Computers & Education 145 (2020) 103734

Contents lists available at ScienceDirect

Computers & Education

journal homepage: http://www.elsevier.com/locate/compedu

Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course

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A R T I C L E I N F O

Keywords:
Augmented reality
Motivation
Interactive learning environments
Applications in subject areas

A B S T R A C T

In this paper, the authors show that augmented reality technology has a positive impact on learning-related outcomes of middle-school Mexican students. However, the impact varies depending on whether students were enrolled in public or private schools.

The authors designed an augmented reality application for students to practice the basic principles of geometry, and a similar application which encompasses identical learning objectives and content deployed in a Web-based learning environment. A $2 \times 2 \times 2$ factorial design was employed with 93 participants to investigate the effect of type of technology (web, augmented reality), type of school (private, public), and time of assessment (pre, post) on motivation, and declarative learning. The results show that: (1) there is an interactive effect of type of technology, type of school, and time of assessment when students' achievement scores are measured; (2) students using the augmented reality-based learning environments scored higher in post-test than those using the web-based application; (3) the augmented reality learning environment was more learning effective compared with the web-based learning environment in public schools, but not in private schools; (4) there is not an interactive effect of type of technology, type of school and time of assessment when students' motivation is measured; (5) students from private schools reported higher levels of motivation compared with those from public schools when using the augmented reality learning environment. The research findings imply that in Mexico, augmented reality technology can be exploited as an effective learning environment for helping middle-school students from public and private schools to practice the basic principles of Geometry.

1. Introduction

The availability of specialized human capital is one of the key factors for the development of science, technology, and innovation in the world. Access to quality education for all is the first step in this process (UNESCO, 2013) leading to the importance of learning processes in the areas of science, technology, engineering and mathematics (STEM). Mexico is inhabited by approximately 124 million

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https://doi.org/10.1016/j.compedu.2019.103734
Received 18 May 2019; Received in revised form 15 October 2019; Accepted 16 October 2019
Available online 17 October 2019

individuals, a third of whom (27%) are between 15 and 29 years old. With such a high share of young population, education issues are of prime importance for the country's development (OECD, 2019).

Major features of the Mexican education system include: the dominance of half-day schooling; the difficult social contexts faced by schools; a suboptimal school infrastructure; numerous challenges facing the teaching profession; the limited school autonomy; and considerable funding inequities (Santiago, McGregor, Nusche, Ravela, & Toledo, 2012). The school system is organised in two sequential levels: basic education and upper secondary education. Basic education pertains to three stages: pre-primary education (ages 3 to 5); primary education (grades 1–6); and lower secondary education (grades 7–9). School attendance is mandatory for 15 years. Further adding to the complexity of the system, there are public and private schools, the former are publicly subsidised whereas the latter derive their resources from student fees (Santiago et al., 2012). In the last decade, the Mexican government began to implement educational reforms following the Education Policies Project from the Organisation for Economic Co-operation and Development (Pisa & O.E.C.D., 2015). Despite some progress, students' learning outcomes in Mexico are considerably below the OECD average.

In Mexico, as it is in other countries, striking differences have been observed between students in public and in private schools. In the results obtained in 2015 in the test *Planea* (Mexican Plan for the Evaluation of Learning) in the area of Mathematics, public institutions obtained an average below indispensable and insufficient result, compared to students from private schools who obtained a satisfactory or very satisfactory average result (INEE, 2015). A study carried out by the Pontificia Universidad Javeriana (Castro Aristizabal, Giménez, & Pérez Ximénez-de-Embún, 2016) concluded student characteristics including sex, (non-)repetitive student, and motivation are the most relevant factors which explain educational inequities between public and private schools followed by family characteristics such as number of books at home, and parents' level of education; finally the differences in school resources such as student–teacher ratio, number of students in the school, and autonomy level of the school. The recommendations of the study are aligned with those suggested by the OECD (Pisa & O.E.C.D., 2015) and include (1) coordination with social policies, attention to health, housing and food problems that are articulated to the education system to avoid dropping out of school; (2) involvement of families in the process of educating their children; (3) promotion of an allocation of economic resources that allow students attending public schools to have educational resources similar to those attending private schools. This study follows the aforementioned first and third recommendations in order to analyze whether the use of augmented reality technology in both types of schools promotes motivation and improves learning outcomes mainly in students of public schools when Mexican middle-school students practice basic Geometry concepts.

Given the nature of STEM problem solving, a student's achievement in STEM rests on how capable they are at solving problems that involve reasoning about spatial information. Geometry courses in middle schools have an important role on helping students to reason about spatial information (Stieff & Uttal, 2015). However, understanding Geometry concepts like three dimensional (3D) views have shown to be difficult for students because it involves complex tasks like visualizing an object in 3D space, interpreting and analysing different shapes and orientation of the 3D object (Lamb, Akmal, & Petrie, 2015; Lubinski, 2010). Aids in spatial visualization reduces students' cognitive load when engaging in Geometry-related tasks through the additional cognitive channels to process data (Gonzalez-Castillo et al., 2012; Konstantinou, Bahrami, Rees, & Lavie, 2012).

The technology of augmented reality (AR) might facilitate the understanding of scientific concepts since it supplements the user's sensory perception of the real world by the addition of computer-generated content to the user's environment and offers a new form of interactivity between real and virtual worlds (Azuma et al., 2001; Billinghurst, 2002). Indeed, results of several studies suggest that AR might be helpful in providing a solution to the problem of 3D visualization (Gecu-Parmaksiz, & Delialioglu, 2019; Kaufmann & Schmalstieg, 2002; Kaur et al., 2018; Lee, 2019; Martín-Dorta, Saorín, & Contero, 2008). Therefore, AR technology is potentially useful to reduce students' cognitive load when engaging in Geometry-related tasks.

On the other hand, constructivism learning theory states that learning is an active process in which the learner constructs new knowledge based on current and previous knowledge (Bruner, 1990). Several learning theories are derived from the philosophical framework of constructivism, including discovery-based learning, situated learning, and problem-based learning. AR technologies allow learners the freedom to actively experience digital content and integrate new information into their existing knowledge base, thus engaging on an individualized path of discovery. As such, AR can be used as a powerful mean to constructivist learning (Ibáñez, Di-Serio, Villarán-Molina, & Delgado-Kloos, 2015; Robinson & Coltz, 2013).

Finally, potential advantages of AR technology include its capabilities to promote psychological states in learners, which might positively impact learning outcomes (Csikszentmihalyi, 2014; Keller, 1987). Motivation, "a source of energy that is responsible for why learners decide to make an effort, how long they are willing to sustain an activity, how hard they are going to pursue it, and how connected they feel to the activity" (Rost, 2006), is among these learning-promoting psychological states, The success of AR-based learning activities on promoting students' motivation has been reported on several studies (Cascales-Martínez, Martínez-Segura, Pérez-López, & Contero, 2017; Chang & Hwang, 2018; Georgiou & Kyza, 2018). However, the motivation for AR-based learning activities has not always been accompanied by improvements in student learning (Erbas & Demirer, 2019; Ibáñez et al., 2015).

The study presented in this paper was designed to investigate the use of augmented reality to practice basic concepts of Geometry by middle-school students from Mexican public and private schools. There were two research objectives for this study:

1. To explore the impact of AR on learning outcomes of students from public and private Mexican schools.
2. To explore the impact of AR on motivation of students from public and private Mexican schools.

This article starts by presenting the design of the learning application (Section 2). Then, it shows the design of the experiment (Section 3). Section 4 presents the results and data analysis of the evaluation of the study. Finally, conclusions are outlined in Section 5.

This study is unique in that it investigates the use of AR technology within real school settings for practicing Geometry at middle-school level, while also comparing an AR-based application to a Web-based application. The study is carried out in two different socio-economic Mexican contexts: public and private schools. The study can help us learn to what extent AR technology can be effective in promoting students' motivation and improving learning outcomes in two socio-economic contexts.

2. Learning application

The authors designed a learning application following the guidelines set by the official program that Mexican schools must use to teach Geometry. The official program not only defines objectives but also key activities that students must perform. The application was designed following these official guidelines with the aim of allowing students to practice basic concepts of Geometry.

Students had access to three types of exercises, and they had to achieve a minimum score in each part to successfully complete the learning activity.

- The first type of exercise requires that students recognize a geometric body among a set of regular prisms, namely triangular, square, pentagonal, hexagonal, decagonal, and cylinder. Once the student correctly recognizes the geometric body, the corresponding 3D prism representation appears on the screen. Then, the application displays a basic calculator along with information that the student must use to calculate, first the area of prism base and then, the prism's volume. If the student makes a mistake providing an incorrect value, the application shows a message with the corresponding formula to help him or her to get the correct answer.
- The second type of exercise allows students to figure out how many times a given prism can be contained in a bigger prism of the same type. The student is asked to fill the bigger prism with as many copies of the smaller prism as possible. As the student performs the activity, he or she observes the ratio among the volume of both prisms, and the amount of volume that still hast to be filled.
- The third type of exercise consisted in identifying cut sections of geometric bodies. A geometric body could be cut in three different forms namely parallel, oblique, and perpendicular to the base. The student must identify in a limited amount of time the two pieces of the geometric body that were initially shown, among several incomplete figures that appear on the screen.

The learning application was deployed as an image-based AR application named ARGeo (see Fig. 1) and as a Web-based application named WebGeo (see Fig. 2). The difference between the deployments is twofold. First, the mechanism to choose among different options is performed with image targets in ARGeo and with menus in WebGeo. Second, students are able to visualize 3D figures from any point of view in real time when using ARGeo whereas WebGeo presents students a static representation of figures with no possibilities for interaction.

3. Method

Two different applications were developed to support the learning activity: one application was Web-based; the other application used image-based AR technology. Both applications offered the same educational content and followed the same workflow according to participants' preferences and their answers to assessment items.

Two types of schools were considered: public and private. The learning activity was mandatory for the students of both schools, pending the previous signing of an informed consent from every student. Parents were also notified of the activity, and participation also required parental consent. Students of both schools followed the same Geometry curriculum.

In this study, the specific research questions aim to explore whether type of technology (AR, Web) and type of school (private, public) significantly affect learning outcomes and motivation of students taking a basic Geometry course.

3.1. Participants

In this study, 93 middle-school students (age 13–15, $M = 4.56$, $SD = 1.64$) from one private and two public Mexican schools were surveyed during the months of April and May 2018 (see Table 1). A text document was provided to students and their parents outlining

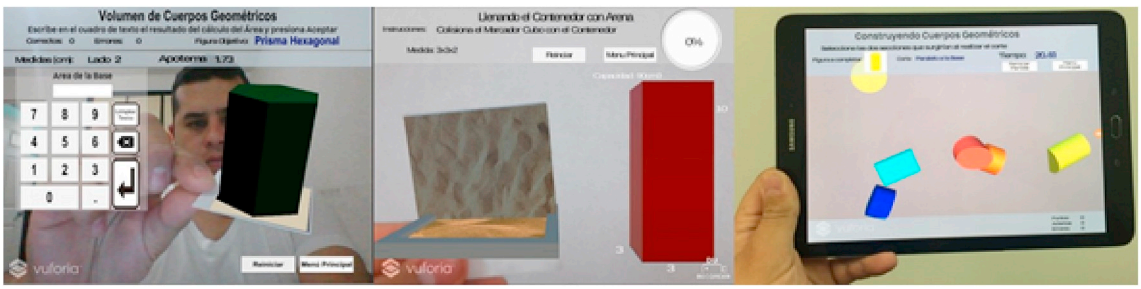

Fig. 1. Stages of the learning activity within ARGeo.

Fig. 2. Stages of the learning activity with WebGeo.

the purpose of the research and their right to withdraw at any moment. Informed consent was obtained from every participant. After the data collection phase, 3 cases from Colegio Sinaloa Guadalupe were censored from the analysis due to missing data.

3.1.1. Samples equivalence

Both for public and for private schools, the results of skewness and kurtosis were public (Sk = 0.262, K = −0.316) and private (Sk = −0.092, K = −0.419) meaning that normality is satisfied. These results indicate that the difference in students' background knowledge may come from a normally distributed population. Therefore, it was determined that parametric tests could be used for the evaluating the remainder of the analyses.

The independent samples *t*-test was conducted to compare students' background knowledge between students from public and private schools. The result indicated that there was no a statistically significant difference between students from public ($M = 4.00$, $SD = 1.42$) and private schools ($M = 5.14$, $SD = 1.67$), $t(90) = 3.481$, $p = .328$. Therefore, students from public and private schools had similar background knowledge about Geometry before the intervention.

3.2. Measurement instruments

3.2.1. Pretest and posttest questionnaires

To assess the effectiveness of the interventions on learners' basic Geometry concepts, knowledge pretest and posttests were conducted and analyzed. The pretest and posttest were comprised of 8 multiple-choice questions, each worth 1.25 points. Tests were designed by researchers and examined as to content validity by teachers of the middle-schools taking part in the study. An example of a question from these tests is listed as follows:

Sample question:

"If the radius of a cylinder is 2 cm and the height is 7 cm, what is the volume of the cylinder?

(a) 125.6 cm^3
(b) 87.96 cm^3
(c) 197.42 cm^3
(d) 175.84 cm^3 "

3.2.2. Motivational survey

To assess students' motivation toward the instructional material used, students completed the 36 items of the IMMS survey (Keller, 1987), with 5-point Likert-scale items. IMMS survey comprises 12 items to measure Attention; 9 items to measure Relevance; 9 items to measure Confidence and 6 items to measure Satisfaction (ARCS).

3.3. Procedure

One week prior to the intervention, all students received two instructional sessions of 100 min. During these sessions, students received instruction related to the concepts involved in the activity. The instructions were given by their respective teachers following the same Mexican Geometry curriculum. During the last 20 min of the second session, students completed the pretest questionnaire.

In the subsequent week, students were randomly assigned to any one of the two groups (control or experimental). Each student

Table 1
Educational institutions and participants.

School name	Type of school	Number of students	Experimental Group	Control Group
Colegio Sinaloa Guadalupe	Private	48	24	24
Secundaria Técnica # 92	Public	18	9	9
Secundaria 24 de Agosto	Public	27	14	13
TOTAL		93	47	46

received a tablet with the corresponding application installed, and general instructions to proceed. The control group received a Web-based application, whereas the experimental group received the AR-based application. The learning activity lasted 50 min. Throughout this time, students received technical and procedural help from the researchers and their teachers, respectively. After the completion of the learning activity, students from both groups completed a knowledge posttest questionnaire and the motivation survey. The maximum amount of time given for the completion of the questionnaire and survey was 20 min for each of them (see Fig. 3).

4. Results and data analysis

4.1. Type of experiment, type of school and learning improvement

A mixed-design Three-Way ANOVA was conducted to compare the main effects of Type of Experiment, Type of School and Time of Test and the interaction effect between two or three of these factors on the Geometry Achievement Scores. Type of Experiment and Type of School are Between Subjects factors, whereas Time of Test is a Within-Subjects factor. Type of Experiment included two levels (control, AR), Type of School included two levels (public, private), and Time of Test consisted of two levels (pretest, posttest).

The analysis revealed that Time of Test affected student's achievement scores significantly and independently ($F(1,86) = 283.37$, $p < .001$, partial $\eta^2 = 0.767$), such that, as expected, student's achievement scores were higher in the posttest ($M = 8.02$, $SD = 1.77$) compared with the pretest ($M = 5.14$, $SD = 1.67$). This was qualified by interaction between Time of Test and Type of Experiment ($F(1,86) = 9.69$, $p = .003$, partial $\eta^2 = 0.101$). The predicted interaction among Type of Experiment, Type of School and Time of Test when measuring student's achievement scores was significant ($F(1,86) = 12.36$, $p = .001$, partial $\eta 2 = 0.126$). To decompose the three-way interaction, we computed two separate 2 (Type of Experiment) x 2 (Time of Test) mixed ANOVAs, one for private schools (Fig. 4) and one for public schools (Fig. 5).

In the private school condition (Fig. 4), the main effect of Time of Test was significant ($F(1,43) = 173{,}71$, $p < .001$, partial $\eta^2 = 0.802$). As expected, mean students' posttest achievement scores ($M = 8.02$, $SD = 1.77$) was higher compared with students' pretest achievement scores ($M = 5.13$, $SD = 1.67$). Neither of the main effect of Type of Experiment nor the interaction between Time of Test and Type of Experiment were significant ($Fs < 0.09$, $p > .7$). Therefore, results suggest that students from private schools improved their learning outcomes with time. However, neither the experimental nor the control group showed significant differences on posttest achievement scores.

In the public school condition (Fig. 4), the main effect of Time of Test was significant ($F(1,43) = 114.43$, $p < .001$, partial $\eta^2 = 0.73$). As expected, mean students' posttest achievement scores ($M = 6.44$, $SD = 1.5$) was higher compared with students' pretest achievement scores ($M = 4.0$, $SD = 1.4$). The main effect of Type of Experiment was significant ($F(1,43) = 6.08$, $p < .001$, partial $\eta^2 = 0.124$). As expected, achievement scores of students following the AR condition ($M = 6.44$, $SD = 1.50$) were higher compared with scores achieved by students in the control group ($M = 4.00$, $SD = 1.42$) and the difference was significant ($p < .001$). Importantly, we found the Time of Test x Type of Experiment interaction significant ($F(1,43) = 20.9$, $p = .001$, partial $\eta 2 = 0.33$). A pairwise comparison showed that at pretest condition there was a small difference in achievements scores between control ($M = 4.13$, $SD = 1.6$) and AR group ($M = 3.86$, $SD = 1.21$). By contrast, AR students' group had much higher achievement scores ($M = 7.38$, $SD = 1.01$) compared with the control group ($M = 5.54$, $SD = 1.34$). In both cases, the differences were statistically significant ($p < .05$). Therefore, results suggest that students from public schools improved their learning outcomes with time, and this improvement was higher on those students allocated to the experimental (AR application) arm of the study compared to those allocated to the control group.

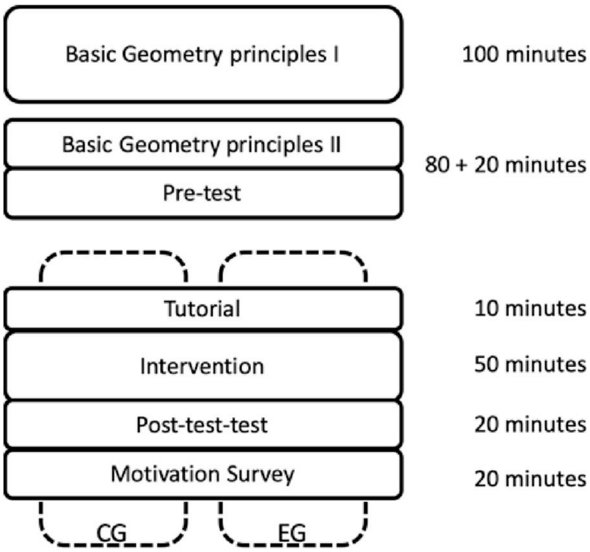

Fig. 3. Steps of the intervention.

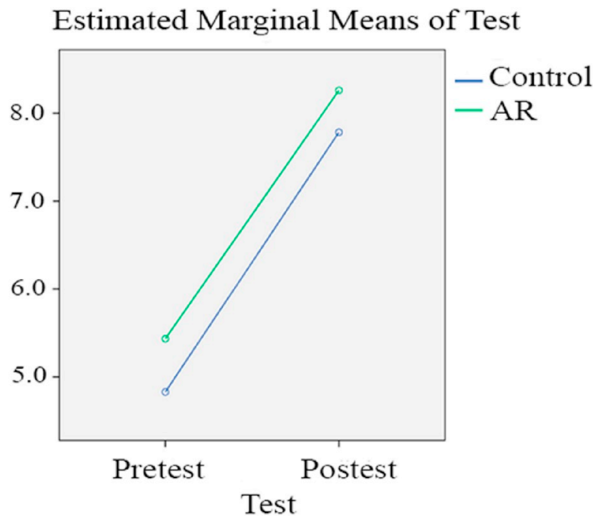

Fig. 4. Estimated Marginal Means of Time of Test and Type Experiment for private schools.

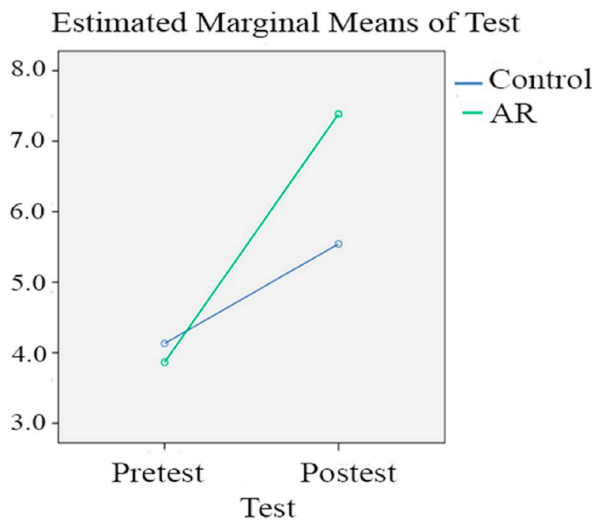

Fig. 5. Estimated Marginal Means of Time of Test and Type Experiment for public schools.

4.2. Type of experiment, type of school and instructional material motivation

Technology might contribute to motivation of students toward learning activities in STEM subjects, but that effect might be different across different types of schools. A two-way analysis of variance tested the level of motivation of students whose learning activities were performed using a Web-based or an AR-based Geometry application, and students who attended public or private schools. Four factorial Two-way ANOVAs were conducted to compare the main effects of type of school and type of experiment and the interaction effect between school and experiment on the reporting value of motivation toward learning technology.

A two-way ANOVA was conducted in order to evaluate the effect of type of school and type of experiment on motivation. An interaction between type of experiment and type of school could not be demonstrated, $F(1,86) = 2.2$, $p = .14$. There was a statistically significant difference between public and private schools ($F(1,86) = 11.29$, $p < .005$). Private schools reported higher levels of motivation ($M = 4.4$, $SD = 0.5$) compared with public schools ($M = 3.79$, $SD = 0.55$). A statistically significant difference between AR experimental group and web control group ($F(1,86) = 32.6$, $p < .005$) was also found. As expected, the AR experimental group reported higher levels of motivation ($M = 4.19$ $SD = 0.44$) compared with the control group ($M = 3.69$, $SD = 0.42$). A deeper análisis was conducted to compare the main effects of type of school and type of experiment and the interaction effect between school and experiment on the reporting value of each motivation factor (attention, relevance, confidence, and satisfaction) considered in the IMMS survey (Keller, 1987).

4.2.1. Attention

A two-way ANOVA was conducted in order to evaluate the effect of school and type of experiment on attention's motivation factor. An interaction between type of experiment and school could not be demonstrated, $F(1,86) = 3.6$, $p = .06$. There was no statistically significant difference between public and private schools ($F(1,86) = 2.38$, $p = .12$). However, a statistically significant difference between the AR experimental group and web control group ($F(1,86) = 48.46$, $p < .005$) was found. As expected, the augmented reality experimental group reported higher levels of attention ($M = 4.37$, $SD = 0.52$) compared with the control group ($M = 3.6$, $SD = 0.55$).

4.2.2. Relevance

A two-way ANOVA was conducted in order to evaluate the effect of school and type of experiment on relevance's motivation factor. An interaction between type of experiment and school could not be demonstrated, $F(1,86) = 1.48$, $p = .22$. There was statistical significant difference between public and private schools ($F(1,86) = 13.0$, $p < .005$). Private schools reported higher levels of relevance ($M = 4.18$, $SD = 0.53$) than public schools ($M = 3.82$, $SD = 0.44$). A statistically significant difference between the augmented reality experimental group and the web control group ($F(1,86) = 10.19$, $p < .002$) was also found. As expected, the augmented reality experimental group reported higher levels of relevance ($M = 4.16$ $SD = 0.44$) than the control group ($M = 3.84$, $SD = 0.53$).

4.2.3. Confidence

A two-way ANOVA was conducted that examined the effect of school and type of experiment on confidence's motivation factor. An interaction between type of experiment and school could not be demonstrated, $F(1,86) = 0.62$, $p = .4$. Unexpectedly, a statistical significant difference between type of experiment was not found ($F(1,86) = 1.1$, $p = .29$). Confidence is the only motivation factor which is not impacted by the learning technology used. A statistically significant difference between public and private schools ($F(1,86) = 8.7$, $p < .005$) was found. Following the trend of the rest of the factors, students of private schools reported higher levels of confidence ($M = 3.96$, $SD = 0.51$) than students from public schools ($M = 3.62$, $SD = 0.51$).

4.2.4. Satisfaction

A two-way ANOVA was conducted that examined the effect of school and type of experiment on satisfaction's motivation factor. An interaction between type of experiment and school could not be demonstrated, $F(1,86) = 0.83$, $p = .36$. There was a statistically significant difference between public and private schools ($F(1,86) = 7.9$, $p = .006$). Consistent with the rest of results, private schools reported higher levels of satisfaction ($M = 4.18$, $SD = 0.62$) than public schools ($M = 3.85$, $SD = 0.65$). There was a statistically significant difference between augmented reality experimental group and web control group ($F(1,86) = 50.9$, $p < .005$). As expected, the augmented reality experimental group reported higher levels of satisfaction ($M = 4.4$ $SD = 0.53$) than the control group ($M = 3.63$, $SD = 0.52$).

5. Discussion and conclusions

In this study we sought to investigate the learning effectiveness and motivation appeal of an AR activity targeting the Geometry subject. To this end, we created the ARGeo learning platform where students of public and private schools practiced basic Geometry concepts.

Regarding the learning effectiveness of AR-based activity compared to the Web-based activity, after conducting a statistical analysis on the pre- and post-test scores, results show that students who used the AR application performed significantly better compared with those who used the web-based application. Our findings meet outcomes of other studies in which AR contributed to improving learning outcomes in STEM subjects compared with other teaching methods (Akçayır, Akçayır, Pektaş, & Ocak, 2016; Cai, Chiang, Sun, Lin, & Lee, 2017; Frank & Kapila, 2017; Huang, Chen, & Chou, 2016; Ibáñez, Di-Serio, Villarán, & Delgado, 2016). Further studies are necessary to identify what specific AR features and affordances may influence students' learning in Geometry. These encouraging results hold true for the group of students coming from the public schools. Unexpectedly, the difference of learning effectiveness between AR-based activity and Web-based activity on students from private schools was not statistically significant. Therefore, results suggest that the use of AR-based learning environments can be more effective compared with web-based learning environments for students coming from public schools. However, further studies with a more robust sample size are necessary to elucidate why the use of AR by students from private schools does not establish a significant advantage in terms of learning effectiveness.

With respect to the motivation toward instructional material, the statistical results of this study indicate that participants who used the AR-based application were more likely to experience motivation toward the learning activity compared with those using the web-based application. This result is consistent with results of other studies that claim that AR-based applications promote higher levels of motivation than Web-based applications (Akçayır et al., 2016; Bursztyn, Walker, Shelton, & Pederson, 2017; Cascales-Martínez et al., 2017; Gopalan et al., 2015; Tarng, Ou, Yu, Liou, & Liou, 2015). When comparing the motivation between students from private and public schools with no discrimination between type of experiment, it was found than students from private schools reported higher levels of motivation toward the learning activity than those from public schools. This result is not consistent with the aforementioned experimental results about learning achievement where students from public schools had better learning achievement than those from private schools. However, the result is consistent with the findings of the OECD (OECD, 2019) where Mexican students report good levels of motivation toward science topics, but motivation is not aligned with their performance in science. Further studies are necessary to understand this misalignment between learning achievement and motivation.

A deeper analysis of the four motivation factors underlying users' motivation experiences showed that AR-based learning activities fostered higher levels of attention, relevance, and satisfaction than Web-based learning activities; this trend was not kept by the confidence factor. According to the ARCS model (Keller, 1987), learners should build confidence by feeling control and expectancy for success. Results suggest that AR technology did not foster better levels of confidence than web-based technology. Further research is necessary to understand whether students feel in control when using AR technology, and whether their perception about success in doing AR-based learning activities is an obstacle to achieve better levels of confidence. Results also show that students from private schools reported higher scores in relevance, confidence and satisfaction. These results are consistent with the results previously reported on motivation as a whole measure.

The results of this study must be appraised in light of some limitations. First, it involved short-term retention of basic principles of Geometry; it is likely that a long-term retention evaluation would have provided more insight into the effectiveness of the AR-based learning activities because the novelty effect could be to some degree responsible for the results shown. Second, data collected were self-reported. Third, before the intervention, students received instruction about basic principles of Geometry by their instructors. Although instructors followed the same lesson script, each one of them might have caused a different impact on his or her course section. Last, it is important to point out that this study includes a limited sample size, and that a larger, multi-centric study must be designed and carried out in order to draw more robust conclusions.

Based on the results presented in this study, it can be concluded that the AR-based application was more effective than the Web-based application both promoting students' knowledge of basic principles of Geometry and also in fostering motivation toward the instructional material. Results also suggest that AR applications can be used as effective learning tools within Geometry courses in Mexican public schools. However, AR technology and Web tecnology seems to be equally effective to improve learning outcomes of Mexican students coming for private schools in Geometry courses.

Acknowledgements

The work described in this paper is fully supported by a scholarship from CONACYT (Consejo Nacional de Ciencia y Tecnología) in México and a grant from PRODEP. This work was supported in part by the Spanish project EEE CICYT (TIN2011-28308-C03-01), RESET-UC3M: Reformulando Ecosistemas Escalables Educativos under grant no. CICYT (TIN2014-53199-C3-1-R), by the Madrid Regional Government (eMadrid-CM Project under grant no. P2018/TCS-4307) funded by the Agencia Estatal de Investigación (AEI) and Fondo Europeo de Desarrollo Regional (FEDER), and by the Spanish Ministry of Economy and Competiveness (Smartlet project, grant number TIN2017-85179-C3-1-R) funded by the Agencia Estatal de Investigación (AEI) and Fondo Europeo de Desarrollo Regional (FEDER).

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