who developed Problem-Based Learning (PBL)-based instructional tools using GeoGebra, also found high validity in the developed materials.

In terms of practicality, the teaching materials achieved a score of 84.6%, categorized as very practical. Contributing factors included clear instructions, interactive presentation, and ease of integration by teachers into classroom activities. Teachers reported that Autograph-assisted activities did not increase their preparation workload, while students felt more motivated as they could directly observe the results of transformations through animations. This finding aligns with Simanjuntak et al. (2024), who argued that interactive media can increase motivation and facilitate mastery of mathematical content. The high practicality score indicates that these teaching materials have strong potential for broader classroom implementation.

Effectiveness was demonstrated by an increase in the mean score from 45.48% in the pretest to 86.80% in the posttest, with an N-gain of 0.78 (high category). The paired t-test revealed a significant difference ($p < 0.05$), indicating that the use of the teaching materials contributed positively to improving students' numeracy skills. Furthermore, Cohen's d effect size of 2.7 indicated a very strong effect, confirming that the improvement from pretest to posttest was not only statistically significant but also practically substantial. This demonstrates that Autograph-assisted teaching materials strengthened numeracy indicators, particularly in students' ability to analyze mathematical representations and interpret results for decision-making. Thus, the evaluation stage of the ADDIE model confirmed the effectiveness of the teaching materials in achieving the research objectives.

When compared with previous studies, the results of this research are relatively consistent. Luthfiralda et al. (2024) reported 79% effectiveness in developing Autograph-assisted worksheets for linear programming, while Sipakkar & Fauzi (2023) found an N-gain of 0.71 in developing interactive e-modules. Likewise, Suprihatin & Manik (2020) highlighted that well-developed teaching materials can enhance learning effectiveness and produce satisfactory outcomes. With an N-gain of 0.78, this study demonstrates effectiveness that is consistent with or slightly higher than previous studies. These findings provide a theoretical contribution to the integration of DGS in numeracy pedagogy. Accordingly, it can be concluded that Autograph-assisted teaching materials on transformational geometry can serve as an effective alternative to improve students' numeracy skills.

The limitations of this study lie in the use of a One-Group Pretest–Posttest design without a control group, which restricts the generalizability of the effectiveness results. Moreover, implementation was limited to a single class, with constraints on computer availability and students' initial proficiency in using Autograph. The practical implication of this research is that Autograph-assisted teaching materials can be adopted by teachers provided that computer facilities and short training on the software are available. The materials are also flexible enough to be adapted for other classes, with adjustments made according to the school context. From a theoretical perspective, this study contributes evidence that the use of DGS such as Autograph not only supports visualization of concepts but also strengthens numeracy indicators that require representation, reasoning, and mathematical modeling.

Overall, this research confirms that the development of Autograph-assisted teaching materials in transformational geometry can produce a product that is valid, practical, and effective, while leaving room for further improvement. The challenges students face in using the software need to be addressed to maximize effectiveness. Future studies employing quasi-experimental designs with control groups are strongly recommended to provide stronger scientific evidence of effectiveness.

Conclusion

This study produced Autograph-assisted teaching materials on transformational geometry that were found to be highly valid, with an Aiken's V index of 0.88; very practical, with a practicality score of 84.6%; and effective, with an N-gain of 0.78 (high category) and a Cohen's d effect size of 2.7 (very high). Thus, the research objectives were successfully achieved. Theoretically, these findings contribute to the literature on the integration of Dynamic Geometry Software in numeracy pedagogy by demonstrating that interactive visualization supports spatial reasoning and mathematical modeling. Practically, the teaching materials can serve as an alternative and applicable learning resource for junior high school mathematics teachers, provided that supporting devices and training in the use of Autograph are available. However, since this study employed a One-Group Pretest–Posttest design in a single class, the effectiveness results should be interpreted with caution and not directly generalized. Therefore, further research using quasi-experimental designs with control groups, long-term trials, and more active teacher involvement in development is strongly recommended to strengthen both the theoretical and practical contributions of these teaching materials.

Conflict of Interest

The authors declare that there is no conflict of interest.

Authors' Contributions

F.L. understood the research ideas presented and collected the data. The other four authors (Z., L.A.E., S.A., and R.H.) actively contributed to the development of the theoretical framework, methodology, data organization and analysis, discussion of results, and approval of the final version of the manuscript. All authors declare that they have read and approved the final version of this paper. The overall contribution percentages for the conceptualization, preparation, and revision of this manuscript are as follows: F.L.: 50%; Z.: 20%; L.A.E.: 10%; S.A.: 10%; and R.H.: 10%.

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Data Availability Statement

The authors declare that the data supporting the findings of this study will be made available by the corresponding author, [F.L], upon reasonable request.

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