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AR-based interactive GeoGebra learning media for optimizing transformation geometry learning in higher education

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ABSTRACT

This study aims to create and develop interactive AR (Augmented Reality) GeoGebra learning tools for teaching transformation geometry to support a blended learning system. This approach employs the ADDIE development model, which consists of five phases. The research subjects include 50 fifth-semester students. The research instruments comprise validated questionnaires for material and media experts, student responses, and pre-test and post-test instruments that are both valid and reliable. The results indicate a high level of validity (90%) and excellent practicality as assessed by experts and users, with an N-gain of 0.39 in the experimental class, which outperformed the control class with an N-gain of 0.02. The study concludes that teaching transformation geometry using interactive GeoGebra learning media is more effective. This research implies leveraging the potential of AR technology integration in mathematics education to create interactive and effective learning experiences.

Media pembelajaran interaktif GeoGebra berbasis AR untuk mengoptimalkan pembelajaran geometri transformasi di pendidikan tinggi

Kata Kunci:

model pengembangan ADDIE, GeoGebra, media pembelajaran interaktif, geometri transformasi

ABSTRAK

*Tujuan dari penelitian ini adalah untuk membuat dan mengembangkan sarana pembelajaran interaktif AR (*Augmented Reality*) GeoGebra pada pembelajaran geometri transformasi untuk mendukung sistem pembelajaran* blended learning*. Pendekatan ini menggunakan model pengembangan ADDIE, yang terdiri dari 5 fase. Subjek penelitian ini adalah 50 mahasiswa semester 5. Instrumen penelitian mencakup angket yang divalidasi untuk ahli materi dan media, respons mahasiswa, serta pre-test dan post-test yang merupakan instrumen yang telah valid dan reliabel. Hasil penelitian menunjukkan tingkat validitas yang tinggi (90%) dan kepraktisan yang dinilai sangat baik oleh para ahli dan pengguna, dengan N-gain sebesar 0,39 pada kelas eksperimen yang lebih unggul dibandingkan kelas kontrol 0,02. Kesimpulannya adalah bahwa pengajaran geometri transformasi dengan menggunakan media pembelajaran interaktif GeoGebra lebih optimal. Penelitian ini berimplikasi untuk memanfaatkan potensi integrasi teknologi AR dalam pendidikan matematika untuk menciptakan pengalaman belajar yang interaktif dan efektif.*

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Contribution to the literature

This research contributes to:

- Advancing mathematics education with AR-based GeoGebra interactive media for transformation geometry.
- Promoting blended learning with engaging and effective AR technology.
- Demonstrating higher validity and learning outcomes of AR-based tools compared to traditional methods.
- Showcasing AR's potential to enhance understanding and performance in geometry education.
- Supporting modern pedagogical practices aligned with 21st-century learning.

1. INTRODUCTION

After the COVID-19 pandemic, lecturers must prepare learning activities to make online or offline studying in higher education more engaging and joyful without being boring. Therefore, lecturers must be innovative in classroom and non-classroom learning by using interesting AR. GeoGebra is used in mathematics learning [1], [2]. The COVID-19 pandemic has changed global lifestyles, including in Indonesia. Since the COVID-19 pandemic rocketed in Indonesia, the education system has radically changed by implementing the system of learning from home.

Consequently, learning transformation geometry in the first semester of 2022/2023 must be conducted by online system or e-learning. The Indonesian Government regulated society to arrange an online learning system to keep psychical and social distancing [3], [4]. Before the covid-19, the activity of learning transformation geometry was done via a face-to-face learning system. Meanwhile, during the COVID-19 pandemic, it was altered to studying from home. This condition insisted the teacher adopt and adapt the learning technology by changing the learning and learning atmosphere model to ensure the students understand the material delivered in the online class. Continuous innovative ways and improvement in the learning process to understand the concept of transformation geometry were urgently needed [5].

Online learning is implemented through a non-face-to-face class system by giving subject material in the form of e-books, learning videos, PowerPoint slides, and individual and collaborative tasks [6], [7]. Online learning, which utilizes an internet signal to power up various online applications, replaces face-to-face learning systems. The COVID-19 pandemic drives the relationship between lecturers and students closer due to online learning applications, such as Google Classroom, video conference, Zoom Meeting, eddlink, WhatsApp group, etc. During the COVID-19 outbreak, online learning appeared to be a relevant solution to the current condition, where lecturers and students gradually adapted and adopted the learning system [8]. It is challenging for lecturers to create a convenient, joyful, and vivid atmosphere during online learning. There are obstacles to running online learning, such as human resources, supporting facilities and infrastructure, and technical implementation. For upcoming recommendations, a sustainable public partnership and involvement from all parties are highly needed. The competency and skills of teachers/lecturers must be improved and upgraded [9].

Since the Indonesian government issued regulation of Work From Home (WFH), all schools directly apply online learning systems. Teachers and lecturers must also run online classes, learning from their homes. Class-based lesson plans are automatically replaced by online-based lesson plans by adapting and adjusting the conditions and necessities during the online learning system [5]. Therefore, lecturers and students must synchronize the

syllabus and lesson plan to meet online learning needs. At this point, lecturers must be creative in running online learning by using joyful and convenient media to remove boredom and passiveness during online learning. The use of tools or media for learning must increase and encourage learning motivation and positively affect students' psychology [10].

The result of a pre-research at the Mathematics Education Department, University of PGRI Semarang, showed that the majority of learning media used by lecturers was PowerPoint, and it was shared in an online platform, such as Google Classroom. The weakness was that materials presented on PowerPoint and shared via Google Classroom only contained important points of taught materials. Consequently, most students learning online felt hesitant to express questions because online classes did not provide discussion sessions, and the lecturer just delivered the material by uploading the PowerPoint files to Google Classroom. Another result of the interview with some fifth-semester students stated that they needed media to discover the concept of transformation geometry. On the other hand, they just received a PowerPoint presentation on transformation without knowing where the formulation of transformation geometry came from. During this term, the lecturers felt how significant it is to upgrade skills in designing mathematics learning models to be more meaningful. Besides, they hoped to master easy and applicative mathematics software [11].

Based on the observation and interview, the researchers concluded that the lecturers did not maximize media use during online learning. The lecturers just transmitted the materials from the textbooks into the PowerPoint, and after that, the PowerPoint was delivered to the students. Eventually, the students did not understand the material, affecting their learning results. Both the lack of students' readiness for online learning and material delivery online without any further discussion drove them to not understand the material they studied. This problem is crucial, and prospective educators must think critically about the technological development for learning by utilizing electronic media such as smartphones, personal computers, laptops, and Liquid Crystal Display (LCD) or projectors. Adapting and mastering the skills required to operate those technologies is a must due to the modern era and the needs of education media [12]. Accordingly, learning media using technology is relevant if someday online learning is re-used for certain reasons and conditions.

One of the most suitable learning media for teaching transformation geometry is GeoGebra. GeoGebra is crucial in this research as it provides an interactive and dynamic platform for teaching transformational geometry in an online learning environment [13], [14]. Its capabilities allow for the visualization of complex geometric concepts such as translation, reflection, rotation, and dilation, making these abstract ideas more accessible and engaging for students. Using GeoGebra aligns with modern educational needs by facilitating an interactive learning experience that traditional methods often lack. Moreover, the high validation scores from media and material experts underscore its effectiveness as a teaching tool. GeoGebra's practicality and positive reception among instructors and students highlight its potential to enhance mathematical understanding and foster a more engaging and effective learning environment [15], [16]. This research underscores the importance of integrating advanced technological tools like GeoGebra to meet the evolving demands of education and improve student outcomes in mathematics.

Building on the strengths of GeoGebra, integrating AR further enhances the educational value of this research. AR provides an immersive learning experience by overlaying digital information onto the real world, allowing students to interact with geometric transformations more tangibly and intuitively. When combined with GeoGebra's

robust mathematical visualization capabilities, AR creates an enriched learning environment where students can manipulate and explore geometric concepts in real-time and three-dimensional space. This synergy deepens students' understanding of transformational geometry and increases their engagement and motivation. Besides, AR GeoGebra also provides teachers with many variations in teaching and learning so students' learning results can increase positively. GeoGebra is deliberately designed for education. AR GeoGebra stimulates students to develop their experimental process through problem orientation. GeoGebra also drives students to discover the concepts of mathematics. Moreover, GeoGebra can overcome problems, for instance, by drawing geometric objects easily and precisely. This project aims to design and construct AR GeoGebra interactive learning resources for teaching learning transformation geometry.

Several studies related to the application of AR GeoGebra have been extensively conducted: modelling bounded surfaces using cylindrical coordinates using GeoGebra AR [17], designing surfaces in cylindrical coordinates using GeoGebra AR [18], exploring the potential use of GeoGebra AR in a project-based learning environment: The case of geometry [19], learning stereometry in a secondary school within GeoGebra's AR app [20], AR in mathematics education [21]. However, upon reviewing the existing literature, it becomes apparent that most of these investigations predominantly focus on facilitating learning basic mathematical concepts, leaving the advanced application in topics such as transformation geometry largely unexplored. This gap signifies a lack of understanding of the potential of AR GeoGebra to enhance conceptual comprehension and problem-solving skills at higher educational levels. This study explores the use of AR GeoGebra in the advanced study of transformation geometry to close this gap, concentrating on deepening students' understanding of complex concepts and enhancing their analytical and creative skills through an interactive and immersive learning approach.

2. METHOD

This research applied R&D (Research and Development). Developing a new product, enhancing an existing one, and assessing its effectiveness is known as research and development [22]. Another theory states that R&D is research that develops certain products to determine certain needs with detailed specifications [23]. Moreover, Dwiranata emphasized that Research and development is a process used to create a certain good and finish an existing product by testing the product's effectiveness [24]. The conclusion is that R&D is a method of research that creates a certain product, completes the previous product, and tests the product to see whether it is effective. The ADDIE model is used in this development research with the following steps (Figure 1).

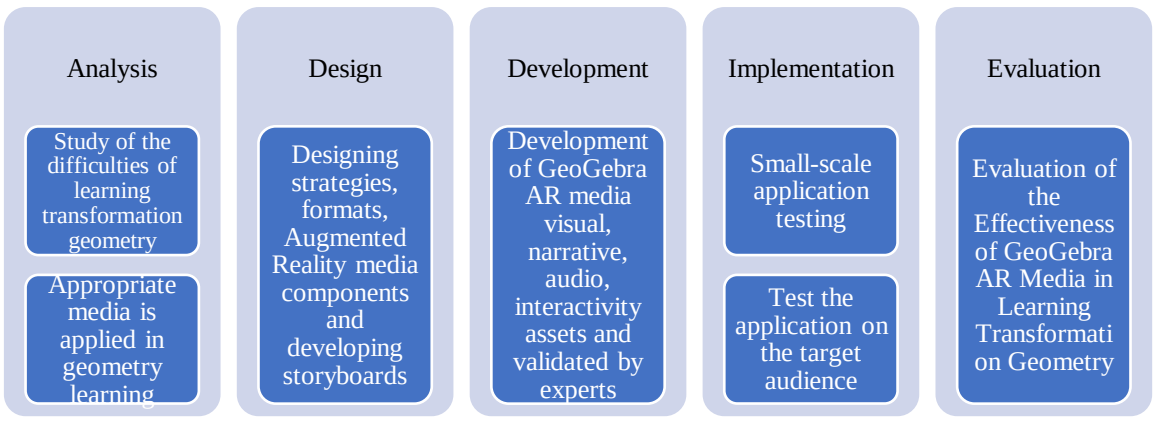

Figure 1. Research Flowchart of the ADDIE Model

The kind of product to be made in this research is virtual learning media, namely AR GeoGebra, for teaching transformation Geometry, especially for using an online learning system. The research's learning media development model is divided into five stages: analysis, design, development, implementation, and evaluation. This study used a Nonequivalent Control group design to ascertain the impact of GeoGebra's virtual learning media on teaching transformation geometry during online learning. After receiving ethics approval, the research was conducted.

Although there is a control group in this study, it is not completely effective in controlling the independent variables that impact how the experiment is carried out. Two groups participated in this study, each using a distinct learning system. Interactive virtual learning for GeoGebra was used in the experiment class, while a traditional learning system was used in the control class. In this study, a class of VB served as the control group and a class of VA as the experiment group. Students with comparatively similar abilities were placed in the class. Thirty-three kids thus made up a complete sample of the population. After receiving consent from parents and students, the research was conducted. Several tools were used in this study, including student response sheets, media validity sheets, and material validity sheets. After that, data on validity, questionnaire responses, first data, and final data are analyzed to determine whether or not learning through AR GeoGebra learning media produces improved learning outcomes according to a comparison of each class's N-Gain scores.

3. RESULTS AND DISCUSSION

The results of this research were applied to the ADDIE model, which was created in accordance with PGRI University Semarang's research guidelines for learning transformation geometry, and yielded the following results:

3.1 Analysis

This study examined the transformation geometry learning needs of the VA Class pupils. They claimed that understanding transformation geometry is challenging, particularly for particular materials like translations, dilations, and rotations. As a result, creating a learning resource that includes a lesson plan, syllabus, and learning materials is essential to helping students grasp the concept of transformation geometry.

3.2 Design

As previously explained, there are three different kinds of learning media that need to be established for research: (1) lesson plans, (2) syllabuses, and (3) learning media, specifically GeoGebra, an interactive online learning tool for transformation geometry teaching and learning. The first draft is the product of the learning media development process. Two qualified material experts and two qualified media experts validated the first draft to determine whether learning applications and media were eligible. After that, make some changes in light of the validators' feedback and recommendations. Finally, the completed draft. Testing was done on the learning materials in the final draft. The following explanation applies to the issue of media development for each medium.

As the first and most fundamental step in achieving appropriate learning objectives, the syllabus is developed in alignment with the process standard, which consists of planning, implementing, evaluating, and assessing. This study focuses on the design and execution of the learning process, specifically by creating a syllabus and lesson plan. According to the validator, while the syllabus was deemed good, minor revisions were suggested, including incorporating values such as humanity, cooperation and teamwork,

respect, and responsibility. Additionally, the validator emphasized that the assessment tool should include clear goals and methods for achieving them. The lesson plan, part of the learning plan arrangement, was also validated and found to be sound and tailored to the organization's needs, with the online learning environment updated accordingly. GeoGebra learning resources, used as virtual interactive learning media for teaching transformation geometry in online courses, were validated with minimal revisions. The validator concluded that lesson plans designed for an online platform are effectively compatible with GeoGebra virtual learning media for teaching transformation geometry.

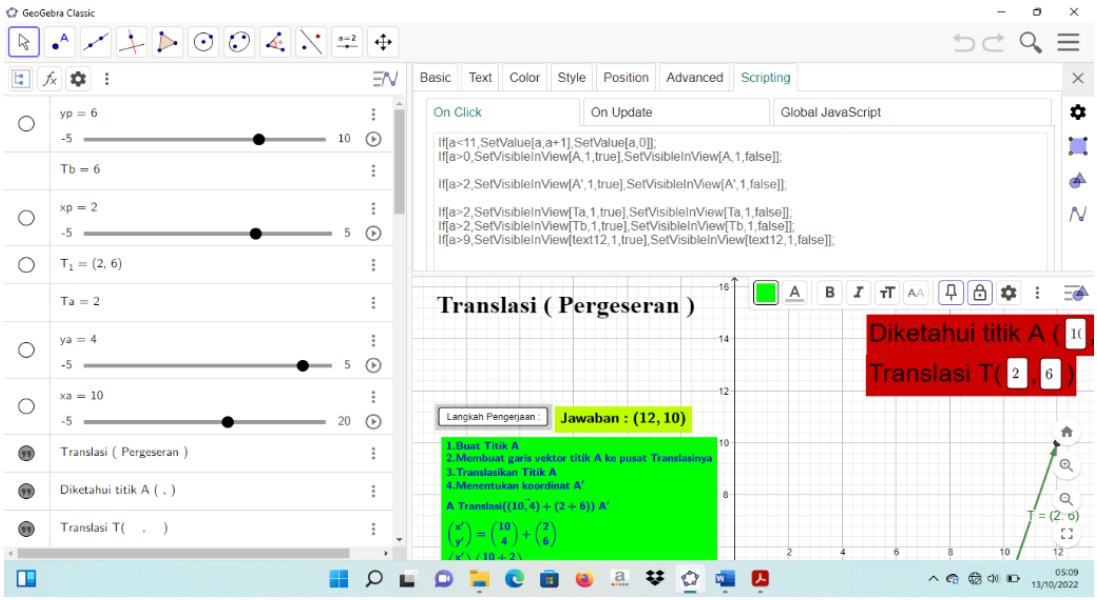

Figure 2. GeoGebra Interactive Learning Resources for Teaching Translations

The development of learning media, including lesson plans, syllabuses, and interactive learning tools like GeoGebra, plays a critical role in enhancing the quality of mathematics education, particularly in transformational geometry [25], [26]. Validation by subject and media experts ensures that the produced materials meet the expected quality standards. The syllabus serves as a fundamental component in achieving educational objectives aligned with the process standards. This study's syllabus includes planning, implementation, evaluation, and assessment. Validators recommended incorporating values such as humanity, cooperation, and responsibility into the curriculum and ensuring that assessment tools have clear goals and methods of achievement. This indicates that the syllabus not only focuses on academic content but also on developing students' character. Despite minor revisions, the lesson plans, designed to align with the revised syllabus, were deemed of high quality by validators. Adapting lesson plans to meet organizational needs demonstrates flexibility and the ability to cater to the specific context of online learning. Using GeoGebra as an interactive learning medium for teaching transformational geometry received positive evaluations from validators. The need for only minor modifications suggests that this medium effectively supports online learning. GeoGebra provides a learning environment that facilitates visual and interactive exploration, which can enhance students' understanding of transformational geometry concepts [25].

3.3 Development

Before the final version of the interactive learning media for GeoGebra is created, the feedback and ideas from the validators are incorporated into the lesson plan, syllabus, and interactive learning media. This allows for the teaching of transformation geometry

for online learning. A field trial test was conducted to get input and ideas for completing and improving the learning medium.

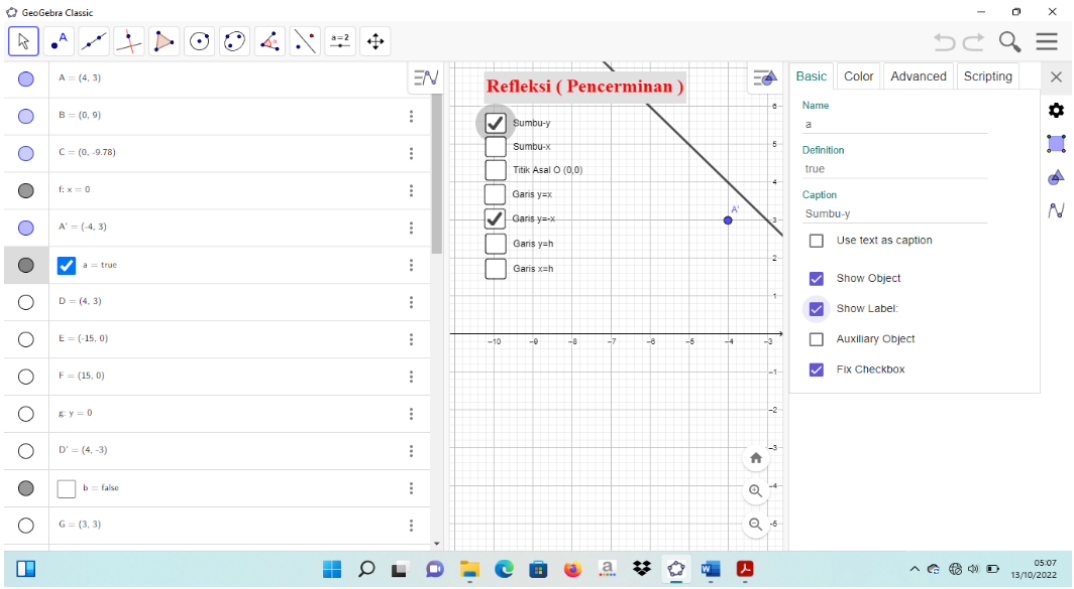

Figure 3. GeoGebra Interactive Learning Resources to Teach Introspection

The school conducted the research from September 7 to October 7, 2022. The objective is to ascertain how well the researchers' product is being used. The investigator uses a survey and an examination to gather data. A product test was conducted on September 17, 2022, to determine the media practicality rate. An examination of data from a survey given to teachers and students following the trial product's testing may be seen below. Learning materials created with the GeoGebra program were evaluated by 90% of teachers based on their responses, and 91% was found when students' responses to the learning implementation that 26 students observed during the short trial phase were analyzed. The average percentage of students' responses to all questions was 90,85973%. The test demonstrated that interactive virtual learning materials for GeoGebra are thought to be effective, as indicated by the large number of students who gave positive answers.

The learning media product was utilized in the experiment class from September 19, 2022, until October 7, 2022. The control group, meanwhile, used traditional instruction. The test aimed to determine whether using learning media or traditional classroom instruction produced better learning outcomes. Pre-tests and post-tests are the two types of tests. Each sample was handled for two meetings for the experiment and class control. This study employed a quantitative comparative quasi-experimental design. In comparative research, the existence of one or more variables is compared to two different samples or the same sample under various circumstances. This study used a non-equivalent control group design to determine the effect of learning media on the efficacy of utilizing GeoGebra to teach transformation geometry in an online learning environment. Although there is a control group in this design, it is not completely effective in controlling the independent variable that influences how the experiment is carried out.

The results of the development phase indicate that integrating feedback from validators into the lesson plans, syllabi, and GeoGebra interactive learning media yielded positive outcomes. High ratings from teachers and students, 90% and 91%, respectively, demonstrate that this learning media is practical and effective in supporting online learning of transformational geometry. The iterative process involving feedback collection from field trials contributed to refining the final product, ensuring that this learning media meets

classroom learning needs. This research employed a quasi-experimental design with a non-equivalent control group to compare learning outcomes between using GeoGebra media and traditional teaching methods. The results showed that GeoGebra was more effective in enhancing students' understanding of transformational geometry, as evidenced by the positive responses from students during the trial phase [27]. These findings support the hypothesis that interactive learning media can enhance the quality of education and students' comprehension of mathematical concepts.

3.4 Implementation

Before the two sessions, each class took a pre-test, and the answers were verified using the same question types from the control and experiment courses. Additionally, the researcher examined the homogeneity and normality of each class's pre-test results. This study used the Lilliefors test, which has a significant rate of 5%, for the normalcy test. The normality test requirement for a normally distributed sample is Lcount≤ $Ltabl$e. In the class under control, it was 0.1241. Given a significant rate of n = 16, a 5% value of Ltable According to the Lilliefors-test table, the critical value was 0.1241. It indicates that H0 is approved since Lcount≤ $Ltael$, or 0,1241≤0,2060. The study says the control group is drawn from a normal distribution population. There were 0,1699 in the experiment class. Based on the Lilliefors test table of critic values, the value of Ltable for N = 17 with a significant rate of 5% was 0,1699. H0 was acceptable since it demonstrated that Lcount ≤ Ltable, specifically 0,1699≤0,2060. It concludes that the population in the experiment class has a normal distribution.

In addition, the researcher used the Bartlett test for the homogeneity test, which had a significant rate of 5%. The homogeneity test using the same sample versions uses the condition bcount >= btable. 1,389573177 and b$tabel$.=0,8836 were found in the control and experiment classes. With a significant rate of five per cent for n1=16, n2=17, and k = 2. H0 was approved since it demonstrated that bcount ≥ btable. It is concluded that The experiment and control classes have identical versions.

Moreover, two meetings were used to test the media in the experiment class. The researcher administers a validated post-test utilizing the same question items from both the experiment class and control class following two learning sessions to determine whether the media-based learning process in class VA is superior to traditional learning done in class VB. Next, the final data will be examined: the homogeneity and normality of each class's post-test scores. This study used the Lillifors test with a significant rate of 5% for the normalcy test of the final data. For the sample having a normal distribution, the normality test requirement was Lcount ≤ Ltable. The class of control was 0.1149. Based on the Lilliefors test table, the value of $Ltab$le for n=16 at a significant rate of 5% is 0,1149. H0 was acceptable since it demonstrated that Lcount ≤ Ltable, specifically 0,1149≤0,2060. The study says the control group is drawn from a normal distribution population. Moreover, it was 0,0999 for the experiment class. Based on the Lilliefors test table of critic values, the value of Ltable for n = 17 at a significant rate of 5% is 0,0999. H0 was acceptable since it demonstrated that Lcount ≤ Ltable, specifically 0,0999 ≤ 0,2060. It suggests that the population from which the experiment class was drawn had a normal distribution.

Bartlett test with a 5% significant rate was employed for the homogeneity test on final data. bcount ≥ btable was the homogeneity test condition for the sample containing the same variants. Was 1,33572252 and btable=0,8836 in the control class. At a significant rate of five per cent, n1=16, n2=17, and k = 2. Given that bcount ≥ btable, H0 was deemed

acceptable. The statement suggests that there are comparable variations between the control and experiment classes.

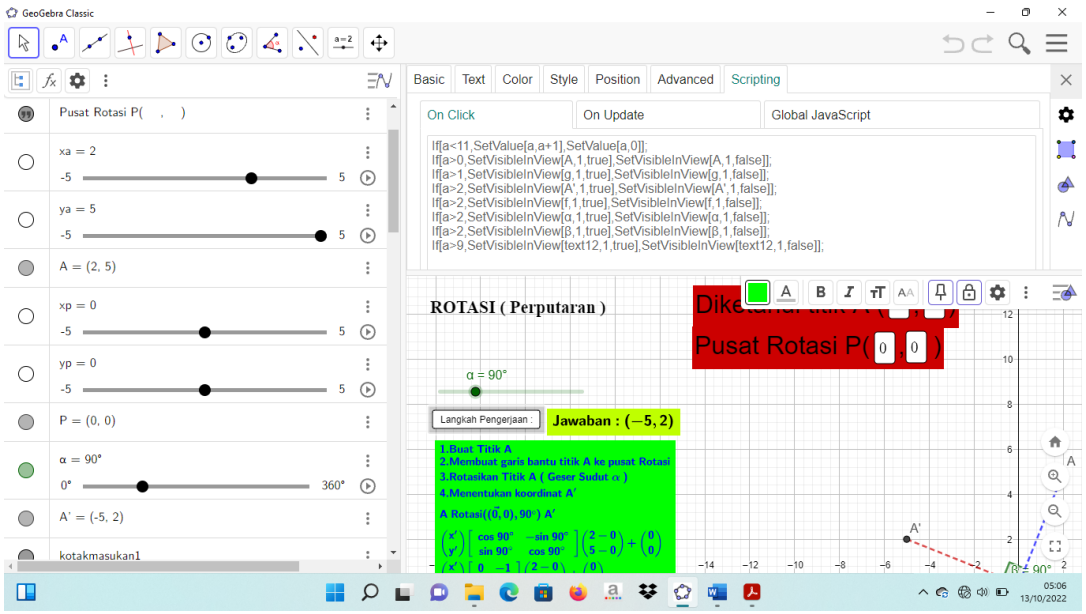

Figure 4. Interactive Learning Materials Using GeoGebra

The findings of this study are corroborated by Asryana *et al*. [28], who demonstrated how creating interactive GeoGebra learning materials can improve students' spatial reasoning skills. Moreover, Mimbadri *et al*. [29] discovered that improving the educational outcomes for students can be achieved through the creation of interactive mathematics learning materials for online classes that use GeoGebra to facilitate the teaching of integrals. Supriadi [30] focuses considerably more on using GeoGebra to teach geometry. He concluded that it could improve the students' mathematics communication for eighty per cent of Islamic Secondary School pupils. Additional studies conducted by Fatoni *et al*. [31] demonstrated that creating online interactive learning through the use of the quadratic equation teaching program GeoGebra increases students' enthusiasm and energy for holistic study. Zarkasyi [32], in his research, also found that improving the GeoGebra learning materials can help students become more adept at visualizing concepts.

3.5 Evaluation

After calculating the values for those two classes, the experiment class's average n-gain score is 0,39%, or 39%, indicating that it is deemed useless. In the meantime, the control class's average n-gain score is 0,02% or 2%, and it is deemed ineffectual. Using GeoGebra learning resources in the teaching-learning process is unsuccessful in improving students' learning outcomes in learning transformation, particularly for students enrolled in Class VA during the academic year 2022–2023.

Meanwhile, using traditional teaching approaches to improve student learning is equally ineffective, leading to a learning transformation in GeoGebra for students in class XB during the 2022–2023 academic year. This makes sense in light of the research that was conducted. According to their research, creating an interactive learning video to teach the linear program's subject and pairing it with the GeoGebra app will help students become more proficient in mathematics literacy. Moreover, it was shown that using GeoGebra to learn improves and facilitates the learning environment for kids. Osypova and Tatochenko [33] emphasized that to improve teaching and learning in the classroom

going forward, all teachers must use the GeoGebra application. This is because the software effectively makes it easier for everyone to understand mathematics, particularly geometry. In addition, Wassie and Zergaw [34] explained how students can enjoyably navigate through virtual geometry and improve their spatial skills by using GeoGebra.

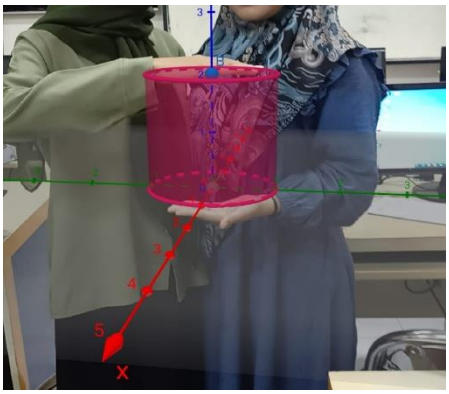

Figure 5. The Research Evaluation Is Being Conducted at PGRI University of Semarang

Being that the average result of the experiment class is superior to that of the control class, as indicated by the experiment class's average n-gain value being higher than that of the control class, the AR GeoGebra virtual learning materials for online learning are a useful teaching tool. It suggests that teaching transformation geometry in online learning environments using AR GeoGebra's development outcomes is deemed beneficial. This result aligns with the earlier investigation by Tatarczak and Mędrek [35]. They found that students find it easier to use and comprehend the spatial aspects of that software when AR GeoGebra is employed in online instruction. Additionally, a study by Kramarenko *et al.* [36] showed the push for instructors to use digital technologies as supplemental material for teaching mathematics due to their development. Dockendorff and Solar [37] found that using AR GeoGebra in the classroom can boost students' motivation since the three-dimensional model is simple to comprehend. Suryani *et al.* [38] explained how using AR GeoGebra for trigonometry teaching and learning can aid pupils in understanding the information that the teacher presents. The limitation of this study lies in the scope of the research subjects, which is limited to 50 5th-semester students in one higher education institution, so the generalization of the research results to a wider population is limited. In addition, this study only focuses on using AR GeoGebra learning media in the Geometry Transformation material without testing its standards on other mathematics topics. For researchers interested in continuing this study, it is recommended that the long-term impact of AR GeoGebra be explored on various aspects of mathematical comprehension and student engagement across diverse educational settings.

4. CONCLUSION

The results of the study indicate that the ADDIE development method can be used to create AR GeoGebra as a virtual learning aid for teaching transformation geometry for online learning. The researchers conducted five steps of the study to adopt ADDIE. During the analytical stage, it was determined that AR GeoGebra was an appropriate and pertinent medium for teaching transformation geometry. During the design process, the chosen media is created to meet the requirements of students studying transformation geometry by creating GeoGebra learning materials that instruct on translation, reflection, rotation, and dilatation. Expert validation is given to the media during the development phase. Two media experts and two material experts were present. They examine and determine whether

or not the media can be used. Evaluation is the last stage. After undergoing trial testing, the product is assessed at this phase. Based on evaluations from media experts (89.5%) and material experts (91%), the validity of the GeoGebra virtual learning materials for teaching transformation geometry in online learning is valid. In online learning, the AR GeoGebra virtual learning materials are found to be ineffective for teaching transformation geometry when comparing the average n-gain score between the experiment class and control class. The average n-gain score in the experiment class is 0,39, or 39%, while 0,02, or 2%, in the control class. Despite being considered ineffectual, the experiment class's n-gan score compares favourably to the control class. It suggests that teaching transformation geometry with GeoGebra is a method that is thought to be successful. According to the results of the instructors' questionnaire, when studying transformation geometry online, the rate of media practicality of AR GeoGebra is 4.5, or 90%. However, the students' questionnaire results showed a higher proportion, specifically more than 90%. It is concluded that there is a high practicality rate for the AR GeoGebra learning resources. This study has implications for utilizing the potential of AR technology integration in mathematics education to create interactive and effective learning experiences.

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AUTHOR CONTRIBUTION STATEMENT

AB contributed to the article's writing, research methods analysis, data collection and processing, data analysis implementation, and results preparation and discussion sections. FGP contributed by providing direction and guidance in topic development, assisting in writing and editing, and providing input on relevant references and literature. NDR contributed by providing direction and guidance in topic development and assisting in writing and editing.

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