DRIVING AUGMENTED REALITY: GEOGEBRA'S NEW AR FEATURES IN TEACHING MATHEMATICS

Andreas Trappmair[1], Markus Hohenwarter[2]

Johannes Kepler University ,Linz, Austria; [1]andreas.trappmair@jku.at,
[2]markus.hohenwarter@jku.at

Over the last few years augmented reality has matured from a niche technology with sophisticated hardware in special laboratories to a mobile mass product requiring only standard smartphones. Research on this topic raised some crucial difficulties that come along with the adoption of augmented reality especially for education. This contribution aims to describe in part how the newly developed features of the GeoGebra Augmented Reality mobile application can be used in mathematics education. Previous problems of augmented reality applications are discussed, examples for in-class tasks are presented and possible future research projects in the field are outlined. Thus, this contribution can inspire other researchers and educators to design their own augmented reality applications or related content for learning and teaching mathematics.

Keywords: augmented reality, GeoGebra, geometry, education

INTRODUCTION AND THEORETICAL BACKGROUND

Augmented reality (AR) can be defined as a technology that connects the real world with virtual information on top of it so that both coexist in the same frame. Without replacing the real-world information, the user has continuous and implicit control of the virtual information (Mehmet, 2012; Azuma, 2001). Over the past few years, technological progress in the field of AR thrived. Platforms like ARKit[1] and ARCore[2] allow AR's adoption and development for standard smartphones. Thus, the adoption for education also seems inevitable.

In parallel with the increasing research interest, various AR technologies and multiple problems connected with them came into being. Several systematic literature reviews of the past two years have come to the conclusion that the existing AR technologies suffer from information overload (Cardenas-Roblade, 2018; Suh, 2018; Chen, 2017; Akcayir, 2017), cognitive overload (Cardenas-Roblade, 2018; Suh, 2018), distraction of attention (Cardenas-Roblade, 2018; Suh, 2018), general technical difficulties (Akcayir, 2017) or even motion sickness when using so-called head mounted displays (Suh, 2018).

Many of the early AR technologies also require extensive technological know-how of the educator or depend on sophisticated hardware. Even attempts of making mobile AR devices have been made, as can be seen for example by the setup for the Austrian "Studierstube" project (Szalavari, 1998) in Figure 1. It shows, that for generating a simple AR model many different hardware components had to be used, which today are almost all combined in a standard smartphone.

[1] See: https://developer.apple.com/arkit/ . *Accessed 27 February 2019*
[2] See: https://developers.google.com/ar/ . *Accessed 27 February 2019*

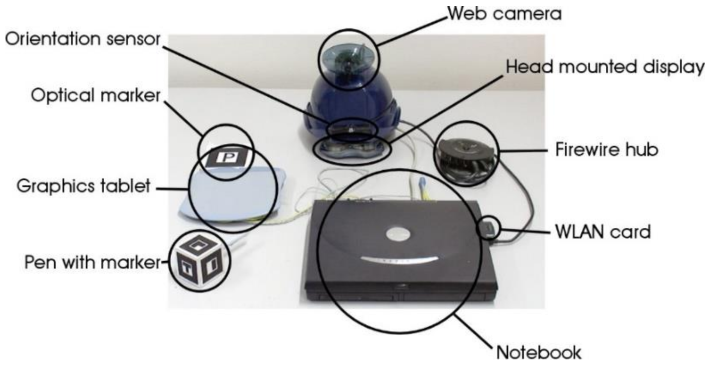

Figure 1. Setup for the early mobile AR system "Studierstube"[3].

However, these early setups are not suitable for mass-adoption in schools. Thornton et al. (2012) point out that AR presents many entry points for educational applications, especially when used on mobile phones. The GeoGebra Augmented Reality mobile application – both available for iOS[4] and Android[5] – intends to offer an easy to use but multi-functional alternative to existing AR technologies and aims to tackle the problems stated above. Hence, this paper investigates the following two questions which will be discussed theoretically on the basis of selected examples:

1. *For which topics of mathematics education can the new GeoGebra AR features be used?*
2. *How do these features tackle the previous drawbacks of AR known from the literature?*

NEW FEATURES OF GEOGEBRA AR

Version 2.0 of the application "GeoGebra Augmented Reality[6]" for iOS already had numerous features convenient for in-class usage, such as the depiction of basic pre-defined solids, 3D function-graphs or even exotic objects like the Sierpinski Pyramid or Klein's Bottle, depicted in Figure 2.

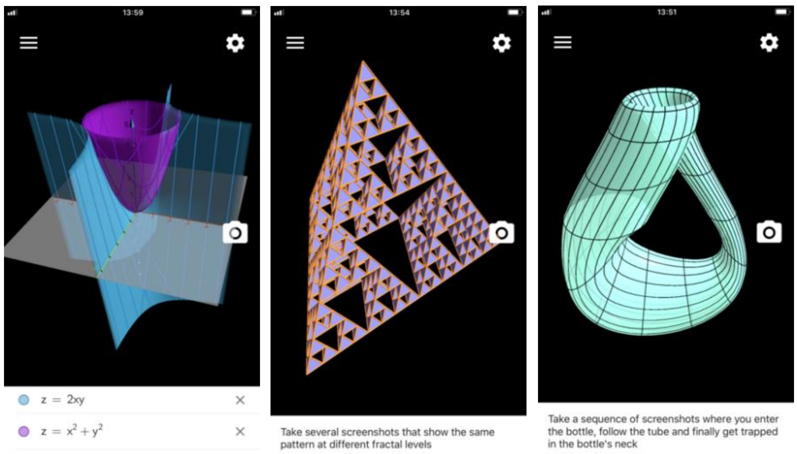

Figure 2. Examples from the GeoGebra AR app 2.0 on iOS: 3D functions, Sierpinski Pyramid, Klein's Bottle

Kerawalla et al. (2006), however, point out that educators would like to have more control over the digital content shown in AR. Therefore, we decided to adjust and enhance the GeoGebra mobile

[3] See: http://studierstube.icg.tugraz.at/media/images/mobile/setupexplained.jpg . *Accessed 26 February 2019*
[4] See: https://itunes.apple.com/us/app/geogebra-augmented-reality/id1276964610?mt=8 . *Accessed 27 February 2019*
[5] See: https://play.google.com/store/apps/details?id=org.geogebra.android.g3d . *Accessed 27 February 2019*
[6] Available since 26 March 2018

application in the following ways as described in Table 1. These additional features should help address the above-mentioned problems of AR. We try to tackle information and cognitive overload by enabling easy filtering of information, altering AR models and functions in a similar way as in previously known GeoGebra desktop versions and preparing for lessons and sharing the activities in class via the geogebra.org online platform.

Also, we hope to support more widespread in-classroom-adoption for mathematics education and reducing general technical difficulties such that teachers as well as students can work in the well-known GeoGebra environment using nothing more than a standard smartphone.

Feature	**Short description**
Direct input	3D models can be transferred from other GeoGebra applications and 3D models can be created in the AR view
Access to known features	Well-known features of GeoGebra can be accessed directly in the AR application and be used to modify the AR objects
Point-and-click / drag-and-drop	In the centre of the AR view a point can be generated, which can be used to select virtual objects such as points, lengths, …
Real-time rendering	Coefficients of functions can be altered through sliders and the 3D functions render in real-time
Labelling	Properties of virtual objects such as lengths, areas, volumes, names, … can be depicted in the AR view
Measurement	Properties of virtual objects such as lengths, areas or volumes can be measured using the AR view

Table 1. Short descriptions of the new features of the Android GeoGebra AR mobile application

Except for the "point-and-click / drag-and-drop" feature all features described in Table 1 and later on in this paper are already available in the latest Android version of GeoGebra's 3D Graphing application, version 5.0.526.0, which can be downloaded since February 2019 from the Google Play Store. The "point-and-click / drag-and-drop" feature is currently in development and will be available soon both for iOS and Android.

USE IN EDUCATIONAL CONTEXT

In this section we present several examples on how these described new features can be used in mathematics education. The basic ideas are described, and afterwards detailed examples are given. All the following examples shown in Figures 3 to 7 are screenshots from the Android version 5.0.526.0 of the 3D Graphing AR application which has been viewed on an inexpensive Android smartphone (Pocophone F1, 6GB RAM, 64GB ROM, Snapdragon 845 with up to 2.8GHz).

Modelling

With the features of GeoGebra students can now model virtual 3D objects on top of real-world objects directly in the AR application. With the help of the measuring / labelling tool it is also possible to determine the real values of given objects, e.g. investigating the volume of a prism, considering appropriate grid scaling. For example, one task could be to calculate the volume and the surface area of a glass vase. Figure 3 illustrates how one can create the base area of the glass vase using the "Polygon" tool. In a second step utilising the "Extrude to Prism" tool, the volume of the prism can be created by simply dragging upwards on the screen with one finger. Again, these tools work in the same way as the tools in GeoGebra's desktop version.

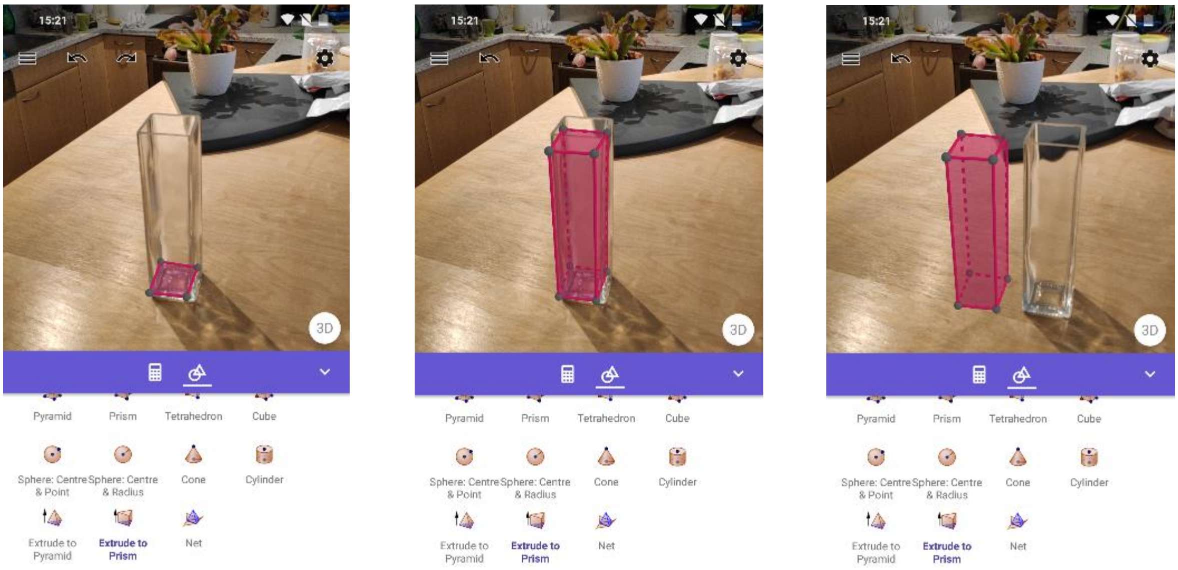

Figure 3. Modelling the volume of a glass vase

Later on, this digital representation of the vase volume can be analysed further. For instance, the net of the prism can be generated, using the "Net" tool or the value of the volume can be displayed and labelled to the prism using the "Volume" tool (see Figure 4). We believe, that these tools enable educators to quickly demonstrate certain properties of different bodies (e.g. surface area, geometrical properties of the volume, etc.). Also students can use these tools to discover geometrical properties with their smartphone in an intuitive way.

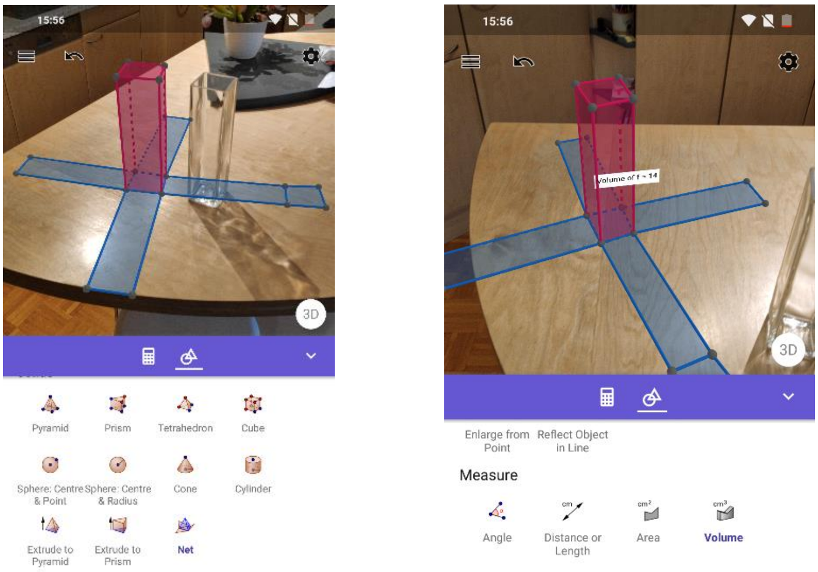

Figure 4. Generating the net of the prism, label with the volume of the prism

Exploring geometry

An extensive part of Austrian lower-secondary geometry education[7] focuses on developing spatial abilities as well as knowing and recognizing special properties of different bodies. Students can use the GeoGebra AR application to develop their skills in these sectors by getting a “deeper look” at certain bodies and their properties. This has yet to be tested but previous work (Kurtulus, 2011) already shows the benefits of using a simple 3D modelling program over pencil and paper in the development of spatial skills. Also, when drawing a diagonal section of these bodies, their real angles and lengths are distorted which makes it even more difficult for students to estimate the real-world properties of the object.

Figure 5 shows an oblique prism with a regular hexagonal base area. Using different measurement tools like “Area”, “Distance or Length” or “Angle” and with a single tap on the screen onto the desired object, our application delivers the asked value. Additionally, when selecting the “Point” tool, a white dot appears in the middle of the screen that snaps to the depicted objects automatically when in reach. Thus, for example coordinates of certain points can be displayed as seen in Figure 6.

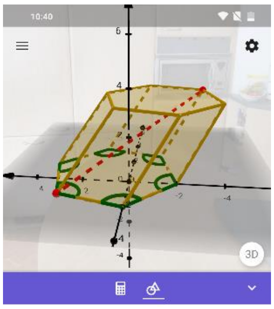

Figure 5. Oblique prism

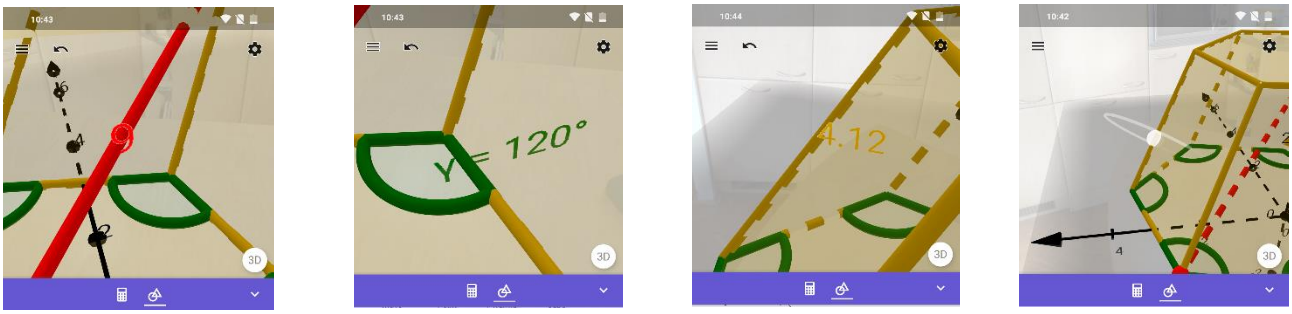

Figure 6. Measuring lengths, areas, angles or coordinates. The background opacity has been set higher in these examples to get a clearer view on the objects.

Exploring conic sections

The new features of the GeoGebra AR application can also be used in higher-secondary education when dealing for example with conic sections. The basic setup is depicted in Figure 7: a simple

[7] See: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=10008568 . *Accessed 26 February 2019 (only available in German)*

cone and a plane which can be moved parallel using a simple slider intersect in this activity. When moving the plane, the intersection thus changes from hyperbolas to parabolas and ellipses.

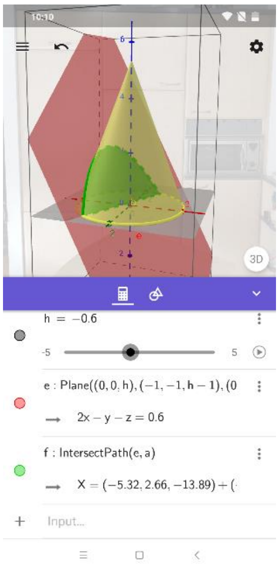

Figure 7. Cone sections

Additionally, within the application the equations for the plane and the intersection can be seen. By using different intersection planes or more sliders to alter the plane, also circles could be created.

CONCLUSION

In this contribution we present new features for the GeoGebra augmented reality mobile application and visions on how to implement these features in mathematics education. We explicitly state, that these approaches are experimental and conceptual, therefore have yet to be researched in follow up studies. Regarding our two initially posed questions, we can come to the following conclusions:

For which topics of mathematics education can the new AR features be used?

The newly developed features can be used in various parts of mathematics education. Different aspects of geometry like creating and analysing digital models of real-world objects or discovering certain properties of special bodies like volumes, areas, lengths or angles can be tackled. Also, when giving attention to spatial geometry in higher-secondary education our features for 3D functions may be useful. However, this will need to be investigated in future work with students.

How do these features tackle the drawbacks of AR known from the literature?

We think that the novel features of our application bring several advancements to mobile AR technology. Because they are built up on the established GeoGebra interface and use the same commands and tools as the desktop versions, we believe that adoption should be quick and thus help to tackle the problem of cognitive overload. Information overload is approached by the different labelling and layout options, e.g. displaying only single highlighted properties or altering the opacity of the in-app background. As our application can be downloaded and operated on any standard smartphone, general technical difficulties should typically not occur.

FUTURE WORK AND LIMITATIONS OF THIS CONTRIBUTION

The adoption of AR in mathematics education is of further interest. Following the latest developments of the GeoGebra AR application and our claims in this paper, we want to test the following hypothesis: *The use of the GeoGebra AR mobile application is intuitive even for less experienced users. Its use furthermore enhances the geometrical understanding of lower-secondary students.*

To test these claims, we are going to evaluate the changes made in our application through observations and interviews in a closed environment to determine student's learning outcomes on given tasks, their motivation and the usability of our application. In Austria students typically encounter technological aid – calculators and / or computer algebra systems – for mathematics education at the age of 12-13. Younger Austrian students typically have little knowledge on the usage of technology in mathematics education. Therefore, we are planning on observing students of the age group of 11 to 12. The observations will have two different foci: first the user experience, second enhancing geometrical skills. Students are audio-video-recorded while they work on specific tasks intended to test the operability of the application. These observations and an additional, slightly modified, system-usability-scale questionnaire (Brooke, 1986) will be evaluated quantitively. Additionally, our observations will focus on the development of geometrical skills of the observed students. Therefore, we provide sample tasks that the students should solve using the GeoGebra AR application. Referring to an open-ended approach (Kwon, 2006) the students are asked to solve the stated problems without any further explanation. In a subsequent interview, explanations to their findings and problem-solving strategies are recorded. These interviews will later be coded and the performance of the students (accuracy of the solution, time needed to solve the task and performance on similar tasks) will be evaluated.

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