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Integrating GeoGebra with Interactive Flat Panels: The Mediating Role of Student Engagement in Spatial Geometry Learning Outcomes

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ABSTRACT

Solid geometry learning in elementary schools remains challenging because its abstract nature makes three-dimensional objects difficult to visualize. This study examined the effect of GeoGebra-Interactive Flat Panel (GeoGebra-IFP) integration on solid geometry learning outcomes, with Student Engagement as a mediating variable. A quantitative one-group pretest-posttest design involved 41 fifth-grade students. Data were collected through a UTAUT2-based GeoGebra-IFP integration questionnaire, a Student Engagement questionnaire covering behavioral, emotional, cognitive, and agentic engagement, a learning achievement test, and classroom implementation observation sheets. The data were analyzed using descriptive statistics, assumption tests, and path-analysis-based mediation with bootstrapping. The results showed that GeoGebra-IFP integration positively affected learning outcomes and Student Engagement. Student Engagement also positively affected learning outcomes and significantly mediated the relationship between GeoGebra-IFP integration and solid geometry learning outcomes. These findings indicate that interactive learning technology improves achievement both directly and indirectly by strengthening students' engagement during instruction. Therefore, GeoGebra-IFP can be considered an innovative instructional medium for improving the quality of solid geometry learning in elementary schools.

Article Information

Keywords:
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geometri ruang;
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student engagement;
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ABSTRAK

Pembelajaran geometri ruang di sekolah dasar masih menghadapi kendala karena sifat materinya yang abstrak, sehingga siswa kesulitan memvisualisasikan objek tiga dimensi. Penelitian ini bertujuan menganalisis pengaruh integrasi GeoGebra-Interactive Flat Panel (GeoGebra-IFP) terhadap capaian belajar geometri ruang dengan Student Engagement sebagai variabel mediasi. Penelitian menggunakan pendekatan kuantitatif dengan desain one-group pretest-posttest dan melibatkan 41 siswa kelas V sekolah dasar. Data dikumpulkan melalui angket integrasi GeoGebra-IFP berbasis UTAUT2, angket Student Engagement yang mencakup dimensi behavioral, emotional, cognitive, dan agentic engagement, tes hasil belajar, serta lembar observasi implementasi pembelajaran. Data dianalisis menggunakan statistik deskriptif, uji prasyarat, dan analisis mediasi berbasis path analysis dengan bootstrapping. Hasil penelitian menunjukkan bahwa integrasi GeoGebra-IFP berpengaruh positif terhadap capaian belajar dan Student Engagement. Student Engagement juga berpengaruh positif terhadap capaian belajar serta memediasi secara signifikan hubungan antara integrasi GeoGebra-IFP dan capaian belajar geometri ruang. Temuan ini menegaskan bahwa teknologi pembelajaran interaktif meningkatkan hasil belajar secara langsung dan tidak langsung melalui peningkatan keterlibatan siswa. GeoGebra-IFP layak dipertimbangkan sebagai media inovatif untuk pembelajaran geometri ruang di sekolah dasar.

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1. Introduction

Mathematics education in elementary schools is a crucial foundation for the development of students' numeracy literacy and logical thinking skills. One of the main domains that poses a major challenge in the elementary mathematics curriculum is solid geometry, which requires spatial visualization skills to understand three-dimensional objects. A(Clements & Sarama, 2021)ccording to , a strong understanding of geometry is not merely the recognition of formal visual shapes, but rather an active process of mental construction of spatial relationships. However, the reality in the field indicates that solid geometry topics, such as nets and volume, are often considered abstract, theoretical, and difficult for elementary school students to understand. These difficulties largely stem from limited spatial visualization skills, challenges in understanding the properties of solid figures, and learning practices that t(Fauzi & Arisetyawan, 2020)end to be monotonous . This condition is exacerbated by conventional learning approaches that present three-dimensional space statically on two-dimensional whiteboards or in textbooks.

The main obstacle in learning solid geometry today is students' low active engagement due to the use of non-interactive learning media. As a solution, the development of geometry learning tools based on GeoGebra software has been shown to significantly stimulate object visualization and enhance students' spatial abilities. In the era of (Sari et al., 2022).digital transformation, this instructional effectiveness can be optimized through the integration of advanced technologies, such as GeoGebra software operated on an *Interactive Flat* Panel (IFP) platform. In line with this, (Buchori et al., 2023)research by confirmed that the use of GeoGebra-based interactive learning media in elementary schools is effective in improving students' understanding of geometric concepts through the presentation of concrete and dynamic visual materials. The use of GeoGebra on the IFP platform enables exploratory learning through *multiple* representations, in which the relationship between spatial visualization and mathematical formulation can be directly synchronized to enhance students' conceptual understanding (Sati et al., 2024).

Nevertheless, the sophistication of this visual technology will not have an optimal impact on learning outcomes without students' active engagement *(student* engagement). Through this digital ecosystem, students proactively construct their learning experiences, including expressing the dimension of agentic *engagement when* they take the initiative to manipulate dynamic features on the technological device. In (Reeve, 2012)the era of digital transformation, this form of active engagement serves as a crucial bridge, given that instructional effectiveness in the classroom depends heavily on the capacity of interactive technology to present accurate representations while stimulating students' (Handayani et al., 2022)learning performance. Without comprehensive engagement, interactive technology in the classroom will merely become a digital display that fails to stimulate students' higher-order thinking processes.

Although the potential of GeoGebra-IFP to improve mathematical visualization has been recognized, research examining the mechanism through which student engagement mediates the relationship between technology and solid geometry learning outcomes remains very limited. Most previous studies have generally only confirmed that the instructional effectiveness of Mathematics in the digital era depends heavily on the capacity of interactive technology to present (Handayani et al., 2022)representations at a macro level, without examining the *internal* process of how students' interactive engagement occurs in the *classroom.* This empirical gap (research gap) constitutes a crucial foundation for this *study. By* positioning student engagement as a mediating variable, this study aims to address the mechanism of "how" technology integration in the classroom can be transformed into tangible learning outcomes. This conceptual approach is reinforced by contemporary methodological theory, which states that the placement of mediating variables is crucial for disentangling the complexity of causal relationships, thereby enabling a more in-depth and comprehensive exploration of the psychological or structural mechanisms linking independent and dependent variables (Sugiyono, 2013)

Based on the urgency of the problem and the research gap, this study aims to analyze and demonstrate the mediating role of student *engagement in the* relationship between the use of GeoGebra-IFP technology integration and students' learning achievement in solid geometry material at the elementary school level. Through this analysis, the study tests the theoretical assumption that GeoGebra-IFP integration not only has direct effects on learning achievement and student engagement separately, but that students' active engagement also acts as a mediator that optimizes their learning achievement.

2. Research Methods

This study fundamentally focuses on mechanistic testing of the use of modern technology in classroom interactions. The relationships among the variables in this study are classified into three main categories:

1. Independent Variable (X): GeoGebra-In*teractive Flat Panel* Integration, namely the use of dynamic GeoGebra software presented through an interactive touchscreen panel medium.
2. Mediating Variable *(M): Student* Engagement, which encompasses students' cognitive, affective, and behavioral dimensions during the learning process.
3. Dependent Variable (Y): Solid Geometry Learning Achievement, measured through the difference in *scores (gain* score) b*etween* the *pretest* and posttest.

The hypotheses proposed in this study are as follows:

H1: GeoGebra-Interactive *Flat Panel integration* has a positive and significant effect on Solid Geometry Learning Achievement.

H2: GeoGebra-Interactive *Flat Panel integration* has a positive and significant effect o*n Student* Engagement.
H3: *Student Engagement* has a positive and significant effect on Solid Geometry Learning Achievement.
H4: *Student Engagement* significantly mediates the effect of *GeoGebra-Interactive* Flat Panel integration on Solid Geometry Learning Achievement.

2.1. Research Design

This study employed a quantitative research method with a causal-associative design using the One-Group Pretest-Posttest *Design model. According to ,* causal-associative (Sugiyono, 2013)research is research aimed at identifying causal relationships or effects between independent variables and dependent variables. This study did not use an experimental method; rather, it focused on testing a structural model of intervariable relationships as they naturally occur in the field. The causal design in this study examined the pathways of the effect of GeoGebra-Interactive Flat Panel integration *(Variable X) on* spatial geometry learning achievement (Variable Y), both directly and indirectly through the mediation of student *engagement* (Variable M).

To examine the mechanisms of influence among variables, this study integrated Path *Analysis to* evaluate mediation effects within a single structural model. Operationally, the causal relationships and hypothesis testing in this research design were configured into four pathways of influence, namely:

1. The direct effect of GeoGebra-Interactive *Flat Panel utilization* (X) on Spatial Geometry Learning Outcomes (Y).
2. The direct effect of GeoGebra-Interactive *Flat Panel utilization* (X) on the level of *Student Engagement* (M).
3. The direct effect *of Student* Engagement (M) on Spatial Geometry Learning Outcomes (Y).
4. The indirect effect of GeoGebra-Interactive *Flat Panel* utilization (X) on Spatial Geometry Learning Achievement *(Y) through* Student Engagement (M) as a mediating variable.

2.2. Research Site and Time

This study was conducted in three elementary schools in Cluster 02, Tegalombo District, Pacitan Regency. The schools were SD Negeri 1 Tegalombo, SD Negeri 2 Tegalombo, and SD Negeri 2 Kemuning. The selection of these three school locations was based on the relatively homogeneous (equivalent) characteristics of students' initial academic abilities, the manageable distance between the schools for the researcher, and the schools' technical readiness to facilitate interactive technology experimentation, as each school had integrated I*nteractive Flat Panel* (IFP) devices into its classrooms.

This study was conducted for approximately three months, from February 18, 2026, to May 18, 2026, during the second semester of the 2025/2026 academic year. Spatial geometry learning using GeoGebra-Interactive Flat Panel *in this study was* integrated as an enrichment (review) and structured remedial program, gi*ven* that the material is one of the crucial topics in the first semester that requires more in-depth reinforcement of students' spatial visualization. The research timeline, in brief, comprised th*e first* two weeks beginning on February 18, 2026, for the preparation stage, instrument validity testing, and Pre Test; the subsequent weeks *until* May 18, 2026, involved the implementation of GeoGebra-Interactive Flat Panel-based spatial geometry learning, measuremen*t of* GeoGebra-Interactive Flat Panel integratio*n, students' level of* engagement (student engagement), Po*st Test of* learning *achievemen*t in the three elementary schools, as well as data processing and interpretation of the research findings through statistical path analysis (path *analysis).*

2.3. Population and Sample

The population in this study comprised all fifth-grade students at three elementary schools in Cluster 02, Tegalombo District, which had integrated Interactive F*lat Panel (IFP) devices* into the learning process, with a total of 41 students. Given the relatively limited population size, the sample for this study was determined using the total sampling (census) technique. According (Sugiyono, 2013)to , total sampling is a sampling technique in which all members of the population are used as the sample. This step is c(Arikunto, 2006)onsistent with the guideline stating that if the population consists of fewer than 100 subjects, it is preferable to include all of them, thereby making the study a population study.

Therefore, the sample in this study constituted a total sample of 41 students distributed across three partner schools, consisting of 11 fifth-grade students from SD Negeri 1 Tegalombo (M= 3, F= 8); 13 fifth-grade students from SD Negeri 2 Tegalombo (M= 7, F= 6); and 17 fifth-grade students from SD Negeri 2 Kemuning (M= 7, F= 10). All participants received an intervention in the form of GeoGebra-Interactive Flat *Panel-based spatial* geometry learning and were fully involved in completing the learning outcome evaluation *instru*ments through N-Gain scores and questionnaires *assessing the level* of student engagement. This selection was also based on the research focus on investigating the effectiveness of interactive technology in a specific group without a control class, in which competency improvement was measured *longitudinally usin*g pre *test and* post test results.

2.4. Data Collection Techniques

Data collection in this study was conducted systematically using two main techniques, namely test and non-test techniques. Both techniques were specifically designed to measure the cognitive performance and psychometric engagement of the sample during the intervention. The operational details of data collection are described as follows:

2.4.1. Test Technique

The test technique was used to obtain empirical data on students' cognitive ability in spatial geometry material (Variable Y). The test instrument consisted of objective questions (multiple-choice items) administered in two stages, namely:

a. Initial *Test* (Pre-test): Administered before students received the instructional intervention using GeoGebra software b*ased on an Interactive* Flat Panel (IFP). This test aimed to measure students' basic ability or initial spatial condition.

b. Final Test *(Post-test)*: Administered after the entire series of GeoGebra-In*teractive Flat Panel* interventions had been completed. The results of these two tests were then calculated using the normalized gain (N-Gain) formula to determine the objective effectiveness of improvements in learning outcomes.

2.4.2. Non-Test Techniques

Non-test techniques were conducted using closed questionnaire instruments and structured observation sheets. The use of these two types of non-test instruments aimed to obtain comprehensive data regarding students' perceptions of technology and their actual engagement during the mathematics learning process on solid geometry. The first instrument was the GeoGebra-Interactive Flat Panel Integration Questionnaire (Variable X). This *questionnaire was* adapted from the Unified Theory of Acceptance a*nd Use of Technology 2 (UTAUT 2) theory, focusing on* four main indicators: (Venkatesh & Thong, 2012)usefulness, ease of use, interactivity, and hedonic motivation and im*mersion.* The second in*strument* was the Student Eng*agement* Questionnaire (Variable M). This questionnaire wa*s developed based on the* multidimensional engagement theory, which i*ncludes indicators* of behavioral, emotional, cognitive, and agentic engagement. Both non-test instruments (the V(Reeve, 2012)ariable X questionnaire and the Variable M *questionna*ire) consisted of *20* Likert-scale s*tatements* ranging from 1–5, completed di*rectly by students* at the end of the data collection session. As a confirmation technique and to ensure the validity of the intervention in the field, the researchers also applied a Teacher and Student Activity Observation Sheet. This observation sheet was completed by an external observer using a 1–5 rating scale to record the quality of the teacher's implementation of the GeoGebra-Interactive Flat Panel integration syntax and the collective dynamics of student engagement in the classroom. *The raw scores* obtained from students' self-administered questionnaires (Variables X and M) were subsequently transformed into a standardized scale of 100 using a linear transformation formula before path analysis was conducted to ensure equivalence of data variance.

2.5. Data Analysis Techniques

Data analysis in this causal-associative quantitative study was conducted in stages using JASP (Jeffreys' Amazing Stati*stics Program) software. Because this* study used two different types of instruments (tests and non-tests), the data analysis procedures were divided according to the distinct characteristics of these instruments. The stages of data analysis are described as follows:

2.5.1. Non-Test Instrument Quality Testing (Questionnaire Validity and Reliability)

Before questionnaire data from 41 students were analyzed, instrument quality testing was conducted on the GeoGebra-Interactive Flat *Panel Integration* Questionnaire (Variable X) *and the Student* Engagement Questionnaire *(Variable M) through the Reliability* -> Unidimensional Reliability menu in JASP.

- Validity Test: The appropriateness of statement items was assessed based on the Item-Rest *Correlation* coefficient. An item was declared valid if it made a positive contribution to the total variance of the ir_{hit} nstrument (r_{tabel}> at the 5% significance level).
- Reliability Test: Instrument reliability was tested using estimates of Cronbach's *Alpha (α) and* McDonald's Omega *(ω) coefficients.* A questionnaire instrument was considered reliable and consistent if the α or ω coefficient was > 0.60.

2.5.2. Validity and Reliability of the Test Instrument (Learning Achievement Variable)

Unlike the attitude/perception variables (X and M), the feasibility of the instrument for the Learning Achievement variable (Y), in the form of *cognitiv*e *tests* (pre-test and post-test), was not tested using internal questionnaire correlations. Test quality testing *relied on Content* Validity through peer and expert *assessment* (expert judgment) to ensure that the test items were aligned with the solid geometry curriculum outcomes.

2.5.3. Classical Assumption Tests

As a prerequisite for conducting linear parametric analysis, the data in the form of 100-scale scores converted from the raw scores of questionnaires X and M, as well as the N-Gain index *scores* of the Learning Achievement variable (Y), had to meet the following basic assumption tests:

- Residual Normality Test: Tested through the *Mediation Analysis* menu in JASP using model residual estimates. Residuals were declared normally distributed if the p-value significance value in the *Shapiro-Wilk* or *Kolmogorov-Smirnov* test was > 0.05.
- Linearity Test: Assumed for the linear relationship between perception variables (X to M), whereas the cognitive-multifactor Learning Achievement variable (Y) was evaluated through the Residuals vs *Predicted scatterplot* in JASP to ensure that there were no extreme curvilinear *(non-linea*r) patterns in the structural model.

2.5.4. Descriptive Statistical Analysis

Conducted through the *Descriptives* menu in JASP to present the general characteristics of the data, including the mean, *maxi*mum score, minimum score, and standard deviation of the 100-scale scores for variables X, M, and Y. In addition, data from the Teacher and Student Activity Observation Sheet were analyzed descriptively using percentages to describe the implementation of the control intervention in the field.

2.5.5. Path Analysis and Mediation Hypothesis Testing

To examine the causal relationship and the mediating role of *Student* Engagement (M) in bridging the effect of GeoGebra-Interactive Flat Panel Integration (X) on Learning Outcomes (Y), this study *utilized the* Mediation Analysis module in JASP. The testing was conducted simultaneously on two structural path equations:

• Path 1: The direct effect of X on M.
• Path 2: The joint direct effects of X and M on Z.

The criterion for accepting the direct-effect *hypothesis* was based on the significance value of the path coefficient *p*arameter ($p \leq 0.05$). Meanwhile, to detect the significance of the indirect effect *(indirect* effect/mediation), JASP applied the *Bootstrapping* method with 5,000 random resamples. The mediation effect was considered statistically significant if the p-value *in the* Indirect *Effects output* was ≤ 0.05 and the *95% Confidence* Interval (CI) *range* betwe*en the* Lower Bound and Upper Bound did not cross or include zero (0).

3. Results and Discussion

3.1. Results

The implementation of GeoGebra-Interactive Flat Panel (GeoGebra-IFP)-based solid geometry learning in this study was first evaluated through teacher and student activity observation sheets to ensure that the treatment was implemented in accordance with the instructional design.

Figure 1. Documentation of Research Activities

Observations were conducted throughout the entire learning process using an instrument containing indicators of teachers' implementation of GeoGebra-IFP and students' engagement during the learning process. The observation results indicated that the implementation of learning was in the very good category. Teachers were able to operate all GeoGebra-IFP features optimally, while students demonstrated high engagement in behavioral, emotional, cognitive, and agentic dimensions. These conditions indicate that the intervention was implemented in accordance with the research design; therefore, the data obtained were suitable for further analysis.

Table 1. Observation Results of GeoGebra-Interactive Flat Panel Learning Implementation

Observation Aspect	Maximum Score	Obtained Score	Percentage	Category
Teacher Activities	100	94	94.00%	Very Good
Student Activities (Behavioral)	25	23	92.00%	Very Good
Student Activities (Emotional)	25	23	92.00%	Very Good
Student Activities (Cognitive)	25	22	88.00%	Very Good
Student Activities (Agentic)	25	22	88.00%	Very Good
Average Student Activity	100	90	90.00%	Very Good

Based on Table 1, it is known that the implementation of learning achieved a percentage of 94.00% for teacher activity and 90.00% for student activity, placing both in the very good category. These percentages indicate that the entire learning syntax using the GeoGebra-Interactive Flat Panel could be consistently implemented across the three research schools. The high level of learning implementation also indicates that students were not merely recipients of information but were actively involved in exploring three-dimensional geometric objects through interactive media, allowing the learning process to proceed according to the research design.

Before hypothesis testing was conducted, the quality of the research instruments was first assessed through validity and reliability testing. The testing was conducted on two questionnaire instruments: the GeoGebra-Interactive Flat Panel Integration questionnaire as the independent variable (X) and the Student Engagement questionnaire as the mediating variable (M). Item validity was analyzed u*sing item-rest* correlation values, whereas instrument reliability was analyzed using Cronbach's Alpha and McDonald's Omega coefficients. The test results showed that all statement items met the criteria for validity and reliability and could therefore be used for research data collection.

Table 2. Summary of the validity and reliability test results of the research instruments

Variable	Number of Items	Item-Rest Correlation Range	Cronbach's Alpha	McDonald's Omega	Description
GeoGebra-IFP Integration (X)	20	0.521–0.842	0.944	0.948	Valid and Reliable
Student Engagement (M)	20	0.548–0.861	0.956	0.959	Valid and Reliable

As shown in Table 2, all items in both instruments had item-rest correlation v*alues above the* established minimum threshold; thus, all items were declared valid. In addition, the Cronbach's Alpha and McDonald's Omega coefficients for both variables were also above 0.90, indicating a very high level of internal consistency. Therefore, the research instruments demonstrated good reliability and were suitable for use as measures of GeoGebra-Interactive Flat Panel Integration and Student Engagement.

The next stage was to describe the data characteristics of each research variable before inferential analysis was conducted. Descriptive statistics were presented to provide an overview of the distribution of GeoGebra-Interactive Flat Panel Integration scores, Student Engagement, and three-dimensional geometry learning outcomes m*easured using* the normalized gain (N-Gain) index.

Table 3. Descriptive statistics of the research variables

Variable	Minimum	Maximum	Mean	Standard Deviation
GeoGebra-IFP Integration (X)	71.00	98.00	88.42	5.81
Student Engagement (M)	69.00	97.00	86.95	6.47
Learning Achievement (N-Gain) (Y)	0.35	0.94	0.74	0.13

The descriptive statistical results in Table 3 show that all research variables have relatively high mean values. The GeoGebra-Interactive Flat Panel Integration variable obtained a mean score of 88.42, while Student Engagement obtained a mean score of 86.95. Meanwhile, learning achievement measured using the N-Gain index had a mean of 0.74, which generally falls within the high category. These findings provide an initial indication that the use of the GeoGebra-Interactive Flat Panel was perceived positively by students, accompanied by high levels of learning engagement and improved learning outcomes after the instruction was implemented.

After obtaining a general overview of the characteristics of the research data, the next stage was to analyze changes in students' learning achievement after participating in spatial geometry instruction using the GeoGebra-Interactive Flat Panel. Measurement was conducted by administering a pretest before the intervention and a posttest after the entire instructional sequence had been completed. Subsequently, improvements in learning outcomes w*ere calculated* using the normalized gain (N-Gain) index to determine the effectiveness of the instruction provided.

Table 4. Pretest, posttest, and improvement in students' learning achievement

Indicator	Pretest	Posttest	N-Gain	Category
Minimum	28.00	68.00	0.35	Moderate
Maximum	80.00	100.00	0.94	High
Mean	54.27	86.83	0.74	High
Standard Deviation	11.82	8.74	0.13	-

The results in Table 4 indicate an improvement in learning achievement following the implementation of instruction using the GeoGebra-Interactive Flat Panel. The mean pretest score of 54.27 increased to 86.83 on the posttest. This improvement resulted in a mean N-Gain index of 0.74, which falls within the high category. These findings indicate that GeoGebra-Interactive Flat Panel-based instruction was able to substantially improve students' understanding of spatial geometry material compared with before the intervention was administered.

To provide a more detailed overview of the improvement in learning outcomes for each respondent, the N-Gain index was subsequently classified into three categories: high, moderate, and low. The distribution of these categories is presented in Table 5.

Table 5. Distribution of students' N-Gain categories

N-Gain Category	Frequency	Percentage
High (≥0.70)	28	68.29%
Moderate (0.30–0.69)	13	31.71%
Low (<0.30)	0	0.00%
Total	41	100.00%

Based on Table 5, it is known that the majority of students were in the high learning outcome improvement category, comprising 28 students (68.29%), while 13 students (31.71%) were in the moderate category, and no students were in the low category. This distribution indicates that the implementation of the GeoGebra-Interactive Flat Panel had a positive impact on most students, such that improvements in learning outcomes occurred not only among certain students but were distributed almost evenly across all study respondents.

Before conducting path analysis to *test the* mediation model, statistical assumption testing was first performed as a prerequisite for parametric analysis. The tests included a residual normality test using Shapiro-Wilk and a linearity test of the relationships among variables. The test results are presented in Table 6.

Table 6. Results of analysis assumption testing

Type of Test	Statistic	Value	Sig.	Decision
Residual Normality	Shapiro-Wilk	0.981	0.481	Normally distributed
Linearity X → M	Deviation from Linearity	1.124	0.368	Linear
Linearity X → Y	Deviation from Linearity	1.071	0.411	Linear
Linearity M → Y	Deviation from Linearity	1.083	0.392	Linear

Based on the test results in Table 6, the model residual had a significance value of 0.481, which was greater than the significance level of 0.05; therefore, the residuals were considered normally distributed. In addition, all relationships between variables met the linearity assumption b*ecause the significance* values for Deviation from Linearity were greater than 0.05. Thus, all basic assumptions for parametric analysis were met, allowing path analysis using a mediation model to proceed.

The next stage was to test the direct ef*fects among* variables while also examining the indirect ef*fects through* Student Engagement as a mediating variable. The analysis was conducted using *the Mediation* Analysis menu in JASP software with a *bootstrappi*ng method involving 5,000 resamples.

Table 7. Results of direct effect analysis (Direct Effect)

Intervariable Relationship	Coefficient (β)	SE	t	p-value	Decision
GeoGebra-IFP Integration → Learning Outcomes	0.314	0.118	2.661	0.011	Significant
GeoGebra-IFP Integration → Student Engagement	0.742	0.086	8.628	<0.001	Significant
Student Engagement → Learning Outcomes	0.496	0.119	4.168	<0.001	Significant

Table 7 shows that all direct effects among variables had significance values below 0.05. GeoGebra-Interactive Flat Panel integration had a positive effect on learning outcomes, with a coefficient of 0.314, and also had a positive effect on Student Engagement, with a coefficient of 0.742. In addition, Student Engagement had a positive effect on learning outcomes, with a coefficient of 0.496. These results indicate that the better the implementation of the GeoGebra-Interactive Flat Panel, the higher the students' engagement in learning and the higher their spatial geometry learning outcomes.

The subsequent test focused on the role of Student Engagement as a mediating variable in the relationship between GeoGebra-Interactive Flat Panel Integration and spatial geometry learning outcomes. The indirect effect was analyzed u*sing* bootstrapping with 5,000 samples and a 95% confidence level. The mediation effect was c*onsidered* significant if the p-value w*as less than 0.05 and the* Bootstrapping Confidence Interval did not include zero. The results of the indirect effect analysis are presented in Table 8.

Table 8. Results of indirect effect testing (Indirect Effect) through Student Engagement

Mediation Path	Coefficient (β)	Boot SE	p-value	Lower 95% CI	Upper 95% CI	Decision
GeoGebra-IFP → Student Engagement → Learning Achievement	0.368	0.082	<0.001	0.214	0.548	Significant

Based on Table 8, the indirect effect coefficient was 0.368, with a significance value of <0.001. In addition, the bootstrapping confidence i*nterval* ranged from 0.214 to 0.548, and thus did not cross zero. These findings indicate that Student Engagement significantly mediates the relationship between GeoGebra-Interactive Flat Panel integration and spatial geometry learning achievement. In other words, improvements in students' learning achievement are influenced not only directly by the use of the GeoGebra-Interactive Flat Panel but also through increased student engagement during the learning process.

To provide a more comprehensive overview of the results of the research model testing, all proposed hypotheses are summarized in Table 9.

Table 9. Summary of the research hypothesis testing results

Hypothesis	Hypothesis Statement	Result
H1	GeoGebra-Interactive Flat Panel integration has a positive effect on spatial geometry learning achievement.	Accepted
H2	GeoGebra-Interactive Flat Panel integration has a positive effect on Student Engagement.	Accepted
H3	Student Engagement has a positive effect on spatial geometry learning achievement.	Accepted
H4	Student Engagement mediates the effect of GeoGebra-Interactive Flat Panel integration on spatial geometry learning achievement.	Accepted

Overall, the hypothesis testing results indicate that all research hypotheses were accepted. GeoGebra-Interactive Flat Panel integration was shown to have a direct effect on both learning achievement and Student Engagement, while Student Engagement was also shown to affect students' learning achievement. Furthermore, the mediation analysis indicates that student engagement serves as a mechanism explaining how the use of the GeoGebra-Interactive Flat Panel can lead to improved spatial geometry learning achievement. Thus, the conceptual model proposed in this study received empirical support based on data obtained from the respondents.

3.2. Discussion

The implementation of learning using the GeoGebra-Interactive Flat Panel (GeoGebra-IFP) in this study was shown to improve elementary school students' spatial geometry learning achievement. This was indicated by an increase in the mean learning achievement score after instruction, accompanied by a mean N-Gain score in the high category. These findings indicate that the dynamic visualization of three-dimensional objects through GeoGebra-IFP can help students construct mental representations of the forms, elements, and spatial relationships of geometric solids that were previously difficult to understand through conventional media. The ability to rotate, enlarge, and directly manipulate objects enables students to connect abstract concepts with more concrete visual experiences, thereby making the knowledge construction process more effective. These results are consistent with the findings of Chivai et al. (2022), who stated that GeoGebra is an effective medium for geometry learning because it can provide accurate visual representations of spatial objects. Similarly, Ziatdinov and Valles Jr (2022) explained that the integration of modeling, visualization, and interactive exploration in GeoGebra makes mathematics learning more meaningful than instructional approaches that rely solely on static images in textbooks. The literature review conducted by Jablonski and Ludwig (2023) also emphasized that developments in modern geometry learning are moving toward the use of interactive visual technology because such technology can strengthen conceptual understanding while improving the overall quality of geometry learning.

The improvement in learning outcomes obtained in this study also indicates that instructional technology functions not only as a tool for delivering material but also as a means of facilitating the development of more active and meaningful learning experiences. In solid geometry, students often encounter difficulties in imagining three-dimensional shapes solely through two-dimensional illustrations in textbooks or on whiteboards. Through GeoGebra-IFP, students can directly observe changes in solid shapes, explore relationships among faces, edges, and vertices, and understand the concept of volume through dynamic simulations. These conditions enable students to conduct independent exploration so that the knowledge acquired is not merely procedural but also conceptual. This finding reinforces the results of Prasetya et al. (2025), which showed that

GeoGebra-assisted learning significantly improves students' spatial abilities through systematic visualization activities. The results of this study are also consistent with the meta-analysis conducted by Marasabessy and Helsa (2024), which concluded that the use of GeoGebra has a positive effect on students' spatial visualization abilities across various educational levels. In addition, Siregar (2025), through a literature review, stated that the use of GeoGebra consistently contributes to improving mathematical understanding because students are given opportunities to construct concepts through visual exploration rather than merely memorizing formulas.

The findings of this study also show that the substantial improvement in learning outcomes is inseparable from the interactive characteristics of the instructional media. Unlike digital instructional media that merely present passive animations, GeoGebra-IFP enables students to manipulate objects directly through a touchscreen, thereby providing them with a deeper learning experience. Activities such as rotating solid shapes, changing object sizes, exploring nets, and observing changes in volume in real time provide students with opportunities to conduct mathematical investigations independently. Such learning experiences are consistent with constructivist theory, which emphasizes that knowledge is constructed through active interaction between learners and their learning environment. These findings are supported by the study of Azizah et al. (2025), who developed augmented reality-based three-dimensional geometry media and f*ound that* interactive visualization can significantly improve understanding of solid geometry concepts. Similar results were also reported by Tefa et al. (2025), who showed that augmented reality media *improve* mathematics learning outcomes because students obtain more concrete representations of objects than through conventional instructional media. The study by Hidayatsyah et al. (2025) on t*he use of* augmented r*eality-based* SmartCard also demonstrated that interactive visual media can improve students' understanding of solid geometry through the presentation of more realistic three-dimensional objects.

In addition to improving learning outcomes, the observational results in this study indicate that the learning process was implemented at a very high level in both teacher and student activities. Teachers were able to implement all stages of learning using GeoGebra-IFP in accordance with the planned design, while students demonstrated high engagement throughout the geometry exploration process. This high level of implementation indicates that the effectiveness of GeoGebra-IFP is influenced not only by the quality of the software used but also by teachers' ability to manage technology-based learning. Teachers serve as facilitators who guide students to explore various possible problem-solving approaches through visual simulations, rather than merely delivering information in a one-way manner. These results reinforce the study by Wangge et al. (2025), which stated that the successful use of three-dimensional geometry instructional media is strongly influenced by educators' ability to motivate students to use such media actively. Similarly, Apriatni and Khaeroni (2025) found that the use of interactive manipulative media can increase students' learning activities because learning becomes more engaging, participatory, and encourages student involvement throughout the learning process. Meanwhile, Solakhudin et al. (2026) reported that interactive mathematics instructional media are considered practical for classroom use because they can facilitate more intensive interaction among teachers, students, and learning materials.

The results of this study also show that improvements in learning outcomes in solid geometry cannot be separated from a shift in the learning paradigm toward student-centered digital learning. The presence of GeoGebra-IFP enables teachers to provide learning experiences that are more contextual, interactive, and exploratory than conventional instruction. This condition allows students not only to receive information but also to construct concepts independently through processes of observation, exploration, discussion, and reflection on objects displayed on the interactive screen. These findings reinforce *the results of Kurniardi et* al. (2026), who, through a systematic literature review, concluded that technology-based interactive three-dimensional media have a positive impact on elementary school students' learning outcomes because they can enhance motivation, attention, and the quality of interaction during learning. The results of this study are also consistent with the research of Meylinda et al. (2026), which showed that interactive digital activity books on solid geometry topics can improve the quality of students' learning experiences through more independent exploratory activities. In addition, the study by Fitriyah et al. (2025) showed that innovations in geometry learning that provide students with opportunities for exploration can improve critical thinking and geometry problem-solving skills. Thus, the findings of this study further strengthen the view that the success of solid geometry learning is determined not only by the content taught but also by the quality of learning experiences developed through the use of interactive technology that can facilitate active exploration of concepts.

The next important finding of this study indicates that the integration of GeoGebra-Interactive Flat Panel has a positive and significant effect on Student Engagement. These results indicate that the use of interactive technology not only improves conceptual understanding but also creates higher learning engagement during the learning process. The high scores on the dimensions o*f* be*havioral,* em*otional,* cogniti*ve, and agentic* engagement indicate that students not only pay attention to the teacher's explanations but also actively participate in discussions, explore simulations, ask questions, and take the initiative to try various GeoGebra features independently. Such learning characteristics reflect a shift from teacher-centered learning to learning centered on student activities. When students are given opportunities to interact directly with geometric objects, they are

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more encouraged to explore the concepts being studied, thereby naturally increasing learning engagement. This finding is in line with the study by Maulana et al. (2025), which reported that interactive digital media can enhance students' learning engagement and motivation because they provide enjoyable learning experiences while offering broader opportunities for exploration. Thus, interactive technology functions not only as a visualization medium but also as a stimulus that builds active learning experiences, encouraging students to participate optimally throughout the learning process.

The results of this study further show that Student Engagement has a positive effect on learning achievement in solid geometry. These findings emphasize that the success of learning is determined not only by the quality of the instructional media used but also by the level of student engagement during the learning process. Students who demonstrate behavioral engagement tend to be more focused during learning, whereas emotional engagement fosters enjoyment and enthusiasm for learning. On the other hand, cognitive engagement encourages students to think more deeply in understanding geometric concepts, while agentic e*ngagement provides* students with opportunities to take the initiative in exploring various alternative problem-solving strategies. The combination of these four dimensions makes the learning process more meaningful, thereby contributing to improved learning achievement. These findings support the research of Adams et al. (2023), which explained that improvements in spatial ability through learning activities requiring active student engagement make a tangible contribution to increased mathematics achievement. Similarly, Tarng et al. (2024) found that the use of interactive visual technology will have an optimal impact only when students are actively involved in the process of exploring geometric objects, rather than merely observing the visualizations presented. Therefore, student engagement is an important factor that bridges the transformation of learning experiences into improved academic ability.

The main contribution of this study lies in demonstrating the role of Student Engagement as a mediating variable in the relationship between GeoGebra-Interactive Flat Panel integration and spatial geometry learning achievement. The mediation analysis results show that the effect of GeoGebra-IFP on learning achievement occurs not only through a direct pathway but also through an indirect pathway involving increased student engagement during learning. This finding provides an explanation of mechanisms that have not been widely revealed in previous studies. Most prior research has focused more on the effectiveness of digital media on learning outcomes without explaining the psychological processes that occur during learning. This study shows that learning technology improves learning outcomes because it first enhances student engagement, which subsequently encourages the development of better conceptual understanding. Thus, this study provides empirical evidence that Student Engagement is a mediating mechanism explaining how learning technology can be transformed into improved learning achievement. These findings extend the results of Batiibwe (2024), who stated that the use of GeoGebra improves the effectiveness of geometry learning through more active interaction between students and learning media. On the other hand, González-Campos et al. (2022) also explained that geometry learning based on independent exploration encourages students to construct concepts through "before and aft*er" activities,* making learning engagement an important component in the development of conceptual understanding.

From a theoretical perspective, the results of this study contribute to the development of technology-based learning models for spatial geometry material in elementary schools. To date, various studies have primarily positioned technology as a variable that directly affects learning outcomes. This study shows that this relationship is actually more complex because it is influenced by a psychological factor, namely student engagement during the learning process. By incorporating Student Engagement as a mediating variable, this study successfully explains the causal mechanism linking the use of technology to improved learning outcomes. These findings also enrich research on the implementation of mathematics learning technology, particularly GeoGebra, which has thus far focused more on visualization and spatial ability. From a practical perspective, the results of this study indicate that the successful implementation of GeoGebra-Interactive Flat Panel does not depend solely on the availability of technological devices in schools, but also requires learning designs that can encourage students' behavioral, emotional, cognitive, and agentic engagement. Therefore, teachers need to design learning activities that allow students to actively observe, manipulate, discuss, and reflect on geometric objects so that the benefits of technology can be maximized in improving learning achievement.

Although this study successfully confirmed all proposed hypotheses, it still has several limitations that should be considered when interpreting its results. First, the study employed a one-group pretest-posttest design without involving a control group; therefore, improvements in learning achievement cannot yet be fully compared with other learning models. Second, the number of respondents was relatively limited, involving only 41 students from three elementary schools within one school cluster; thus, the generalization of the findings to a broader population should be undertaken cautiously. Third, the independent variable was measured based on students' perceptions of the implementation of GeoGebra-Interactive Flat Panel, making subjectivity in questionnaire responses still possible. In addition, this study positioned Student Engagement as the sole mediating variable, whereas the relationship between learning technology and learning achievement may also be influenced by other variables, such as learning motivation, spatial ability, self-efficacy, digital literacy, and students' cognitive load. Therefore, fu*ture* research is recommended to use experimental

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designs involving control groups with larger sample sizes, expand the research area, and develop more complex mediation or moderation models so that the mechanisms through which learning technology affects spatial geometry learning achievement can be explained more comprehensively.

4. Conclusion

This study concludes that the integration of GeoGebra-Interactive Flat Panel (GeoGebra-IFP) has a positive and significant effect on elementary school students' spatial geometry learning achievement, both directly and indirectly through Student Engagement as a mediating variable. The findings show that the use of GeoGebra-IFP can enhance student engagement in behavioral, emotional, c*ognitive,* an*d* ag*entic* dimen*sions, which* subsequently contributes to improved spatial geometry learning outcomes. These findings indicate that the successful implementation of learning technology depends not only on the ability of media to present dynamic visualizations of concepts, but also on its ability to create active, interactive, and student-centered learning experiences.

The implications of this study provide a theoretical contribution by strengthening the model of relationships among acceptance of learning technology, student engagement, and learning achievement, while also offering practical implications for teachers and schools to optimize the use of GeoGebra-Interactive Flat Panels as media for learning spatial geometry. Nevertheless, this study still has limitations, namely the use of a one-group pretest-posttest design without a control group, the involvement of a relatively limited sample size, and the examination of Student Engagement only as a mediating variable; therefore, the generalization of the findings should be undertaken cautiously. Accordingly, future research is recommended to use experimental designs involving control groups, expand the number and characteristics of respondents, and develop research models by adding other mediating and moderating variables, su*ch as spatial* ability, learning motivation, self-efficacy, digital literacy, or cognitive load, so that the mechanisms through which learning technology affects learning achievement can be explained more comprehensively.

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