Exploring the potential use of GeoGebra augmented reality in a project-based learning environment: The case of geometry

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Abstract. The Curriculum in Indonesia requires teachers to be more interactive using one of the potential learning models, namely Project-Based Learning (PjBL) and technology integration. However, the existing learning instruments with that model are still superficial and limited in number. Augmented Reality (AR) as interactive technology is able to increase learning motivation and visual-spatial skills of students. This current study mainly aims to develop learning instrument with PJBL model and GeoGebra AR for geometry topic. We conducted this development study with the Plomp model. Yet, this paper merely reported the result from the prototyping stage and assessment phase. Six students were chosen for the small group trial, while for the field test, thirty-two students and a teacher were selected, and six validators participated. To collect data, this study utilized a questionnaire, an observation log, and an interview guide. The findings showed that the learning instrument has been valid since it was built on firm theory, and the components of the instrument were consistently connected and practical. The instrument is easy, appropriate, and effective to use in the learning process. Finally, students’ visual-spatial skills had been improved, and they responded positively to the learning with PjBL and GeoGebra AR.

1. Introduction

Teachers should integrate technology that is able to create an interaction between one object and other objects as well as between objects and human beings during the learning process in the classroom. This technology integration and an interactive lesson will promote the 21st century learning [1]. Indonesia has been implementing Curriculum 2013 that has similar demands to foster the 21st century skills. This Curriculum recommends three learning models: Discovery Learning (DL), Problem-Based Learning (PBL), and Project-Based Learning (PjBL) [2]. Teachers could opt for the suitable learning model to achieve the learning objectives.

Capraro, Capraro, and Morgan mention that PjBL provides more extensive problems than other learning models do since it involves more contextual and authentic experience [3]. As such, students are expected to be able to enhance the competencies and skills needed for 21st century. Capraro et. al suggests that in the mathematics context, PjBL is preferable to use for geometry and trigonometry [4].

Based on the observation and interview during the pilot study in three junior high schools in Banda Aceh, the implementation of PjBL in a lesson plan was still on the surface, and the lesson plan designed for
flat-sided three-dimensional objects (polyhedrons) contained only simple math projects. The interview result showed that eight out of nine students faced difficulties to imagine the 3D objects provided in the task, and the lesson should have been supported by appropriate software. Currently, excessive learning media have been developed for mathematics learning. The implementation of the learning media in the classroom, however, has not met the demands of the Curriculum 2013.

The Curriculum 2013 expects the optimal use of learning media and ICT integration, aligned with education in the era of industrial revolution 4.0 characterized by the cyber system. In 2010, a smartphone is an effective tool for lesson delivery. The popular technology used in the smartphone for mathematics learning is Augmented Reality (AR) [5]. There has been a number of prior researches studied AR and GeoGebra AR in mathematics context. A study revealed that AR could be used to teach a lesson related to solid geometry, and students could confirm the task they had done [6]. Another study reported that integrating ICT into mathematics classroom enabled teachers to modify math concepts and teaching practices to be more constructive [7]. The study on the use of GeoGebra for teaching geometry suggested that learning geometry with GeoGebra made geometry more visual. However, the study did not use GeoGebra AR, but rather classic GeoGebra. Moreover, Tomascho and Hohenwarter showed that GeoGebra AR allowed students to explore 3D objects virtually situated in students’ environments so that they could walk around the objects and observe the object from different perspectives [8]. Therefore, drawing from the studies, it is undeniable that GeoGebra AR is crucial for learning geometry.

The PjBL learning instrument with the use of GeoGebra AR as interactive media assisting students in constructing their knowledge is highly needed. However, the PjBL learning instrument using GeoGebra AR that comprises activities to foster students’ spatial skills is still limited. Hence, it is necessary to conduct a development study on such a learning instrument. This current study aims to look into the development of a valid, practical, and effective learning instrument with the use of PjBL and GeoGebra AR for geometry topic implemented in a junior high school.

2. Method
This current study used Plomp model [9], and we reported the findings from the prototyping phase and assessment phase of preliminary research. In the prototyping phase, the learning instrument was designed to suit the intended needs. Then, the readability of the instrument was assessed by some teachers and validated by experts, using the provided validation sheet. The revised version of the instrument, as the result of this phase, was labelled prototype-I. The prototype-I was further developed, validated and revised until we obtained the new revised version, called prototype-2. After the validators claimed that the learning instrument could be used without any revision, we conducted a trial for a small group of six students; we call this assessment phase. The trial aimed at evaluating the readability of the learning instrument. After we came up with the revision of the instrument, the field test was then carried out for 32 students to examine the practicality and effectiveness of the instrument.

Data in this study were collected using several instruments, namely: (1) validation sheet comprised questionnaire to evaluate if a theory or a basis upon which to build the development of the learning instrument was sufficient enough and to review the suitability and consistency among the components that had been developed. The questionnaire was completed by the validators, consisted of media validators, content validators, and lesson plan validators; (2) observation log for practicality test was completed by observers to evaluate the learning process implemented by the teacher; (3) response questionnaire was completed by students to assess their responses to the learning instrument developed; (4) interview to confirm data on the questionnaire; and (5) documentation and field notes related to the activities during the learning process. The procedures for developing the learning instrument were described in figure 1.
The learning instrument was considered to be valid based on the validators’ judgment. The development was grounded on theory and the components developed were consistently linked to each other. Moreover, upon the validators’ judgment, this learning instrument was deemed to be practical at least four out of five experts give a recommendation that the learning instrument is easy to use and the and the usability test showed the instrument met the relevant quality criteria. The effectiveness of the instrument was based on the result that more than 80% of the students responded positively, more than 75% of the students earned the minimum passing score, and more than 80% of the students gained a score of 80 on the project.

3. Results and Discussion

3.1 Lesson Plan

This PjBL lesson plan was implemented for two lessons, the fourth and the sixth ones, in which 3x40 minutes were allocated for each lesson. For the lesson of 1, 2, 3 and 5, the conventional learning was applied, making use of a lesson plan designed by the teacher. In lesson 4, we assigned the class with a project task that asked to design a unique handcraft that consisted of various 3D objects.

In Activity 1, students were asked to write all information they had obtained during the learning process. In Activity 2, they were required to choose any kind of handcraft they intended to design and develop. They could take a picture of a handcraft from the internet or their surroundings, then attached it in their worksheet. This activity contributed to their psychomotor assessment. In Activity 3, a group of students assigned a task for each member so that each individual would be responsible for a task. They also made a timeline to keep their project on track. After completed Activity 1, 2, and 3, each group discussed their design draft with the teacher until they got approval. Then, they continued to the next step, which is the design process.

Since the class had limited time, Activity 4 and 5 were completed at home. In Activity 4, students constructed their final design and documented all steps they had done as mentioned in the instruction in the worksheet. Activity 4 was designed to train students’ visual-spatial skills. Afterwards, Activity 5 was to prepare a stand to display the project result. In lesson 4, students learned 3D objects with irregular shapes. They were given an opportunity to consult the design they would present later. In lesson 6, each group
demonstrated their design by visiting one another. During the visit, a presenter in each group was demanded to explain their project result, and the visitors posed questions and gave comments or feedback in the provided comment cards. Each group subsequently did a refinement of their project if necessary. Last, they presented their refined work and feedback they received.

3.2 Student Worksheet

The student worksheet was given for two lessons comprised six activities. Pages 1 to 7 were designated for the first lesson. The first page is for the group identity and the second page contained a project asked to design a handcraft with various 3D objects, such as a cube, small and big pyramid, cuboid, prism, and so on. The report included the process of designing and making the handcraft, as well as materials, tools, and budget needed. Pages 3 to 6 consisted of Activity 1, 2, and 3 that should be done prior to the design process. Page 7 included Activity 4 and the last two pages encompassed an instruction for Activity 5 and 6, that stands preparation and project report. In the second lesson, students were required to check the completeness of their project report and to follow up the comments and feedback from the other groups regarding the design they had done.

3.3 Test

The tests included the cognitive assessment on flat-sided 3D objects and the visual-spatial assessment developed to seek students’ achievement on the competency. These tests were administered in the last lesson, subsequent to finishing all learning activities. The indicator of visual-spatial skill was embedded in the tests. That is, the ability to imagine the alterations made to the figure after rotation.

3.4 Validity

For the lesson plan, the validators suggested that it was necessary to consider mathematics competency in the 21st-century learning focusing on students and emphasizing on characteristics known as 4C [10]. For the student worksheet, majority of validators gave advice for the presentation. An attractive presentation and clear instruction were urgent to motivate students indirectly to complete the project. For the test, we needed to look over the instruction of the test. In brief, the PjBL learning instrument using GeoGebra AR developed in this study, based on the validators’ recommendation, was valid.

The next step is to conduct an intervention for a small group of students. In this intervention, students were asked to read all information in the student worksheet and solve the problem in the test. Several ambiguities and unclear information mentioned by the students were the words of ‘rotation’, the instruction in the student worksheet, the instruction in the test, and others. After refinement of the instrument was made, a field test was then carried out to evaluate the practicality and effectiveness of the learning instrument.

3.5 Practically

The developed learning instrument is considered practical if it satisfies the following practical criteria. The observation result for each lesson was presented in table 1.

Furthermore, the interview with the teacher revealed that the learning instrument was easily usable, and the students showed their interest in the learning process. Analysis of the observation also demonstrated that the implementation of the learning instrument satisfied within the range of 81-100, indicating the category of ‘good’. This finding indicates that teachers will be able and are willing to use teacher resources in their classroom. Also, teachers perceived that the teaching resources are practical to be integrated into a lesson.

3.6 Effectiveness

To assess the effectiveness of the teaching resource, we collected data on teachers’ responses, geometry tests, and spatial tests. Regarding the teacher’s acceptance toward the learning recourse, a questionnaire was distributed to the students after the learning process. It contained 18 questions, as listed in table 2.
Table 1. The observation result of the field test

| Question                                                                 | Day-1 | Day-2 |
|--------------------------------------------------------------------------|-------|-------|
|                                                                           | Obser-1 | Obser-2 | Obser-1 | Obser-2 |
| 1. Is the learning process in the classroom relevant to geometry learning based on GeoGebra AR? | 4      | 5      | 4       | 5       |
| 2. Does the teacher manage the learning well?                           | 5      | 3      | 4       | 4       |
| 3. Does the teacher play his/her roles properly?                        | 5      | 3      | 4       | 4       |
| 4. Is the language used to describe the activities in the lesson plan clear enough to understand? | 5      | 4      | 5       | 5       |
| 5. Is the problem provided in the student worksheet clear enough to understand? | 4      | 5      | 5       | 5       |
| 6. Is the student worksheet easily usable?                              | 4      | 4      | 5       | 5       |
| 7. Is there any activity that potentially promotes students’ visual-spatial skills? | 4      | 4      | 5       | 5       |
| 8. Is the time allocated for the task in the worksheet sufficient?       | 4      | 4      | 3       | 4       |
| 9. Does GeoGebra AR make students easier to do their project?            | 4      | 5      | 4       | 4       |
| 10. Is the learning objective achieved?                                 | 4      | 3      | 4       | 4       |

Score

- Total score: 83, 88
- Average score: 4.15, 4.4
- Percentage: 83%, 88%

Table 2 shows that a number of participants who agreed and strongly agreed with the questioner items are more than those who disagreed and strongly disagreed. The results indicate that more than 80% of the participants gave positive responses to the teaching resources. This indicates that the resources are effective to be implemented in the classroom. In term of geometry test, the results of students’ achievement on the topic were presented in figure 2 and figure 3.

Figure 2. The percentage of student test scores on the PjBL learning

The results of students’ visual-spatial skills based on the test embedding visual-spatial skills were presented in figure 4.

Figure 4. The percentage of students’ visual-spatial skills based on the test.
The products, output of the developed learning instrument on geometry using GeoGebra Augmented Reality (AR), contained a set of a lesson plan, student worksheet, test, and visual-spatial test, which was valid, practical, and effective. Core competency and basic competency were KD 3.11 and 4.11.

4. Discussion
The finding of this current study aligned with González’s study reporting that the popular AR technology could be used to teach students geometry in term of solid objects and students were able to confirm the work they had done independently [6]. Consequently, the skills expected in the 21st-century learning, such as creativity, critical thinking, collaboration, and communication, could be achieved. Similarly, a previous study demonstrated that AR could be accessed from Android and become affective learning media in mathematics [12]. Another study also mentioned that the student learning outcomes had been increased subsequent to the AR implementation [13].

In respect to student improvement on visual-spatial skills, we came out with two different ways of analysis. First, the student improvement was based on the test on flat-sided 3D objects embedding visual-spatial skills, as a comparison for the initial achievement. Second, the student improvement was based on a

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**Table 2. The response questionnaire results**

| Items                                                                 | Percentage |
|----------------------------------------------------------------------|------------|
|                                                                      | SDA  | DA  | N   | A   | SA  |
| I can use GeoGebra Augmented Reality easily.                        | 0    | 3,12% | 50% | 37,5% | 9,38% |
| Learning how to use GeoGebra Augmented Reality is easy for me.     | 0    | 6,25% | 53,12% | 31,25% | 9,38% |
| It is easy to have skills on how to use GeoGebra Augmented Reality | 0    | 3,12% | 31,25% | 56,25% | 9,38% |
| If I learn it more thoroughly, I will be skillful in using GeoGebra Augmented Reality. | 0    | 0    | 25% | 56,25% | 18,75% |
| GeoGebra Augmented Reality as media for a project is useful to learn mathematics in everyday life. | 0    | 0    | 25% | 53,13% | 18,75% |
| I easily understand geometry as it is supported by a GeoGebra Augmented Reality-based project. | 0    | 3,12% | 40,63% | 34,38% | 21,87% |
| The GeoGebra Augmented Reality-based project helps to broaden my knowledge and promote my learning achievement. | 0    | 0    | 50% | 37,5% | 12,5% |
| When I use GeoGebra Augmented Reality, learning geometry and completing the project takes less time. | 0    | 0    | 25% | 56,25% | 18,75% |
| I think GeoGebra Augmented Reality is interactive media at present. | 0    | 0    | 43,75% | 46,88% | 9,37% |
| The use of GeoGebra Augmented Reality-based project is a good idea. | 0    | 0    | 18,75% | 75% | 6,25% |
| Learning with GeoGebra Augmented Reality is an insightful idea.     | 0    | 0    | 12,5% | 68,75% | 18,75% |
| In all aspects, GeoGebra Augmented Reality is good.                 | 0    | 0    | 46,88% | 43,75% | 9,37% |
| I will use GeoGebra Augmented Reality in mathematics learning, not specifically for geometry | 0    | 0    | 59,38% | 25% | 15,62% |
| I will recommend GeoGebra Augmented Reality to my friends          | 0    | 0    | 40,63% | 53,13% | 6,24% |
| I will watch tutorial videos of GeoGebra Augmented Reality-based learning more often. | 0    | 0    | 3,12% | 65,63% | 21,88% |
| It is true that GeoGebra Augmented Reality is relevant to the usage | 0    | 0    | 34,37% | 56,25% | 9,38% |
| It is true that GeoGebra Augmented Reality is easy to use           | 0    | 0    | 37,5% | 43,75% | 18,75% |
| In conclusion, the review from PEU, PU, AT, and BI is that GeoGebra Augmented Reality will be effectively used as media for the PjBL learning on geometry. | 0    | 0    | 37,5% | 50% | 12,5% |

Figure 2 shows that more than 75% of the student obtained a score above the minimum required scores. Furthermore, in term of student visual-spatial skills, figure 4 shows that 55% of the students obtained a great improvement of the spatial skill. This result indicates that the learning resources satisfies indicators of effectiveness, as proposed by Morrison, Ross, Kalman, & Kemp [11].
specific visual-spatial test, as a comparison for the initial achievement. The two-analysis resulted in different findings. The first analysis indicated that more than 80% of students showed an improvement in their visual-spatial skills. Whilst the second analysis did not demonstrate any improvement in the students’ visual-spatial skills. We allocated a certain amount of time for each test: 10 minutes for the geometry test, 20 minutes for the specific visual-spatial test, and 10 minutes for the pre-test. It is noted that geometry test refers to the test on flat-sided 3D objects embedding visual-spatial skills. Maier pointed out that time allotted for a test did not necessarily give a negative impact on student achievement [14]. As such, other factors might contribute to this result, and the statement on the problems was deemed one of which.

Students answered all questions by applying the concept they had learned during the intervention. They were able to distinguish the difficulty levels of each question so that they could predict the strategies for solving the problems and decided which one they would solve first. For the latter, students had difficulty predicting the questions they should initially answer, inasmuch as the statements and the level of difficulty of the problems looked similar. As a result, the time the students spent to finish the test exceeded the allotted time. They strived to carefully solve the problems and put excessive focus on each problem without good time management. Whereas, good time management could be learned through frequent practices on math problems fostering students’ thinking and focus so that they will gradually be more competent in solving math problems [15].

We admitted that the students were not offered adequate practices during the learning due to time limitation. The students were only given a pre-test and a post-test. Based on the data analysis, time management during the pre-test were better than during the post-test. Hence, we concluded that multiple-choice questions were appropriate to use for the visual-spatial skill assessment since such a question type could assess visual-spatial skills, but the rubric of the test had to use punishment score or penalty score. According to Bakhti, the penalty score has high reliability compared to the reward score or compensation score [16]. The punishment score or penalty score is a score that gives a penalty for the wrong answer. This type of scoring technique forces students who do not comprehend and have no knowledge about the question not to answer it since they worry about the score reduction.

The limitation of the study also arose due to the screen size of the smartphones utilized. The learning process conducted in this present study employed four units of smartphones, namely: a unit of Samsung J5 Pro, a unit of Samsung J7 Pro, and two units of Samsung A30. The screen size of the phones ranged from 5.2” to 6.4”. These sizes were deemed small for the screen used as the learning media. This issue was discussed by Huang, Allen, and Livingstone in their book about the factors in Augmented Reality [17]. They considered the big screen size was 9.5” and the small one was 5”. The small screen size does not allow users to see a detailed object in Augmented Reality. The similar case happened to the students in this study. The size of the screen made them so difficult to construct the designed object using GeoGebra AR that their visual-spatial skills had not been developed promptly and properly.

Although students’ visual-spatial skills were in a low category, their experience in doing the project helps to develop their visual-spatial skills. Dockendorff and Solar suggest a similar case that experience using GeoGebra tends to shift a learning approach of geometry to be more visual and to place emphasis on mathematics representation [7]. In line with an earlier study, AR has a potential not only to improve scores or affective domain but also to enrich concepts and learning strategy in depth [18]. As a result, we suggest teachers to adapt and utilize the learning resources developed in this study to improve students’ spatial skills.

5. Conclusion
The comprehensive analysis and discussion in the previous section conclude that the PjBL learning instrument with the use of GeoGebra AR on geometry that had been developed met the criteria of being valid, practical and effective. It is claimed to be valid as the validators declared the developed learning instrument valid, theoretically and empirically. That is, the development of the learning instrument was grounded by firm theories, and all components developed were consistently linked to each other. Further, being practical means, the validators considered the learning instrument practical, and its implement ability performed the relevant quality criteria. The learning instrument was judged
to be effective as the field test results implied that the instrument satisfied the effectiveness criteria, namely: positive responses, achievement reaching the minimum passing score, psychomotor assessment reaching the minimum required criteria and students’ visual-spatial could be improved after the test. Regarding the finding of this study, we argue that the size of AR devices and numbers of users in a group play an important role in implementing AR technology in the classroom.

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