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# Augmented Reality to Support Geometry Learning

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**ABSTRACT** Currently digital educational applications are employed in education, since technological tools are very interesting and engaging for pupils. Augmented Reality (AR) is one of the most explored and successfully used technology. Thanks to the AR, the situated learning can occur; it suggests that people easily acquire new knowledge if learning occurs in a specific context and is embedded in a physical environment. This paper presents an AR application, called Geo+, for supporting primary school students in the acquisition of knowledge on the solid geometry. Geo+ has been developed by following a Human-Centered Design approach, thus several formative evaluation studies were performed to enhance the quality of the resulting application. A user study involving 96 pupils of the 3<sup>rd</sup> grade of primary school was performed in order to investigate the learning effectiveness, the engagement and the perceived workload of Geo+ at school. The results showed that Geo+ is effective in terms of student learning gain. In addition, pupils really appreciated the ease of use of the game; they were satisfied and felt engaging and comfortable during the interaction, none of them ask for help during the execution of the learning activities.

**INDEX TERMS** Augmented reality, STEM, educational technology.

## I. INTRODUCTION

Technology and learning have always been integrated to make the learning process more engaging, motivating and attractive. The game-based learning theory is based on Piaget's Constructivism [1], which claims that knowledge can be effectively acquired through genuine experiences if a real context for that knowledge is provided to the learner. In particular, in this approach the experience uses a mobile application. There are different examples in traditional classroom in which some disciplines, such as Science and Mathematics, are taught using educational application.<sup>1</sup> Currently, digital educational is the most common approach, since using technological tools and solutions is very interesting and engaging for learners [2]–[6]. In recent years, research has been focused on the Augmented Reality (AR) [7] as a promising technological approach in the context of constructivism theory. AR allows users to be completely immersed inside a synthetic environment. From a pedagogical point of view, the AR allows to apply the situated learning approach [8],

which claims that learning is more effective when it occurs in a specific context and is embedded in a physical environment. AR permits to create interaction experiences that are enhanced by the overlapping of information between virtual and real objects. Indeed, the main objective is to enrich sensory activities and stimulate emotional factors in users, in order to improve their involvement during the learning process. Lara Jongedijk, Researcher, Instructional Design at University of Calgary states [9]: “Augmented reality (AR) is an environment where real life is enhanced by virtual elements in real time. The purpose of AR is to enhance the information we naturally receive through our five senses, by adding superimposed, constructed virtual elements to bring complementary information and meaning that may not be possible by natural means.”

The application of AR has been explored and successfully implemented in various domains, e.g. visual art [10], architecture [11], e-commerce [12], and so on. Moreover, the AR relies on mobile devices already available to most users, and it does not require any particular hardware or software to work. This is an important advantage that makes AR more used than Virtual Reality.

In this context, the research aims at using AR technology to support teaching of geometry in primary schools.

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<sup>1</sup>Examples are: <https://www.matika.in/en/>, <https://learningapps.org/>, <https://www.tabelline.it/>

Specifically, the “Geo+” AR application is proposed; its knowledge content was developed in collaboration with primary school teachers. The Geo+’s learning objective is related to basic knowledge about the main solid figures. The idea is to use this tool to enrich traditional lessons about solid geometry, the tool as it is, cannot replace teachers’ lessons or geometry books. Geo+ is not actually a game, but as application software pupils perceived the activities with it as entertainment more than a lesson in classroom.

The remainder of the paper is organized as follows: Section II describes the state of the art of AR in Education; Section III presents Geo+, the AR application developed to support teaching of basic geometric solid figures; Section IV reports the study carried out to investigate the effectiveness, the perceived workload and the engagement of pupils in using the application. Concluding remarks and future directions are outlined in Section V.

## II. RELATED WORKS

The AR technology is one of the newest trends applied in educational applications to support learning of many disciplines. When contents are implemented using AR, users are involved in almost real experiences, thus higher quality of interaction is reached. This impacts on students’ emotional states that improve learning effects [13]. Kye and Kim have proved that typical factors of AR applications, such as sensory immersion, manipulation, presence and flow, can influence both knowledge and understanding [14]. The AR has been used to support learning of different subjects not only for STEM (Science, Technology, Engineering and Mathematics). As an example, TeachAR [15] is an AR tool for teaching basic English words (colors, shapes, and prepositions) to non-English speaking children. TeachAR is a desktop AR application with Microsoft Kinect for speech recognition. The pupil interacts with the game using different markers to change shapes and colors in the software application. The comparison between the AR tool and a mouse-based interface of the same software showed higher subjective engagement and post-test scores. Another application of AR in the context of language learning is HELLO (Handheld English Language Learning Organization) [16]; in this case, the final users are college students and its aim is to increase students’ learning motivation and improve their English level. The application uses the 2D barcodes technology to allow students to supply context-aware materials in the different campus zones.

The EcoMOBILE project [17], instead, has been developed in the context of science and environment sustainability. Its aim is to foster the acquisition of skills concerning the water quality measurements. Students using a mobile app are required to navigate the pond environment and to observe virtual media and information overlaid on the physical pond. They should collect water quality measurements using the information supplied in the system. Again, in the context of environment sustainability, an AR application has been used also to improve awareness on green consumption of electronic devices [18]. The idea is to enable individuals

to learn energy consumption of electronic devices. Using the application, the user scans the environment in order to detect electronic devices and to get tips and information about their green use. A study revealed that users appreciate the application and significant improvements were registered in the knowledge about green practices.

In the context of geometry education, some solutions have been designed and implemented to supply math teachers in elementary schools with interactive learning media. In [19], for example, the AR application uses the plain figures as markers to model the 3D solid on the smartphone. By clicking on the screen, the formula information used to calculate figure area and volume are displayed. ARGeo [20] is another AR application for middle school students to practice the basic principles of geometry. It aims at fostering the acquisition of both basic knowledge and key activities following the guidelines set by the official program schools. In particular, three types of exercises have been defined to recognize regular solid figures and to acquire information about related formulas and to identify cut sections of geometric bodies. All the contents are proposed as exercise and only if the student gives the right answers more contents are displayed. The comparison of the learning effectiveness of AR-based activity compared to the Web-based activity, showed that users performed significantly better with the AR application than those ones interacting with the Web-based application. Moreover, the AR application promoted higher levels of motivation, in terms of attention, relevance, confidence, and satisfaction than Web-based application. An interesting result of this study was that AR technology did not foster better levels of confidence than Web-based technology.

AR Geometry Tutorial System [21] was designed for middle school students to improve their 3D thinking skills. Some virtual buttons are used to interact with AR teaching materials and to explore the different shapes from different perspectives. As a result, the AR-supported geometry teaching was found to significantly increase the students’ 3D thinking ability. However, when the effect of the AR-supported geometry training on the subcomponents was examined, its effect on the ability to structure 3D arrays of cubes and calculate the volume or area of 3D solids was limited.

Differently from the other existing applications that address to older students, probably since the AR technology is considered too difficult to use and understand by young people, Geo+ appeals to primary school children. Many AR applications. In our opinion, the AR allows primary school students to feel fascinated and excited as if they were in a magical world, feelings that boost effective learning. Moreover, Geo+ supplies multimedia content to acquire information about each figure. An evaluation study was performed in order to investigate pupils’ engagement and cognitive workload during the use of Geo+ application.

## III. THE AR APPLICATION Geo+

The research aimed at designing and developing an AR application for learning solid geometry addressed to the 3<sup>rd</sup> and

the 4<sup>th</sup> grades of primary school pupils [22]. Geo+ application allows small group students to explore the structure of a geometric solid figure, to acquire and to discuss basic information using multimedia contents. The application requires the use of smartphones and tablets and a target image that is used just as a start marker. The main learning objectives, in accordance with the Italian Education Department guidelines, are:

- recognize solid figures
- draw and translate representations of different 3D solids in 2D figures
- recognize the significant features (corners and edges) and distinctive properties

The human-centered design (ISO 9241-210) [23] was used to develop the Geo+ application to be effective in terms of both interaction and content. It is essential, indeed, for Educational Technology to develop tools that are easy to use and easy to understand.

**A. THE Geo+ ARCHITECTURE**

The architecture of the application is represented in Figure 1. The GameSolidiAR is the main component of the application and it contains: the Hierarchy and the Component elements. The Hierarchy contains all the graphical elements and the GameObject to set-up the scene in the application, the Component contains all the scripts useful to implement the different functionalities of the application.

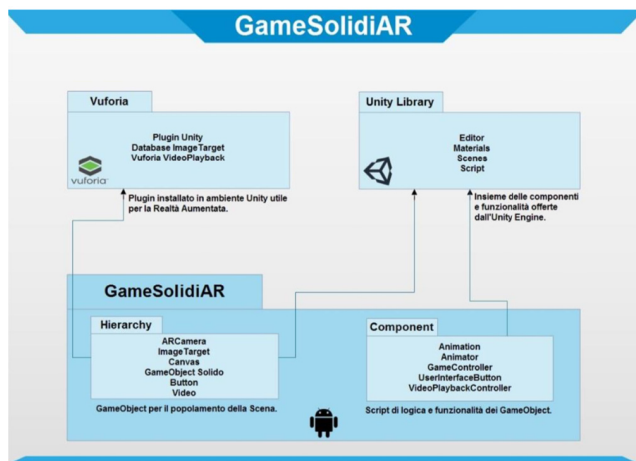


FIGURE 1. AR application architecture.

All elements are built in Unity, the UnityLibrary is the set of all Unity Engine components to create the GameObject and the related scripts. Vuforia is the plugin of Unity used to build and manage Augmented Reality contents.

**B. THE USER INTERACTION**

The application was developed using the developed by following a Human-Centered Design approach. Initially, Geo+ starts with a main menu, from which the user can select the solid figures to explore. To navigate among the figures, buttons have been introduced. They are divided in two groups:

a) on the left side the rotating solids (the sphere, the cylinder and the cone, in Figure 2 “Sfera”, “Cilindro” and “Cono” in Italian); b) on the right side the polyhedral solids (the cube, the parallelepiped and the pyramid, in Figure 2 “Cubo”, “Parallelepipedo” and “Piramide” in Italian).

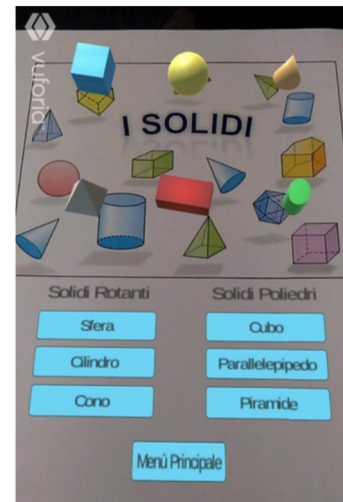


FIGURE 2. The menu to select the solid figure. On the left the rotating solids and on the right the polyhedral solids [22].

Once the solid is chosen, the augmented object is displayed. In this view (Figure 3), users can zoom in and zoom out, can rotate the object, and can also pause the rotation in order to observe all the details of the solid. This is important to allow them to count the number of faces, the number of vertices and edges, and to recognize the shape of each face and polygons. Hence a video to observe how the solid is developed, as depicted in Figure 4 (this is possible using the “Sviluppo della Piramide” button in Figure 3).

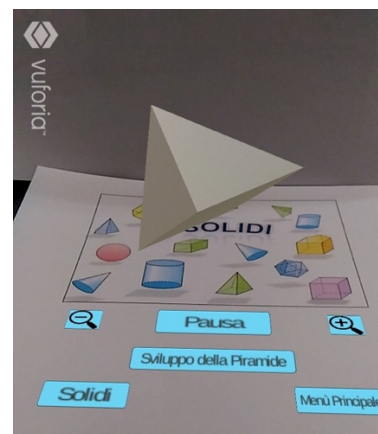
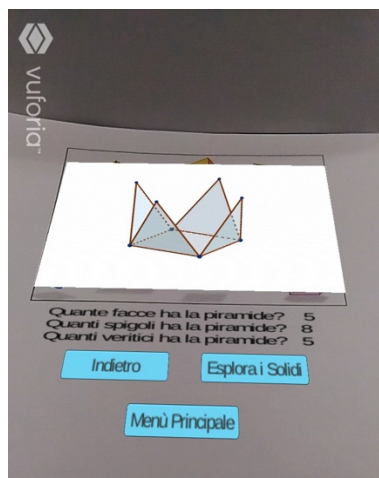


FIGURE 3. The pyramid visualization. The functionalities available are: zoom-in, zoom-out, pause the rotation (pausa), to see transformation from 3D to 2D (Sviluppo della Piramide), return to solid menu (Solidi) and to return to the main menu (Menù Principale).

The video lasts about 3 minutes. It also shows real objects that have the same shape of the selected solid. The development of the solid were implemented using



**FIGURE 4.** The video-lesson of the development of the solid. In the screen are showed also information about how many faces, edges and vertices there are in the pyramid.

Geogebra,<sup>2</sup> a dynamic mathematics software that supports STEM education and innovations in teaching and learning worldwide.

#### IV. EVALUATION

The Geo+ has been developed by following a Human-Centered Design approach: the prototypes were developed and evaluated through different qualitative formative studies, whose results were instrumental to enhance the quality of the successive prototypes. In addition, a field study was carried out on an advanced interactive prototype of Geo+, in order to investigate the learning effectiveness, the engagement and the perceived workload of Geo+ at school. As working hypotheses, we expected that Geo+ would have the following implications.

*Learning.* Geo+ positively impacts on learning by allowing pupils to acquire knowledge.

*Workload.* Pupils do not perceive the cognitive workload of educational activities with Geo+, since they look at the technological tools as means to play and not to study.

*Engagement.* Geo+ is engaging as it permits to interact with solid forms by showing them in three-dimensions.

Section A presents the results of a pilot study conducted on Geo+ prototype, in order to evaluate the system reliability and study methodology, e.g., time constraints, coding techniques, while Section B illustrates the results of the evaluation study performed on the new version of Geo+, developed for implementing new features based on the data collected from the observations of the pupils' interaction during the pilot study. Obviously, the two studies involved different participants who used the application at school.

##### A. PILOT STUDY

A total of 33 pupils (18 M and 15 F) of two classes of the 4<sup>th</sup> grade of two primary schools in Gioia del Colle (Bari, Italy) and Sammichele di Bari (Bari, Italy) were involved

in the study. All the pupils had acquired knowledge of the basic principles of geometric solid figures through traditional lessons.

##### 1) PROCEDURE

Initially, all participants were given a pre-test aimed at verifying their knowledge acquired during the previous traditional class activity. Pupils had 30 minutes for completing this test.

Then, pupils went to the multimedia laboratory of the school, where the study activities took place. A short demo of the Geo+ application and its functionality were introduced to the pupils. Pupils were divided into small groups of 4 or 5 members and each group was provided with a tablet with the AR application installed and the target image printed on paper. One pupil acted as leader of the group and he/she was in charge of the tablet. During this time, each group freely interacted with the application for 30 minutes.

Two days later, all pupils answered to the post-test, structured similarly to the pre-test; it aimed at verifying the possible knowledge acquired during the AR-based learning activity in laboratory. As for the pre-test, the time available for filling in the test was 30 minutes.

Finally, a questionnaire was administered to all pupils, in order to assess the pupil involvement and the workload perceived during the interaction with Geo+.

All the study activities were performed with the presence of teachers and two Human-Computer Interaction (HCI) researchers.

##### 2) DATA COLLECTION

A pre-test and a post-test were filled in by the participants before and after the AR-based activities. They were composed of a total of 10 questions and exercises prepared by the teachers according to the national learning indications for the primary school curriculum; specifically:

- recognition and distinction of solid figures and real solid objects and their correspondent flat figure.
- description and characteristics of rotating solids and polyhedrons.

##### 3) RESULTS

The collected data demonstrated that pupils improved their knowledge on the solids after the interaction with Geo+ (see Table 1). Those exercises that obtained the maximum in the pre-test (i.e. exercises n. 4, 6, and 7) were confirmed, while all the remaining exercises improved their scores.

Table 1 shows the average scores of each exercise respectively in the pre-tests and in post-tests along with the learning gain. The difference was tested by a T-test; since  $T_0 > t_\alpha$  ( $5.7455 > 2.4487$ ), with  $\alpha = 0.01$ , a statistically significant difference emerged. In other words, the null hypothesis was rejected, whereas the experimental hypothesis  $H_1$  was accepted.

The pilot study proved the reliability of the study methodology and provided some important suggestions to improve the usability of the AR application. Specifically,

<sup>2</sup><https://www.geogebra.org/>



**TABLE 1.** Average scores of each exercise in pre-test and post-test.

Exercise no.	1	2	3	4	5	6	7	8	9	10
Pre-Test	0.9 5	0.9 2	0.9 2	1.0	0.9 8	1.0	1.0	0.7 3	0.7 2	0.9 7
Post-Test	0.9 8	0.9 4	0.9 2	1.0	0.9 9	1.0	1.0	0.8 5	0.8 6	0.9 9
Learning gain	0.0 3	0.0 2	0.0	0.0	0.0 1	0.0	0.0	0.1 2	0.1 4	0.0 2

the observations, carried out by the two researchers, highlighted some interactions problems. that pupils as well as the teachers, found very uncomfortable using the different marker images, each representing the corresponding plane figure. The prototype consisted of a family of applications, namely an app for each solid figure was developed; each of them will start using a different image depicting the specific solid. In the final version of Geo+, a single marker image is necessary, and a menu was introduced in order to allow pupils to choose the solid that users want to interact with using directly the AR application.

In addition, we notice that pupils try pinching the image to zoom in. Thus those features were added. Moreover, pupils would they expected to be able to do more, to see something else about the solid figures. In the final version the video which shows the development of solid figure starting from the plane shape. This to let users better understand the difference between plane and solid figures.

We finally observed that all pupils learnt how to use it as soon as they received it, with no need for further explanation.

## B. EVALUATION STUDY

This section describes the method applied in the summative evaluation study. Where not otherwise stated, the procedure, and consequently the data collection, are exactly the same as in the pilot study. The hypotheses driving the study have already been stated at the beginning of the “Evaluation” Section.

### 1) PARTICIPANTS AND DESIGN

The study involved 96 pupils (51 boys, 45 girls) of the 3<sup>rd</sup> grade of the same primary schools involved in the pilot study. All pupils had already acquired, in previous traditional learning activities, knowledge and skills related to geometric solids.

A single group pre-test post-test study was performed, with the learning as an independent variable.

### 2) DATA COLLECTION

Learning was assessed by collecting the answers of the pre-test and post-test filled in by the participants before and after the AR-based activities. Like the ones used for evaluating learning in the pilot study, pre and post-test of the summative study were composed of a total of 10 questions and

exercises prepared by the teachers according to the national learning indications for the primary school curriculum.

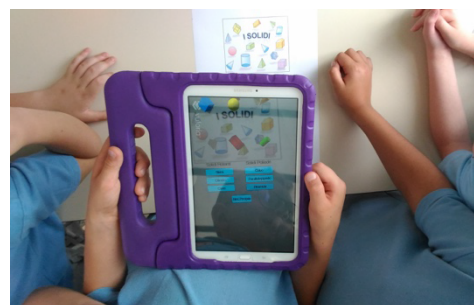
In this study, pupils filled in a questionnaire at the end of the study consisted of two sections. The first section is related to the NASA-TLX questionnaire, used to rate perceived workload in using a system. It is a 6-item survey that investigates 6 subjective dimensions, i.e., mental demand, physical demand, temporal demand, performance, effort and frustration [24]. The second section presented the new UES (User Engagement Scale) short form, derived from the UES long form. It is a 12-item survey used to measure the user engagement, a quality of user experience characterized by the depth of a user’s investment when interacting with a digital system [25], which typically results in positive outcomes [24]. This tool measures the user engagement by averaging an index that ranges from 0 to 5. It also provides detailed information about four dimensions of the user engagement, i.e., focused attention (FA), perceived usability (PU), aesthetic appeal (AE) and reward (RW).

### 3) PROCEDURE

Data collection took place at the primary schools in Gioia del Colle e Sammichele di Bari, Bari (Italy). Two days after the experimental sessions a follow up session was held at school to evaluate the learning.

Initially, all participants underwent a pre-test consisting of 10 questions/exercises. They had about 30 minutes to answer the questions independently. The tests were anonymous. At the end of the test, the participants attended a class on geometric solids (cube, cone, cylinder, sphere, pyramid, parallelepiped). A PowerPoint presentation was used in this phase. The lesson was held by their teachers.

Subsequently, the actual experimental phase started in the laboratory of the schools. The pupils were divided into small groups composed of 4 or 5 children (Figure 5). Each group had the target image and a tablet with the installed application. The researcher introduced the Geo+ application and demonstrated its usage by showing examples. A leader was defined for each group; this phase lasted 30 minutes.

**FIGURE 5.** Pupils are interacting with the AR application.

At the end of the interaction with Geo+, a debriefing phase took place. Pupils were first asked how they felt about the experience, to sound out their emotional response.

Two days later, all participants were given a post-test structured as the pre-test. Both the tests were revised by the teacher, who assigned a total score from 0 to 10 (1 point for each correct answer). At the end of the post-test, a questionnaire containing 18 questions aiming at measuring workload and user engagement was administered.

The last phase was focused on observations of the pupils and discussions between them and the observer to obtain feedback and useful suggestions to improve the application.

4) DATA COLLECTION

Both quantitative and qualitative data were collected through (1) the notes taken by the observer on significant behaviors or externalized comments of the participants during the study, (2) the answers of the questionnaires the participants filled in during the study.

V. RESULTS AND DISCUSSION

Results are reported in separate sections addressing learning, cognitive load and engagement. Reliability analysis was run for every questionnaire index reported and yielded satisfactory values ( $\alpha > .80$ ). The T-test for paired data was used to analyze the learning effect with a p-value  $< 0.05$  that was considered statistically significant.

A. LEARNING

The summative study clearly demonstrated the pedagogical value of Geo+ application. Before carrying out the T-Test for paired data and for independent data related to the final application, the pre-tests and post-tests administered to the pupils were analyzed. Table 2 shows the comparison of average scores obtained for each exercise respectively in the pre-tests and in post-tests along with the learning gain.

TABLE 2. Average scores for each exercise in pre-test and post-test.

Exercise no.	1	2	3	4	5	6	7	8	9	10
Pre-Test	0.9 6	0.7 0	0.6 7	0.9 8	0.9 1	1.0 0	1.0 0	0.6 7	0.5 6	0.8 1
Post-Test	0.9 7	0.9 3	0.9 2	1.0 0	0.9 6	0.9 9	0.9 9	0.8 2	0.8 8	0.9 6
Learning gain	0.0 1	0.2 3	0.2 5	0.0 2	0.0 5	- 0.0 1	- 0.0 1	0.1 5	0.3 2	0.1 5

From the results of these first descriptive analyses, the average post-test score for each exercise is overall higher than the average score obtained during the pre-test.

The T-Test was applied to the difference between the averages. The alternative hypothesis  $H_1$  from the right unilateral test will be accepted if the difference is  $> 0$ . This means that the use of the application is effective in this learning setting.

- $H_0: \mu_y - \mu_x = 0$ ; no difference between the average scores
- $H_1: \mu_y - \mu_x > 0$ ; there is a difference between the average scores.

The  $\alpha$  value was fixed at 0.01. Since  $T_0 > \alpha$  ( $11.9315 > 2.3662$ ), the null hypothesis  $H_0$  could be rejected, whereas the alternative hypothesis  $H_1$  could be accepted. A statistically significant difference emerged. Indeed, a difference between the pre-test and post-test average exists, confirming that the use of AR technology in these learning settings is effective in terms of student learning gain. Specifically, the AR application acted as a reinforcing tool for concepts that pupils have already well acquired. But it is worth noticing that it has effectively supported pupils in learning concepts related to solid dimensions, vertices, edges and faces.

B. WORKLOAD

The workload data gathered through the NASA-TLX were  $\bar{x} = 3.6$ ,  $SD = 1.5$  which can be considered a positive result. Namely, Table 3 shows mean and standard deviation of the NASA-TLX dimensions for the AR application. The mean of the dimensions, less than the performance dimension, is below 3.00. This result highlighted that pupils did not feel frustrated, did not perceive any type of frustration, effort, or demands in interacting with Geo+ application. In addition, the mean of the performance dimension was 9.02.

TABLE 3. Mean and standard deviation of each NASA-TLX dimension for the AR application.

	Mean	SD
Effort	2.26	1.92
Frustration	2.77	2.40
Mental demand	2.59	2.15
Performance	9.02	1.19
Physical demand	2.24	1.77
Temporal demand	2.73	1.82

The pupils felt comfortable in using the system and they were very satisfied with their performance. They were able to interact with the AR application easily. In fact, they did not ask for help during the execution of the learning activities.

C. ENGAGEMENT

UES short form provided indications about the user engagement in using the system. The items through a 5-points Likert scale measure: focused attention (FA), perceived usability (PU), aesthetic appeal (AE) and reward (RW). The mean and the standard deviation of UES scores ( $\bar{x} = 3.79$ ,  $SD = .39$ ) showed that pupils were engaged in the learning activity. A more detailed analysis was also performed to examine possible differences with respect to the UES dimensions. Table 4 reports mean and the standard deviation of the UES dimensions for the Geo+ application. Also in this case, the mean and the standard deviation of each UES dimension indicated that all the participants really appreciated the game. They judged Geo+ very attractive and liked the visual appeal of its interface. Pupils felt absorbed in the interaction and lost track of time. Pupils reported a good perception of the usability of the AR application; they experienced a positive

**TABLE 4.** Mean and standard deviation of each USE dimension for the AR application.

	Mean	SD
Aesthetic Appeal (AE)	4.17	0.79
Focused Attention (FA)	3.05	0.72
Perceived Usability (PU)	3.74	0.68
Reward (RW)	4.21	0.73

effect on the result of the interaction and the degree of control and expended effort. Finally, pupils felt adequately rewarded by the usage of the application. In other words, they felt a sense of being “drawn in” the AR application and had fun. Pupils appreciated the novelty of the AR application and were very interested in the interactive task.

#### D. THREATS TO VALIDITY

This section analyses issues that are potential threats to the validity of the experimental study and presents how they were minimized.

The internal validity refers to the extent to which the researcher can be confident that the observed changes in the dependent variable were due to the effects of the independent variable and not to the effects of extraneous variables [26]. The main threats to the internal validity of our study were: 1) the subject effect, 2) the available time, 3) the method authorship, 4) the subject effect, and 5) understandability of the documents.

*Subject Experience:* It was alleviated by the fact that none of the subjects had any experience with the experimented system, as well as with similar systems in general.

*Available Time:* The pilot study showed that 30 mins were adequate to familiarize with the application and effectively interact with it.

*Method Authorship:* We eliminated the biases that different researchers could introduce, as we had the same researcher for every study session. In this way, we reduced any variability in the initial training as well as in the way participants had been observed.

*Subject Effect:* When people know they are being observed, they may behave differently than they normally would. Participants are often sensitive to cues from the researcher. In our case, the researcher was particularly careful in retaining his emotions, both positive and negative, in order to mask any type of signal.

*Understandability of the Material:* A pilot study was performed in order to verify the study methodology. Thus, one of the goals of the pilot study was to verify the understandability of the materials (i.e. questions of pre/post-tests, questions of the final questionnaire, and Geo+ application itself), pupils have to use. The results of the pilot study were instrumental for clearing up all the misunderstandings and alleviated this threat.

The external validity refers to the degree to which researchers can generalize the results of a study to other participants, conditions, times, and places. We think that the participants’ selection and the task complexity, i.e. the main

threats to the external validity, were supervised since pupils, that are the target users of our application, were involved in the study; in addition, they were free to interact with the application, that was analyzed with the teachers, who confirmed its appropriateness to children of 8/9 years old.

The construct validity refers to how well the study results support the theory behind the research study. The construct validity of a study might have been influenced by the reliability of the questionnaire. The pre and post-tests, used for evaluating learning, were defined in collaboration with the teachers thus guaranteeing their understandability and effectiveness. Regarding the questionnaires for evaluating the workload and the engagement, we used the NASA-TLX and the UES short form, which are well-known and thoroughly validated models.

Finally, the statistical validity refers to the question of whether these statistical conclusions are reasonable, i.e., the accuracy of the p-value on which a statistical decision is based. In our study this was addressed by applying the most common tests employed in the empirical software engineering field [26] and by considering a p-value below 0.05.

#### VI. CONCLUSIONS AND FUTURE WORKS

The use of different kinds of technologies is spreading quickly in education, both formal and informal contexts. All those approaches that allow users to be actively involved in the learning process have been demonstrated that are very effective in acquiring both cognitive and metacognitive skills. The AR technology, in particular, allows users to be immerse in a virtual world in which the real situations can be simulated. The research in this article concerns the application of AR technology as support tool in primary school to learn solid geometry. The proposed application, called Geo+, was developed according to a human-centered approach in order to develop an application to be effective in terms of both interaction and content, since this is essential for educational purposes. Geo+ was evaluated with 96 pupils through a user study at school, whose results were very positive on all measured dimensions. Specifically, learning effectiveness was measured: pupils did a greater work in the post-test rather than in the pre-test. The discussion with the teachers pointed out that using the technology for children was so exciting that they were more concentrated on the task. In support of the teachers’ thought there are the results on the Nasa-TLX and UES questionnaires. Data confirmed that pupils appreciated the use of the Geo+ application, they felt a sense of being “drawn in” the AR application and had fun. This confirm what we expected, an AR application creates the so-called “wow factor” which makes pupils feel like they’re in a magical world, which also encourages them to take an interest in the theme of the game. It is worth noticing that a ceiling effect was observed in investigating the learning effect. i.e. the participants’ score in pre and post-test was very high. This highlighted that a different instrument to assess the pupils’ learning before and after the use of the AR application should be used. This issue will be discussed with teachers



in order to identify a more accurate method to use in a next evaluation.

Since the objective of the study presented in this paper was to investigate if Geo+ allows pupils to reinforce their knowledge, a single group pre-test post-test study was performed. However, we are planning a between-subject design study comparing a traditional lesson and the innovative Geo+, in order to verify if and how much Geo+ can substitute the work of teachers and to generalize the discovered findings. In addition, more multimedia contents will be added to show more didactic concept concerning the solid figures, and some questions in order to self-assess her/his knowledge.

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