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Research Article

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STEAM Practices to Explore Ancient Architectures Using Augmented Reality and 3D Printing with GeoGebra

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Abstract: In this study, we develop mathematical educational practices for students to explore ancient buildings using GeoGebra, Augmented Reality and 3D printing. It is an interdisciplinary approach, intertwining history, culture, mathematics, and engineering. For example, the 3D modelling of Cheomseongdae in Korea and the Temple of Dendera in Egypt can enable students to practice a multimodal set of traditional and innovative learning approaches. Students might use their mathematical knowledge to reflect on architectural and cultural history in a modeling task.

Keywords: Modelling; STEAM education; AR; 3D printing; GeoGebra.

1 Introduction

Education related technology provides an opportunity to develop different complementary ways to explore interdisciplinary subjects in STEAM (Science, Technology, Engineering, Arts and Math). Specifically, in this study history, culture, mathematics, and engineering are intertwined. We combine augmented reality and 3D printing using GeoGebra mathematical software. AR (Augmented Reality) can help us see and add augmented objects to real life views. This feature is very powerful as it adds digital content to the real world without immersing humans in the digital environments completely but rather bridges the gap between the two. 3D printing also helps connect digital and physical worlds. This can help people to materialize their ideas and designs in printing physical objects.

AR and 3D printing in education have a huge potential synergy, they are a good combination for physical and digital representations attested by the studies of Yingprayoon, (2015) and Figueiredo, (2015). Nilsson et al. (2010) describe an experiment where real-world images are mixed with computer-generated 3D images in an AR environment, posing mathematical problems for students to answer. Teachers participating in the experiment gave a positive feedback on AR in the classroom as it encouraged students to solve blended activities and increased student autonomy, which in turn can help them to develop confidence to explore different learning strategies. The interactive process of AR makes a powerful contribution towards the multimodal learning approaches. (Azuma et al., 2001) AR also provides mobile-based learning which gives a more concrete understanding to the geometry concepts practiced (Zheng, 2015). (Auliya & Munasiah, 2019) in their study of AR in geometry learning measured the impact of AR on various aspects such as the relation to the language, learning contents and the design of the learning tasks.

Students participating in Auliya & Munasiah's study found the learning experience interesting and the technology was easy to use for teachers and students. In summary, the most powerful finding of their research was that AR in the presented context helped the students to gain a useful understanding of learning geometry. 3D printing, (Szulżyk-Cieplak et al., 2014) enhances this process in that the printed physical models support students in acquiring a better understanding of the creation process.

In the project presented in this paper we are using the AR and 3D printing technologies together. By combining these technologies, we intend to give students in Egypt and Korea opportunities to explore real examples of ancient architectures in their cultural environment that they can

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see and even visit. These proposed examples of ancient architecture from Egypt and Korea can be adjusted to meet other cultural and historical contexts.

In all Korean schools various equipment such as tablets, 3D printers, and laser cutters have been introduced. The SMART school in Korea is based on the concept of distance education with Wi-Fi installed in every classroom in every school. This lays the foundation for an online STEAM learning environment. Also, it supports smart devices at each level of the school and builds an integrated platform for online education to provide customized learning contents and various educational contents and big data analysis (MOEF, 2020).

In Egypt, students are provided with tablets to access the Egyptian Knowledge Bank (EKB) which provides translations in Arabic and English. Schools are generally equipped with high-speed Internet connections.

However, few educational programs have been developed and research is needed for the development of educational activities that enable students to learn and connect to various fields of study such as mathematics, history and culture in Korea and in Egypt.

In this study, ancient buildings were selected as the context for a learning experience with the intention to enable students to utilize their mathematical knowledge. The architects of the ancient Egyptian pyramids, temples and the Greek temples were all architects and mathematicians (Peet, 2017). The ancient Egyptians used a wide spectrum of possible proportions from the square to other elongated shapes, and the relationship between the rectangle and its resemblance to a square and the double square (Rossi, n.d.).

In Korea, not many historical buildings have remained, but it can be assumed that mathematical elements were applied in the design process (Chung, 2009). Thus, it was intended to implement an educational program that provides students with the experience of redesigning ancient buildings using GeoGebra. Since, mathematical knowledge is reflected in the ancient building design process. Therefore, students might have the experience of applying their ideas using mathematical knowledge while learning mathematics subjects through the activities of this study.

The process of modelling ancient buildings follows the general process of mathematical modelling i.e. modelling any 3D object and applying mathematical equations and rules to achieve the final result as in parametric design. Through the process of learning mathematical modelling, students could develop the ability to solve math problems as well as the ability to live in the 21st century (Asempapa, 2015; Lesh & Doerr, 2003). Some researchers have suggested that learners can apply mathematical modelling to solve problems that develop mathematical skills. Moreover, the mathematical modelling tasks tend to solve societal problems (Doerr & English, 2003; Common Core State Standards Initiative, 2010; Asempapa, 2018). From this perspective, we explored the connection between AR, 3D printing, and mathematical modelling and how new teaching content based on their connection could be developed. All the proposed practices aim to increase and foster the creative thinking of both teachers and students in finding and expressing their mathematical knowledge using different technologies and applying them to architecture. Norton and Hathaway (2015) elaborated the need for teacher education that is mainly design-based, because teachers are being encouraged to adopt creative methods that are encapsulating recent technologies and don't follow the traditional teaching methods when applying mathematics practices.

Our research goal is to introduce new mathematical concepts to students and explore them in various dimensions using physical representations such as 3D printing and digital representations such as AR. These representations are intended to enable visualization of various forms and spaces.

In our research we aim to explore the effect of various digital and physical representations on modelling ancient architecture and how new technologies can be applied to connect the architectural models to our cultural heritage. These proposed practices fall under the STEAM umbrella which encourage the fusion of different fields focusing on the intersection points between the adopted fields of study in each practice. Therefore, our proposed program adapts STEAM and we refer to it as "STEAM Program".

2 STEAM Program Objective

In this paper we are proposing an educational program that can be practiced with teachers and students. The program goal is to implement mathematical modelling of ancient architectures to foster the student's mathematical and engineering knowledge while connecting to the culture and history.

This program will apply the concepts of STEAM education based on the authors' backgrounds who developed this program to help in fostering the student's creativity during the modelling of the proposed practices. The educational program is of an exploratory nature, where we are eager to see how students can break down ancient architectures into simple polygons and how they reflect on their mathematical knowledge while modelling.

The educational program proposed doesn't apply to any particular country; it can be implemented in various countries to various cultures because it is a conceptual program and the concepts it holds can be applied to any ancient architecture in any place around the world. The two main goals behind introducing this paper under the proposed program is that first, students can explore the differences between architectural design traditions based on two significant examples from ancient architecture. Second, the mathematics students learn at school can seem very abstract. However, through this educational activity, students can understand that math is beneficial in our lives. (Alalouch, 2018) studied the effect of introducing parametric design using computer software to help novice students to model. He derived the complex parametric form and broke it down into a set of generative simple planes and rulesets, which achieved the connections between the plane's points and edges. This gives us an opportunity to use modelling as a tool to help students break down ancient architectural models into simple forms and equations. This connects the cultural and historical backgrounds of students to their mathematical knowledge during the modelling process.

In this program, researchers carried out educational activities to connect various technological knowledge to real-world examples while using mathematics knowledge in the process of selecting ancient buildings and designing them on a computer.

The ancient buildings, Cheomseongdae in Korea and the Temple of Dendera in Egypt, were selected because they are well known, are well preserved and contain simple geometric concepts that can be easily applied by the students in a classroom.

The common aspects between the two buildings are significant cultural heritage in each country, and the students can easily decompose into geometric elements.

The researchers will introduce the activities of designing Cheomseongdae in South Korea and Temple of Dendera in Egypt in 3D space and reflecting them through AR or actualizing them through 3D printing.

3 Historical Background

Cheomseongdae is known as the oldest astronomical observatory in the East of Korea, built around 640 AD, the era of the ancient kingdom of Korea (Silla). The height of Cheomseongdae is 9.4m, the bottom diameter is 5.17m, and the length of one side of the pedestal is 5.35m. Cheomseongdae has the same shape in all directions except for the window as seen in Figure 1. It was used for the accurate measurement of the seasons. Also, it was used as a standard for direction as the center of astronomical observation in Silla (Chung, 2009).

Figure 1: Cheomseongdae.

In Egypt the ancient buildings that belong to the ancient era are considered a significant cultural heritage. The temple of Dendera is one of the largest and most impressive ancient buildings in Egypt, with its grand entrance, detailed carvings, hieroglyphs, and decorated ceilings. The Dendera Temple Complex is situated around 2.5 km to the southeast of the city of Dendera which is a small town in Egypt situated on the west bank of the Nile river. The temple of Dendera was started under Ptolemy XII Auletes in 54 BC and completed in 20 BC (Arnold, 1999). The complex is confined by a wall of air-dried bricks which is nearly entirely ruined, whose sides are between 925 and 990 feet long; on the north and east sides are two magnificent gateways built during the period of Roman rule. A deep rectangular hollow enclosed by a boundary wall can be found on the temple's west side and was used as a sacred lake. Sacred lakes are a typical feature of ancient Egyptian architecture and are often found in well-preserved reserves that were undisturbed by man. Figure 2 shows the Dendera temple complex and how it looks today.

The ancient Egyptians based most of their constructions on a mathematical basis. Through various studies on Egyptian architecture, it is known that various structures in Egypt reflect mathematical structures. Hieroglyphs describing the temple as perfect, correct, beautiful, and excellent were found in the literature related to the building (Cerny, 2001). Figure 3 shows the reconstruction site map of the temple complex. The temple site map features the rooms that start from the central chapel at the back of the reservation. The temple consists of a sequence of progressive numbers which represent the length, width and height in cubits and fractions of cubits of each room in the temple. Complex calculations must have been used to establish the dimensions of the various architectural elements of these temples which prove that they have been built to a set of precise mathematical rules. In addition, there are two texts which express the special relationship between the length, width and the height of the temple. As stated by (Frieze, 1959) one of these statements is 'its length is exact, its breadth is according to the spell'. The word 'spell' was interpreted as 'formula' by (Badawy, 1965). In his study, Badawy linked this interpretation to the triangles, which makes sense to relate the length, width and height of places by means of their bases and heights from his point of view. Using simple calculation, it suggests that the Dendera temple might have been planned based on the same ratio between its length, width and height.

The historical backgrounds of the two chosen ancient architectures were designed in the proposed program to be discussed with students to reflect on the cultural and historical knowledge and the time period they belong to. Teachers can encourage the students to collect data on the buildings they wish to model, or the teachers can provide them the historical information on the models directly. This phase can act as an introduction to the modelling exercises that can be practiced in any culture or based on any backgrounds, but its greatest importance is to help students reflect and connect.

Figure 2: Front view of the Temple of Dendera.

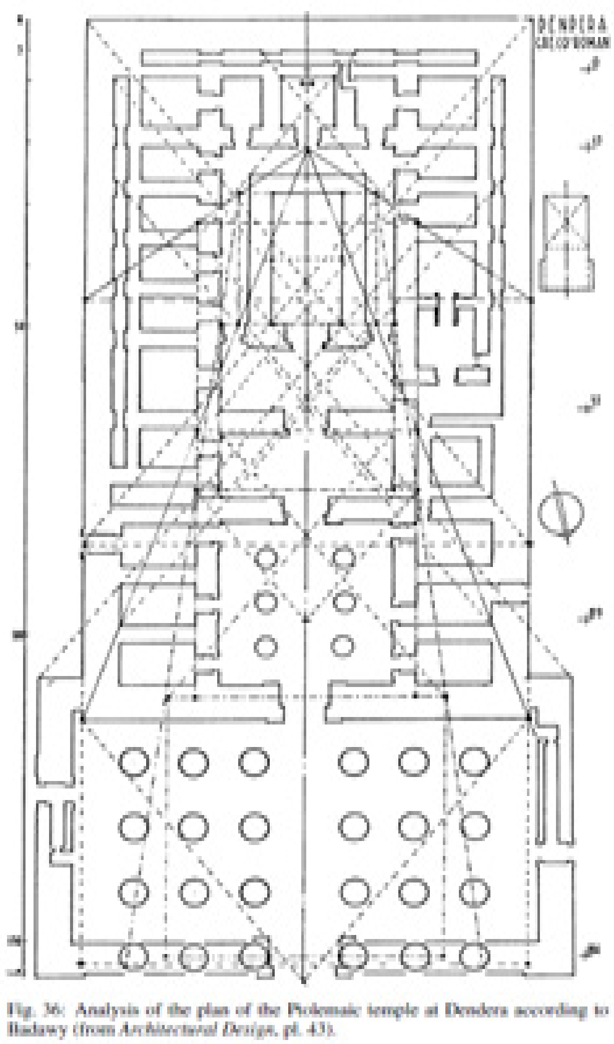


Figure 3: Dendera Complex Temple Site Map.

4 Modelling Procedure

Based on the information from the historical documentations, modelling procedures were constructed using GeoGebra to guide the students in a step-by-step way to develop a 3-D representation model of the two ancient buildings. This program was conducted in collaboration with a Korean and an Egyptian mathematics education researcher. The two researchers chose the example from their historical and cultural backgrounds that they thought would be appropriate for the students to model and with

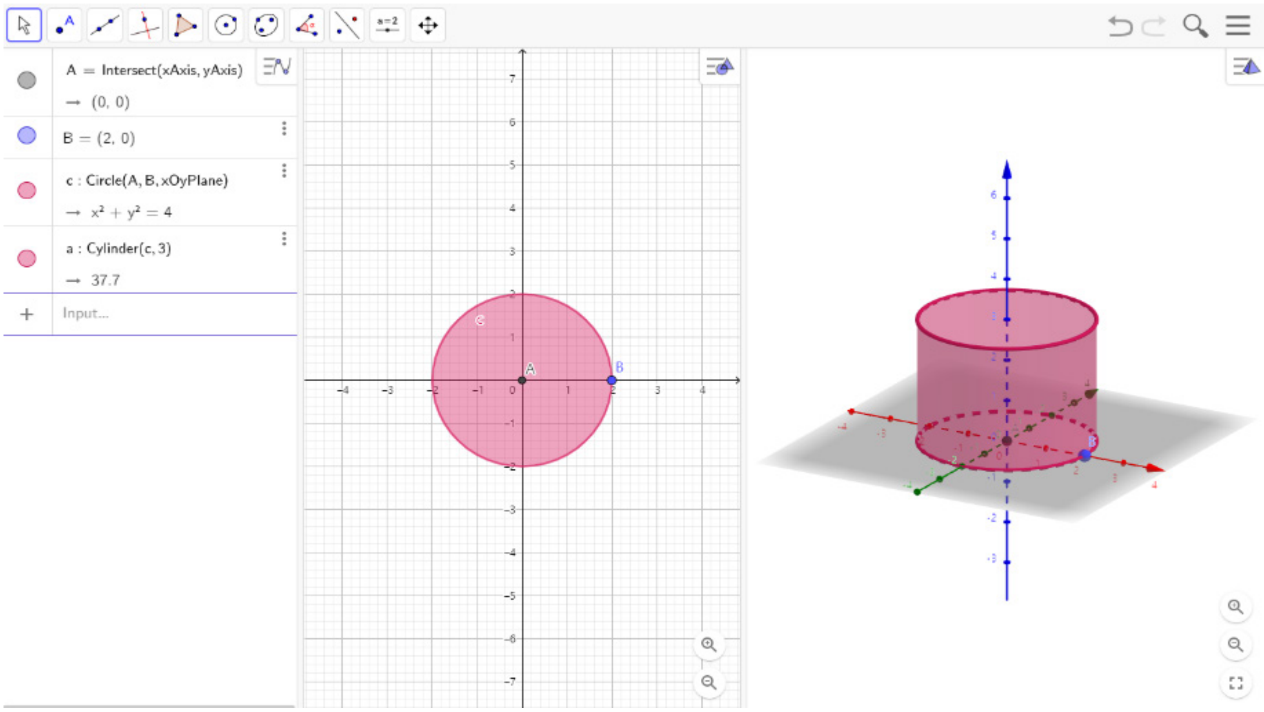


Figure 4: GeoGebra's 2D view with a circle and a 3D geometry view with a column.

enough information for these models from pictures and site maps (Top view of the architectural model as shown in Figure 3). These resources are crucial in the modelling experience to assist students to trace these pictures and lines and form actual polygons of the models. The two researchers also considered these two examples because they include mathematical knowledge that the students can reflect on during the modelling process.

5 Modelling Tool

GeoGebra was chosen for the modelling process over other softwares such as sketch-up or CAD as they are used to perform very sophisticated modelling, but it is not easy for students to apply mathematical objects or use geometric knowledge. GeoGebra can not only deal with various mathematical objects in 2D and 3D but also can efficiently deal with mathematical objects in various areas learned in school. Besides, models constructed from GeoGebra can be exported as STL files for 3D printing. As shown later in Figure 4, GeoGebra can help students in understanding the mathematical representations in various forms as in algebraic equations or as 2D/3D views. By using the extrude tool in GeoGebra any polygon can be transformed from 2D polygon to a 3D polygon. (Lieban & Lavicza, 2017) noted that GeoGebra gives the users access to an object with its various views and cross sections. This feature can aid in multiple representations from 2D to 3D. We are eager to promote spatial thinking, by allowing students to represent the same models but in various ways especially when transformations are applied; they give the students a speculating modelling process. If students use GeoGebra to design Cheomseongdae or Temple of Dendera, they can simply experiment with AR or perform 3D printing without using any other software.

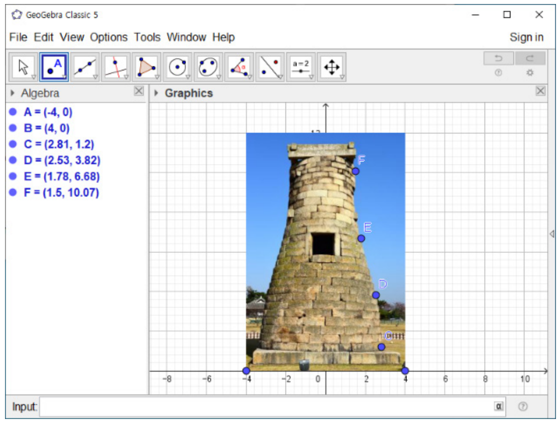
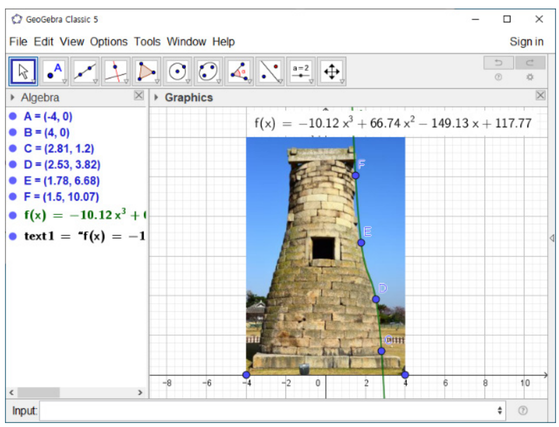
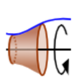
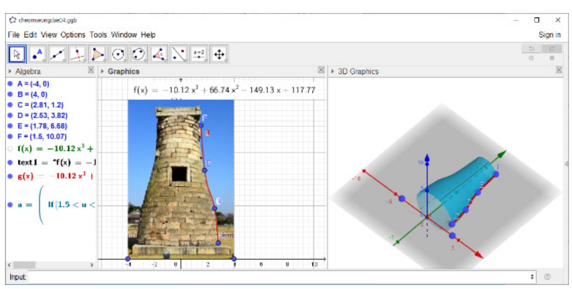
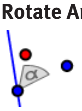
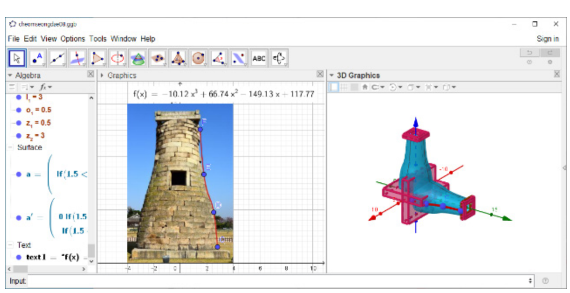
6 Results

This section will show the results in a step-by-step manner in order to model the two selected ancient architectures from the Korean and Egyptian cultures.

7 Cheomseongdae

To model Cheomseongdae in GeoGebra, its structure was analyzed, and this section explains how tools and ways were used in the modelling process. Cheomseongdae can be understood as a rotating body except for the bottom and top. Therefore, the teachers along with their students model the three-dimensional figure by rotating the side curve of the building about the central axis.

Table 1: The modelling process of Cheomseongdae.

Step	Tool	GeoGebra Screenshot	Description
1	Tool: 		Make points along the side curve of Cheomseongdae.
2	Command: **Polynomial()**		Use the polynomial () command to obtain a polynomial curve that passes through all points on the screen. (After that, adjust the scope of the function.)
3	Tool: **Surface of revolution** 		Create a surface using the Surface of Revolution tool.
4	Tool: **Rotate Around Line** 		Using the Rotate Around Line tool, place the Cheomseongdae on the XY plane.

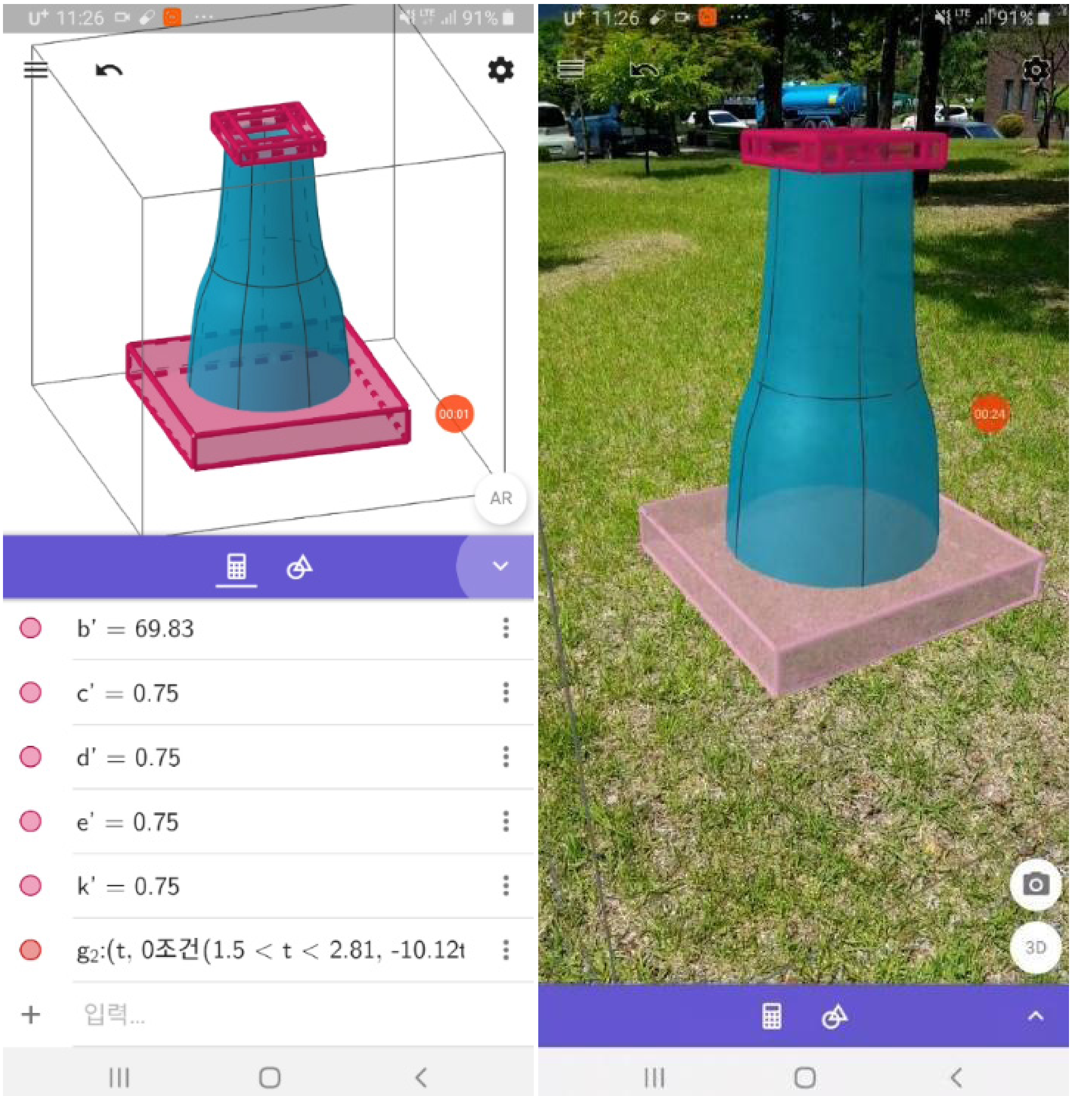


Figure 5: Cheomseongdae and AR in the GeoGebra 3D Calc app.

First, the front picture of Cheomseongdae was inserted into GeoGebra's 2D geometry view. Then, after making a point along the curve of the side of Cheomseongdae, a polynomial equation was passed. GeoGebra's Surface of Revolution tool was used to define the surface. Through this process, the shape of Cheomseongdae was completed. The next step was to represent the pillars above and below the Cheomseongdae. Finally, rotate the Cheomseongdae using the Rotate Around Line tool and place it on the XY plane.

Throughout this process, it is also possible to apply AR in GeoGebra's smartphone app to Cheomseongdae modelled in GeoGebra. After running the Cheomseongdae model in the GeoGebra 3D Calc app, press the AR button to apply AR to reality as shown later in Figure 5. Through this process shown previously in Table 1, Cheomseongdae can be applied to the environment in which students learn and so is considered an opportunity to understand Cheomseongdae in various ways as mathematically, culturally and historically.

3D shapes created in GeoGebra are exported as STL. In this way, the Cheomseongdae 3D model can also be made real through 3D printing as shown later in Figure 6.

Cheomseongdae is located in the city of Gyeongju, located on the edge of Korea. Every year, many students go there on a trip which connects the students to their cultural backgrounds.

We must be aware that there may be differences in the method of designing Cheomseongdae according to the grade of the students. In the case of high school students,

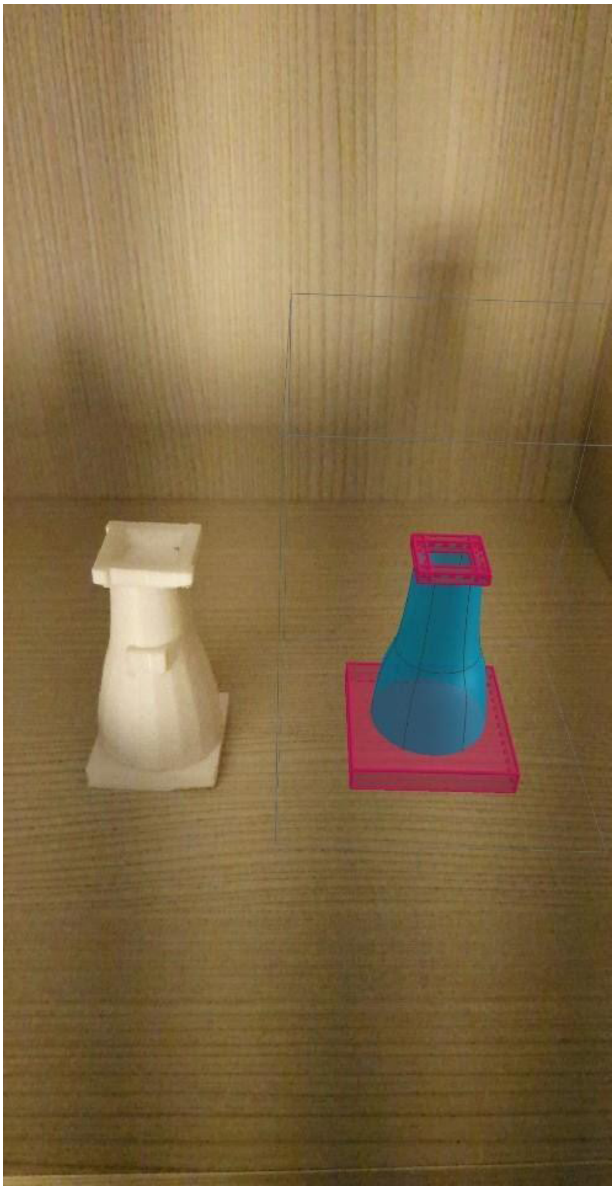


Figure 6: 3D printed Cheomseongdae and AR

the polynomial function presented previously in Table 1 may be used. However, if they are young students, they can draw the side curves of Cheomseongdae using GeoGebra's pen tool. Although the curves drawn by young students may not be accurate, the Cheomseongdae can be redesigned using the Surface of Revolution tool of GeoGebra. Through this process, very young students can understand each part of Cheomseongdae as a mathematical figure.

8 Temple of Dendera

The Temple of Dendera consists of several pillars and walls, as Figure 3 shows the base of the temple. Later, in Table 2 we explain which tools and methods were used in the modelling of the Dendera temple. We began with drawing the 2D plane as the base of the Dendera temple floor plan and transforming it into a 3D shape using the Extrude to Prism tool. In our case we are interested in extruding with the prism option in order to maintain the site map polygon shapes and forms. Next, polygons and circles were created along the drawing in a 2D view.

The next step is using the extrude tool which is a tool that works on an existing 2D shape or in the current scene. It creates an extruded 3D shape from the selected 2D shape by defining various parameters as the height of the extruded prism.

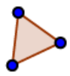
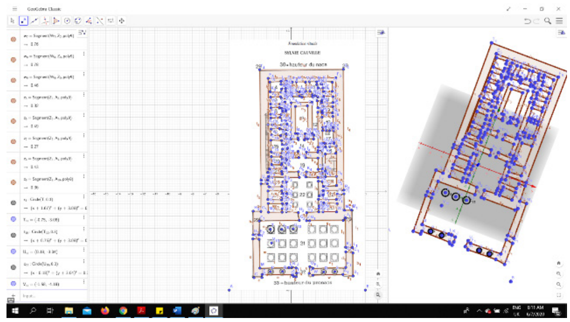
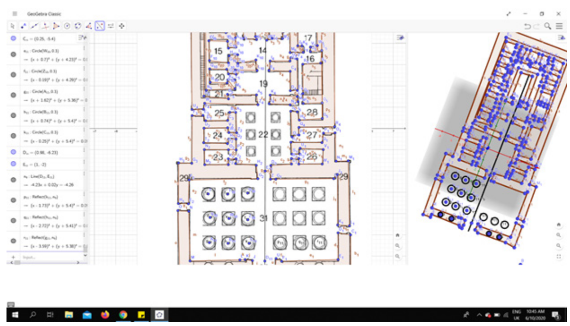
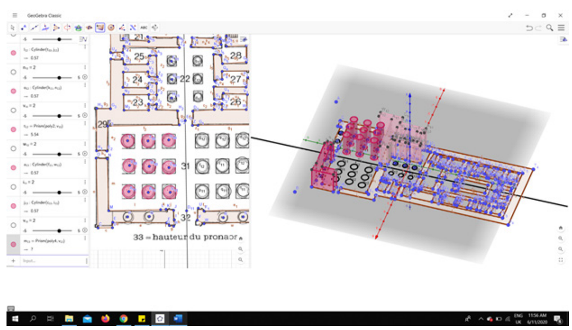
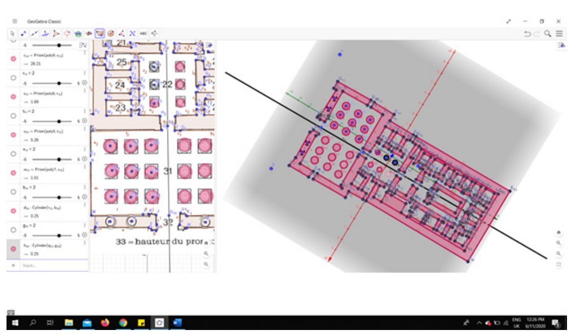
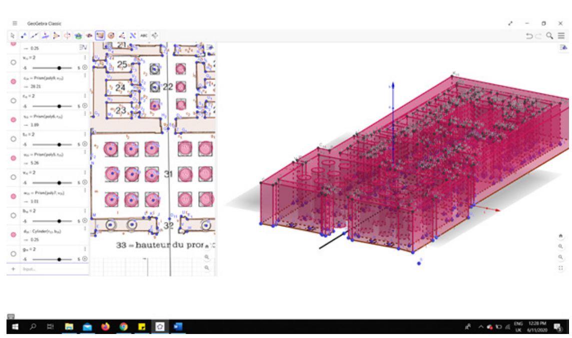
GeoGebra's Extrude to Prism tool can be used to transform the generated two-dimensional shapes into three-dimensional space constructed from all the temple columns and walls of the temple. Through these repeated and reflection processes, modelling of the Dendera temple was performed. Table 2 explains the steps that were taken to model the Dendera temple in Egypt.

After the modelling process and constructing the temple shape in 3D Form, the 3D printing process takes place in GeoGebra as shown later in Figure 7. Then the students can experience the AR representation of the Dendera temple as shown later in Figure 8.

Students will be able to achieve a complex and sophisticated output. Also this modelling process may allow students to think in a 3D visual-spatial way that could be hard to understand and imagine from a normal 2D drawing.

As stated by (Rossi, 2004) the Dendera complex temple was constructed on a mathematical basis which was proven in the papyrus found about these temple complexes. While the students are redesigning the building, they will understand and interpret the mathematical concepts behind its constructions. As the students undergo the modelling process step by step they will see the relationship between the model components. This will reflect on their mathematical knowledge. Also, the sophistication of the building, which is not sufficiently conveyed in the 2D drawing, can be communicated to the students through the 3D printing process.

Table 2: The modelling process of the Temple of Dendera.

Step	Tool	GeoGebra Screenshot	Description
1	Tool: **Polygon**  		Draw polygons and circles along the drawings of the Dendera Temple floor.
2	Tool: **Create a Line** (Using the line equation)		Instead of creating each circle and each polygon on all sides, we created a midline to reflect the circles on it after extrusion
3	Tool: **Extrude to Prism** 		Use the Extrude to Prism tool to pull out the 2D shapes on one side of the temple.
4	Tool: **Reflect on the line**		Reflect the extruded columns on the same reflection line in the mid of the temple
3	Tool: **Extrude to Prism and Reflect on the** 		Extract all shapes using the Extrude to Prism tool.

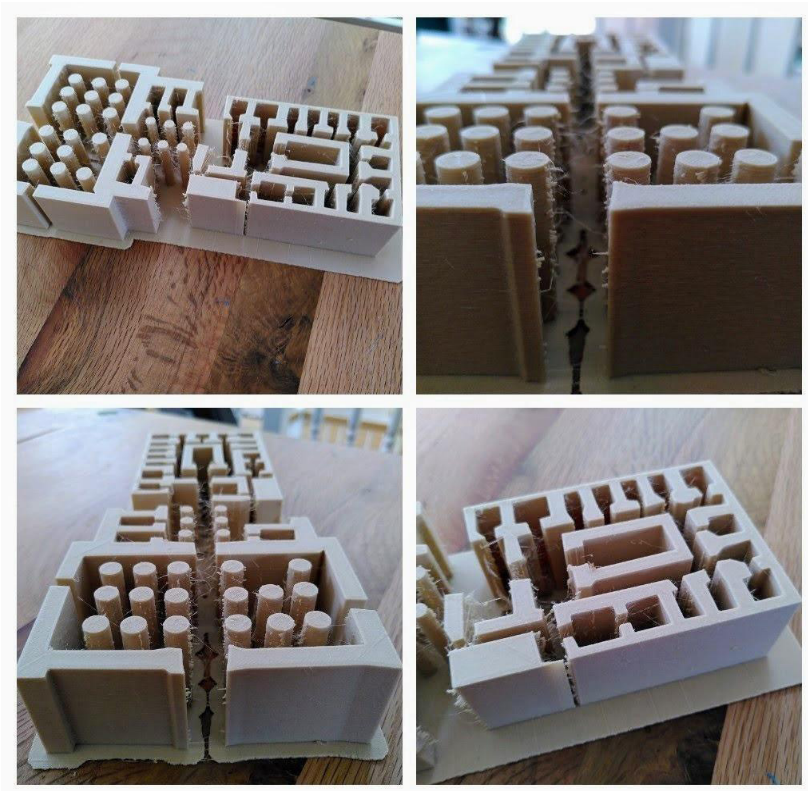


Figure 7: 3D printing of the GeoGebra model of the Dendera Temple.

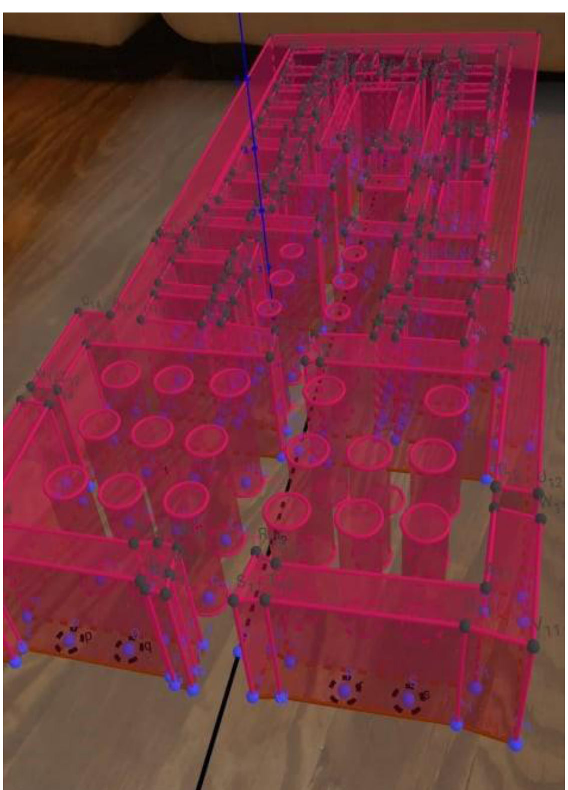


Figure 8: Dendera temple in AR mode in Geogebra 3D Calc app.

9 Discussion

The architectural model chosen to represent the Korean architecture Cheomseongdae, was used to enable students to understand the mathematical equations. Students use the Surface of Revolution to analyze Cheomseongdae mathematically. This is done through a mathematical analysis process before developing a 3D model in GeoGebra. If the student models Cheomseongdae differently than the shown steps previously in Table 1, another creative 3D model of Cheomseongdae will appear. If students can design Cheomseongdae on their own, apply it in AR and 3D print it, they might develop a clear understanding of Cheomseongdae without visiting the city.

The architectural model chosen to represent the Egyptian Architecture Dendera temple, was used as building this model in GeoGebra, requires basic skills ranging from the knowledge of simple shapes to understanding the relationships between triangles, squares and rectangles. Students have the opportunity to discover the relation between length, height and width: the relation between the temple sides is a well-known feature in ancient Egyptian architecture. Students reconstruct a complex temple in 3D using simple shapes.

The teachers presenting and implementing such a complex temple can leave the students with two options which are to imitate or innovate. Both options will be of added value to the students and will help them find a solution or an approach to the given temple site map. The students can imitate the existing site maps of the ancient models as has been described previously in Table 2, - how to follow the site map in the construction of objects. On the other hand, the students can also start to innovate and add a new component or form on the existing site maps. They will be able to picture their choice in AR mode and go a step further and see the printed version of their decision using 3D printing.

From the educational point of view this may foster creativity while they are modelling such complex temples and it may help in collaboration between students if they are considering group work.

10 Conclusion

In this concept, we designed a student activity that modelled Cheomseongdae in Korea and Temple of Dendera in Egypt in GeoGebra and connected it with AR and 3D printing. In general, students often go on a school trip to explore nature or historical artefacts. This study may help students connect and reflect the culture with their mathematical studies. Through this process of analyzing and realizing the real buildings, students who are participating in this activity will get a perspective of looking at the world mathematically and it may open a new window to mathematics practice in the classroom.

This study aims to provide quality experiences to students at school together with STEAM education that preserves individual creativity.

In this study, modelling was done using the computer software GeoGebra and teachers need to recognize and understand its capabilities. The results of this study are presented as an example, and the application is endless. Students will be able to recognize that the oldest science that has been with humanity is mathematics through the process of redesigning historical artefacts in GeoGebra. Reproducing these ancient architectural models with AR and 3D printing is an achievable combination and provides an interdisciplinary education in history, culture, mathematics, and engineering.

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