GeoGebra Integration in Elementary Initial Teacher Training: The Case of 3-D Shapes

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Abstract—The integration of technology in learning is increasingly popular and inevitable, especially during the Covid-19 pandemic. In mathematics education, Geogebra has been used as a pedagogical tool in learning mathematics from elementary to university. The present study aims to explore first-year prospective elementary teachers' experience constructing 3-D shapes using GeoGebra. This study uses a case study method with 40 first-year prospective elementary teachers from an elementary initial teacher training from a public university in Riau, Indonesia. The participants worked in small groups and discussed some 3-D shapes through an online platform, and in the end, each participant reflected their attitudes towards the integration of GeoGebra in learning 3-D shapes. The findings show that prospective elementary teachers discussed six types of 3-D shapes; cube, rectangular prism, rectangular pyramid, cylinder, cone, and spheres. They prefer to discuss curved surfaces rather than flat surfaces of 3-D shapes. In addition, prospective elementary teachers have positive attitudes towards integrating GeoGebra in elementary initial teacher training. They believe that GeoGebra supports them to understand better the concepts of volume and surface area of 3-D shapes, facilitate students to understand the properties of a geometry object, and compare the object one made using hand drawing to using GeoGebra. Meanwhile, difficulty in using the tools to construct 3-D shapes in GeoGebra becomes a hinder to understand mathematics concepts and properties. The implication of this study is that there is a potential to integrate GeoGebra in mathematics learning in elementary teacher training.

Keywords—3-D shapes, attitudes, GeoGebra, prospective elementary teachers

1 Introduction

Technological advancements have influenced all aspects of life, including education [1]–[3]. The use of digital technologies has been employed in kindergarten [4]–[8], primary school [9], [10], secondary school [8], [11] even at higher education level [12], [13]. Digital technology can provide students with new ways to build and understand mathematical skills and new problem-solving approaches [14]. Therefore teachers

are encouraged to use technology in their classrooms, such as dynamic software [15], [16], video learning [17], gamification [18], and augmented reality [19]–[21], particularly in the current situation of the Covid-19 pandemic. However, when digital technologies were used in addition to other teaching methods rather than as a substitute, the impact size was greater [22].

In mathematics education, GeoGebra is one of the popular dynamic software that is beneficial to individuals' professional development [23]. GeoGebra was simpler to use by pre-service instructors than other dynamic mathematics software [24]. GeoGebra is preferred by primary school instructors owing to its free resources and pedagogical influence in meeting a learning aim [25]. Several studies related to GeoGebra have been carried out on prospective teachers [26], [27], but still few studies focus on prospective primary school teachers. In the context of Indonesia, Putra et al. [28] found that there is only a study on GeoGebra with the subject of prospective elementary teachers comparing to twelve studies with prospective mathematics teachers. With the current pandemic situation, prospective primary teachers are required to be ready to integrate technology, especially GeoGebra, in learning mathematics in elementary schools. Therefore, the learning process in initial teacher training should introduce them to GeoGebra as early as possible. Concerning this situation, we are interested in integrating GeoGebra in Geometry and Measurement courses for first-year prospective primary teachers in the initial teacher training.

This study explores how prospective primary teachers' experiences with GeoGebra in constructing 3-D shapes and their attitudes towards integrating GeoGebra in mathematics learning of 3-D shapes. Thus, the research questions of this study are:

1. What types of 3-D shapes are constructed and discussed by prospective primary teachers using GeoGebra?
2. What are their attitudes towards the integration of GeoGebra in the elementary initial teacher training courses?

In the following sections, we describe a literature review related to GeoGebra and the integration of Geogebra in teacher training. Then, we present the methodological approach chosen by this study. It is followed by presenting the findings into two sub-sections, prospective primary teachers' experiences with Geogebra in understanding 3-D shapes and their attitudes to the integration of GeoGebra in the initial teacher training. After that, we discuss the results and compare them to some previous studies and theories. Finally, the paper is closed by presenting the conclusion, limitation, and recommendation to further studies.

1.1 Literature review

GeoGebra is dynamic math software that can be used at all levels of education and combines geometry, algebra, spreadsheets, graphs, statistics, and calculus into a single user-friendly package [29]. GeoGebra has developed rapidly and has been used by millions of people all over the world. GeoGebra has grown to be a leading provider of dynamic mathematics applications, promoting STEM (science, technology,

engineering, and mathematics) and creativity in teaching and learning worldwide [29]. GeoGebra has many benefits, including the following:

1. Geometry, Algebra, and Spreadsheets are all linked and completely dynamic.
2. The interface is simple to use but contains several powerful features.
3. It provides designers with tools to build interactive learning opportunities as web pages.
4. Available in a variety of languages for millions of users around the world.
5. Non-commercial users may use open-source software for free.

As a result, GeoGebra has emerged as the leading math application for mathematics education in various institutions, including Indonesia [20].

Several previous studies [10], [11], [26], [27], [30]–[32] have focused on using GeoGebra in mathematics learning from elementary school to university. A study conducted by Khalil et al. [33] showed that the use of GeoGebra in learning analytical geometry in high schools had a significant positive effect on students' abilities compared to students who traditionally studied using paper and pencil. More specifically, the use of GeoGebra has a perfect role in supporting low-ability students to understand the concept of analytic geometry. The study conducted by Bulut et al. [10] also showed that the use of GeoGebra in grade 3 elementary schools had a positive effect on students' ability to understand the concept of fractions.

In initial teacher training, Tatar and Zengin [26] discovered that prospective teachers have optimistic attitudes toward incorporating GeoGebra into their courses. They mentioned that the computer-assisted instructional method using GeoGebra should be used in mathematics classes because it provides an enjoyable and engaging environment of diverse learning components, visualization and opportunities to learn mathematics through practice and experiments, thorough comprehension, and explication of abilities, and logical learning ratchet. Meanwhile, Dockendorff and Solar [27] conducted a case study with four prospective mathematics teachers, and they found that those prospective elementary teachers appropriated and became acquainted with GeoGebra tools and applications, allowing them to rediscover school mathematical content through technology and implement a more exploratory approach in their school teaching practice.

In a study conducted by Açıkgül [34], teachers' perspectives revealed the change in the role of the teacher in the classroom, benefits on the cognitive and affective progression of the students, the teaching quality, challenges, and drawbacks of using the GeoGebra. However, they expressed dissatisfaction with the absence of an appropriate teaching setting in which to use GeoGebra. Those, it can be concluded that the challenges of employing GeoGebra software can be categorized into the teachers (teachers' inability to use technology and their perspective toward technology), students (a lack of student preparation, incompetence in using technology, and adaption issues), instructional situations (trouble finishing the subject in the allocated time, difficulties implementing in a busy classroom) and insufficient technological infrastructure. Thus, introducing and integrating GeoGebra as early as possible to prospective teachers in mathematics courses is expected to reduce their awkwardness in using GeoGebra in future learning.

2 Research methods

This study is part of the researchers' larger project about developing a model to support teachers' mathematical, didactic, and technological knowledge by integrating GeoGebra. In this present paper, the researchers present a case study of first-year prospective elementary teachers' experiences with GeoGebra. The case study method enables in-depth, multifaceted investigations of complex topics in their real-world contexts [35]. Moreover, Yin [36] indicates that case studies can then be used to explain, illustrate, or investigate occurrences or events in their natural settings. The researchers choose this method to give an experience to prospective elementary teachers with GeoGebra and to deeply understand what they have learned from this task and their attitudes towards integrated GeoGebra in initial elementary teacher training.

Participants of this study were 40 female first-year prospective elementary teachers from an elementary teacher education study program, a public university in Riau, Indonesia, in the even academic year 2020/2021. During this study, all participants took a mathematics course, namely Geometry and Measurement, and they have already taken another mathematics course in the previous semester, namely Numbers and Algebra. The Geometry and Measurement course contents are basic geometry figures, perimeter and area of 2-D shapes, volume and surface areas of 3-D shapes, relationships between angle and measurements, congruent triangles and properties of parallelograms, and similar triangles. The main textbook used in this course is written by Bittinger and Beecher [37], and all teaching materials were available in Google classroom integrated to the University, so the participants can access them anytime and anywhere.

The participants got some online learning instruction and participated in the course using zoom meeting. Two teachers conducted the lecturers, one of them is the first author, and the course was run as a common approach, where first the lecturers presented and discussed some topics, then asked prospective elementary teachers to solve some tasks related to the given topics. While, in the fifth meeting, the lecturers introduced GeoGebra, and showed some activities on GeoGebra. Then, at the 6th meeting, the prospective elementary teachers were asked to have some experiences using GeoGebra to understand 3-D shapes. They were given a task to discuss it in a small group of 3–4 prospective elementary teachers (13 groups). They have to record their discussion for 15 minutes. After practicing with GeoGebra on 3-D shapes, the researchers asked them to explain their experiences using GeoGebra on 3-D shapes.

The instrument used in this study to collect the data was an observation sheet for video recording of prospective elementary teachers' online discussion and an open-ended question given to the participants at the end of the course. The observation sheet was used to classify the types of 3-D shapes discussed by prospective elementary teachers and to answer the first research question. Meanwhile, the question aims to evaluate their attitudes towards the integration of GeoGebra in the elementary initial teacher training courses.

The data of this study consist of video recording and prospective elementary teachers' responses to the open-ended question. Prospective teachers' discussion on the 3-D shapes was evaluated for correctness. Then, we categorized their discussion of the 3-D shapes into six categories; cube, rectangular prism, rectangular pyramid, cylinder,

cone, and spheres. Besides, we also look at what 3-D shape properties they discussed and how they come to the volume and area of 3-D shapes. Meanwhile, the data from the open-ended question were analysed to understand their attitudes toward the integration of GeoGebra in learning 3-D shapes.

3 Findings

The findings of this study are presented in two subsections. First, the researchers present prospective elementary teachers' experience and share their mathematical knowledge of 3-D shapes on GeoGebra integration. Then, the researchers present prospective elementary teachers' attitudes toward GeoGebra integration.

3.1 First-year prospective elementary teachers' experiences with GeoGebra in constructing 3-D shapes

The number of 3-D shapes discussed by each group ranged from one to five objects. Three groups only discussed a 3-D shape, as group 1 only discussed how to visualize the spheres and find the volume of that object. On the other hand, group 6 presented and discussed five 3-D shapes; and the only 3-D shapes did not discuss was the cylinder.

Figure 1 presents the number of each 3-D shape discussed by prospective elementary teachers. They preferred to explain curved surfaces of 3-D shapes rather than flat surfaces. Cylinder becomes the most 3-D shapes discussed by those prospective elementary teachers, and seven groups have mentioned it. On the other hand, the rectangular prism was the least discussed by those prospective elementary teachers.

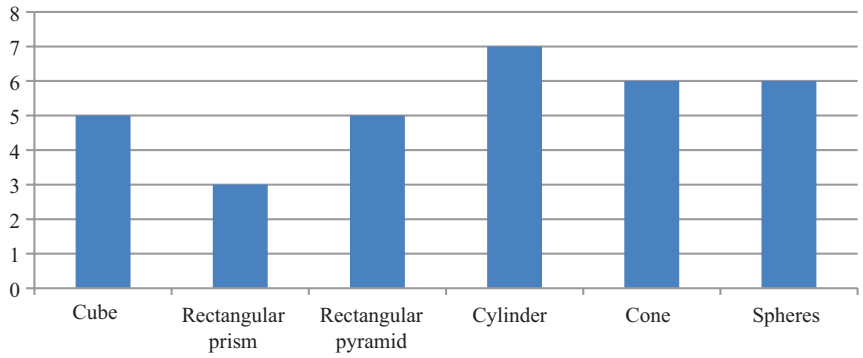

Fig. 1. The number of 3-D shapes discussed by prospective elementary teachers

From observing the video of prospective elementary teachers' discussion, we found that most of them did not have any difficulties on visualizing 3-D shapes on GeoGebra. They could use the tools on the top of GeoGebra screen to construct a 3-D shapes. For instance, Figure 2 presents a prospective elementary teacher (PET8a) from group 8 explained how to visualize a sphere in GeoGebra. Then, she presented the formula of volume and surface area of the sphere. But, she wrote incorrect formula for the

surface area of the sphere. After some moment, another prospective elementary teacher (PET8b) from group 8 noticed that the formula was incorrect. PET8a realized and corrected the formula or surface area of the sphere as $4\pi r^2$.

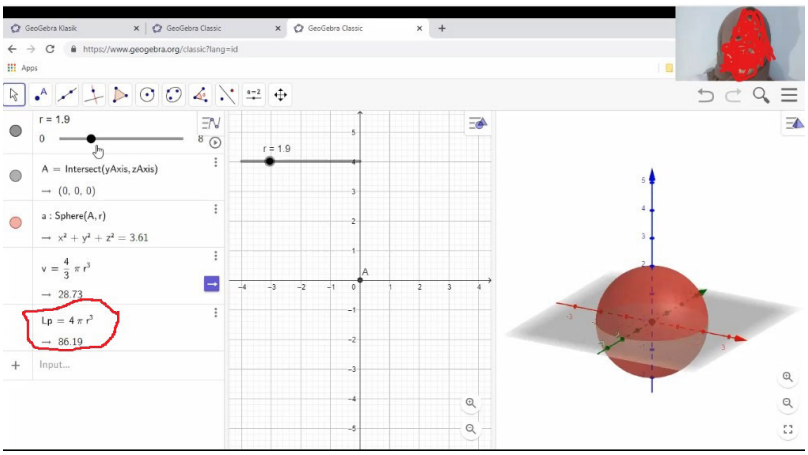

Fig. 2. Prospective elementary teachers' visualization of sphere

There was only a group of prospective elementary teachers (group 7) who tried to explore more on the relationship between the volume of a sphere and cones (Figure 3). They discussed an activity in GeoGebra applet developed by El Hage [38]. Through this activity, they tried to understand that volume of a sphere is equal to the volume of 4 cones $\left(V_{sphere} = 4V_{cone} = 4 \times \frac{1}{3}\pi r^3\right)$.

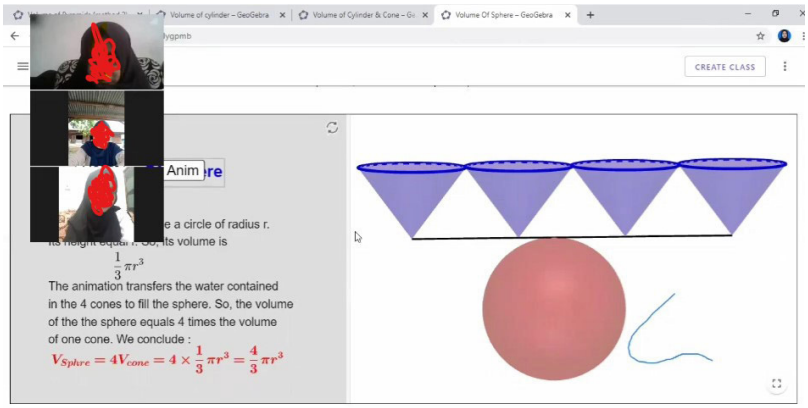

Fig. 3. Relating the volume of a sphere to the volume of cones

3.2 First-year prospective elementary teachers' attitudes toward GeoGebra integration

In general, the study found that almost all prospective elementary teachers have positive attitudes towards the integration of GeoGebra in learning 3-D shapes. Although, many of them mentioned that it was their first experiences using GeoGebra in learning mathematics. As expressed by the following prospective elementary teachers.

> *In my opinion, using GeoGebra application can be said to be a bit complicated at first. However, the advantages of GeoGebra application are excellent. We do not need to look for the answer, and we just need to enter the formulas of 3-D shapes. Even the formulas are already available because I was working on the 3D cone and cube. I use GeoGebra application with great pleasure when I find the surface area and volume of the shape. (PET6)*

PET6 mentioned that she got some challenging in using GeoGebra application for the first time, but she believed that GeoGebra provides some advantages in learning mathematics, especially in constructing 3-D shapes and finding the volumes or surface area of an 3-D shape. By the end, she showed a positive attitude towards GeoGebra integration in learning 3-D shapes.

The integration of GeoGebra in learning could help prospective elementary teachers better understand the concepts of volume and surface area of 3-D shapes. This was revealed by several students, one of them was follows:

> *In my experience, GeoGebra can help me understand the concept of volume and surface area of 3-D shapes well, compared to using a pencil, ruler and compass. [Using GeoGebra] is faster and more accurate, and has animation and manipulation functions so that [the object] is clearly visible. In the process of understanding it, I am still a little confused when using the features in GeoGebra, and had to use them very carefully. (PET21)*

PET21 compared the use of GeoGebra and manual in drawing 3-D shapes, and she confirmed that using GeoGebra is much more precise. GeoGebra could help someone to manipulate a 3-D object through rotation, fold, and unfold. However, PET21 still found that using GeoGebra is a little bit complicated, and therefore one needs to practice it attentively.

Some prospective elementary teachers concerned on the use of GeoGebra as instructional learning for students at elementary schools. They believe that GeoGebra can support students visualize 3-D shapes, and it can be used as a tool to evaluate students' drawing of 3-D shapes using paper, pencil, and compass. This statement was conveyed by the following prospective elementary teacher.

> *The experience that I got after using the GeoGebra application is that it makes it easier for us to draw and work on problems and produce geometric figures quickly and accurately compared to using a pencil, ruler, and compass. The animation*

> *facilities and manipulation movements (dragging) in GeoGebra can provide a more precise visual experience for students in understanding the concept of geometry, can be used as an evaluation to ensure that the graphic that has been made is correct, and makes it easier for teachers or students to investigate or show the properties that apply to a geometric object. (PET36)*

Therefore, through GeoGebra, teachers can facilitate students to understand the properties of a geometry object. Students can compare the object they made using hand drawing to using GeoGebra, so they can evaluate their work.

Although many prospective elementary teachers have positive attitudes toward integrating GeoGebra in learning mathematics, especially geometry, we also found few prospective elementary teachers having pessimistic about using this application as instructional learning at school.

> *From the discussion, in my opinion, using GeoGebra to find the volume and surface area of 3-D shapes is more fun because some direct calculations and models describe the visuals of the objects. But still, in the use of GeoGebra, not all shapes can be easily applied. Difficulty in determining the next step in using existing tools in GeoGebra takes longer, and sometimes missed steps add complexity. If we are not used to it, GeoGebra is challenging to apply in learning, and it is not recommended. (PET34)*

PET34 realized that there are several challenging that could be encountered by the new user. This will have an impact on the time it takes to visualize objects and understand them. Therefore, one needs to practice and grasp some features on GeoGebra application.

4 Discussion

GeoGebra, as a dynamic math application, becomes a powerful tool for visualizing mathematical objects. We can support learners to discover a relationship between mathematical objects and their visual representations [32]. This study explores prospective elementary teachers' construction towards 3-D shapes and their attitudes towards GeoGebra integration in mathematics learning.

Concerning the first research question, this study revealed that first-year prospective elementary teachers could construct several 3-D shapes using GeoGebra. They could visualize six types of 3-D shapes, and they prefer to discuss curved surfaces of 3-D shapes rather than flat surfaces. This finding could reflect that prospective elementary teachers consider GeoGebra as a potential tool to visualize more complex 3-D shapes. Their choice could be based on their experiences in which curved surfaces of 3-D shapes are more complicated to be visualized and understand the properties. Meanwhile, dynamic software has been potential as a pedagogical tool to explain geometry figures compared to paper, pencil, and compass [39].

Towards the attitudes of prospective elementary teachers on GeoGebra integration in learning mathematics, this study indicates that prospective elementary teachers have optimistic viewpoints on their experiences of constructing 3-D shapes, even though

many of them had never used GeoGebra before. This finding reflects a previous study conducted by Tatar and Zengin [26], who found that prospective teachers support that the computer-assisted instructional method using GeoGebra should be used in mathematics classes to provide an enjoyable and engaging environment of diverse learning components, visualization, and opportunities to learn mathematics. Meanwhile, the use of GeoGebra in school mathematics becomes an opportunity to support students' learning mathematics, especially during the Covid-19 pandemic.

The use of GeoGebra in elementary initial teacher training provides some opportunities and challenges for supporting prospective elementary teachers' mathematical and didactic knowledge. By integrating GeoGebra, prospective elementary teachers could construct their mathematical knowledge of 3-D shapes and build their understanding of the mathematical concepts, such as how to construct the formula for the volume of spheres (Figure 3). Therefore, integrating technology could change prospective elementary teachers' understanding of the mathematical practices and theories, previously known as praxeological change [40].

5 Conclusion

GeoGebra integration in initial elementary teacher training provides some opportunities and challenges for supporting prospective elementary teachers' knowledge of 3-D shapes. First-year prospective elementary teachers successfully constructed some 3-D shapes, explained some properties of the shapes, and found the volume and surface areas of the 3-D shapes. Through this experience, most of them have positive attitudes towards the integration of GeoGebra in learning 3-D shapes. However, due to a lack of knowledge and experiences with GeoGebra, especially related to coding and tools on GeoGebra, few prospective elementary teachers having pessimistic about using this GeoGebra as instrumentalization at school mathematics. On the other hand, we consider the limitation of this study related to a short period for prospective elementary teachers to engage with GeoGebra in constructing 3-D shapes. Further research is needed to develop more instructional learning and activities that can support prospective elementary teachers to develop their mathematical and didactic practices and reasoning related to the 3-D shapes and other mathematics domains.

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