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# Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course

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A R T I C L E I N F O

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A B S T R A C T

The purpose of the current research was to explore the effect of an augmented reality app on the academic level, motivation, and technology acceptance of students of a university-level chemistry course. The study followed a pre/post-test design with a control group. At the end of a lecture on carbon bonds, we requested 95 university students to develop three models using modeling clay. The experimental group used the augmented reality app, while the control group used 2D pictures. The academic achievement increased for the students who used the augmented reality app. Motivation scores were not different between the control and experimental group. Our results indicate that augmented reality technology could be helpful in an academic setting.

## 1. Introduction

Augmented Reality (AR) combines the real world with virtual objects so that the virtual objects coexist in the same space as the real world (Azuma, 1997, 2001). AR differs from Virtual Reality (VR) in that AR devices overlay digital content onto the physical world. In contrast, VR devices are entirely closed off from the physical world, presenting a synthetic 3D virtual world (Wang, Callaghan, Bernhardt, White, & Peña-Rios, 2018). According to Azuma et al. (2001), AR has three characteristics: it combines real and virtual objects in a real environment, runs interactively in real-time, and registers real and virtual objects with each other.

AR technology has been used in assembly (Curtis, Mizell, Gruenbaum, & Janin, 1998), medical applications (Barsom, Graafland, & Schijven, 2016; Eckert, Volmerg, & Friedrich, 2019; Zhao, Ong, & Nee, 2016), marketing (Huang & Liao, 2017), tourism (Fenu & Pittarello, 2018; Jingen Liang & Elliot, 2021), entertainment (Arino, Juan, Gil-Gomez, & Molla, 2014; Thomas, 2012), and educational settings (Frank & Kapila, 2017; Pribeanu, Balog, & Iordache, 2017).

The use of AR in education environments is supported by the psychological theory known as constructivism, which states that learning is an active process for students to construct new knowledge based on previous knowledge (Bruner, 1990). A learning environment based on the principles of the constructivist theory is bound to be interactive and dynamic, allowing students to modify the elements in their environment to try ideas and implement experiments (Dunleavy & Dede, 2014; Roussou, 2004). AR allows the creation of such learning environments since it creates the opportunity for students to be active in the process (Kirner, Reis, & Kirner, 2012; Wojciechowski & Cellary, 2013; Yilmaz & Goktas, 2017; Yuen, Yaoyuneyong, & Johnson, 2011) and to experiment with the material to be learned (Ibáñez, Di-Serio, Villarán-Molina, & Delgado-Kloos, 2015; Robinson & Coltz, 2013) through learning-by-doing, which can be more effective to allow the understanding and retention of the material when compared with traditional teaching methods (Yang, 2012).

On the other hand, the use of AR in the learning context can have a positive emotional impact on students, so it improves their cognitive processes and academic performance (Csikszentmihalyi, 1990; Efklides, Kuhl, & Sorrentino, 2001; Ibáñez, Uriarte, Zatarain, & Barrón, 2020; Linnenbrink & Pintrich, 2002; Qingtang, Shufan, Chen, Wang, & Xu, 2021; Sumadio & Rambli, 2010). Additionally, it increments their attention, motivation, and satisfaction (Chang & Hwang, 2018; Di Serio, Ibáñez, & Kloos, 2013; Erbas & Demirer, 2019; Furió, Juan, Seguí, & Vivó, 2015; Hung, Chen, & Huang, 2017; Ibáñez, Di Serio, Villarán, & Kloos, 2014).

Another benefit of the use of AR in education is that it allows the creation of scenarios that are difficult to be available in real life (Wojciechowski & Cellary, 2013; Wu, Lee, Chang, & Liang, 2013), and it allows students to stay in control of the virtual environment which can increase their self-confidence and self-efficacy (Bujak et al., 2013; Chang

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& Chuang, 2011; Verhagen, Swen, Feldberg, & Merikivi, 2015).

AR in education can be especially beneficial when learning abstract and invisible concepts since it allows the student to visualize and manipulate the material to learn (Chen, Chi, Hung, & Kang, 2011; Chiu, DeJaegher, & Chao, 2015). In addition, studies show that learning this type of concept through AR is more effective than using printed materials or desktop software (cf. Radu, 2014).

Several studies show that many students have difficulties understanding abstract concepts in areas such as chemistry (Kozma & Russell, 1997; Mahaffy, 2015; Wu et al., 2013; Cardellini, 2012; Woldeamanuel, Atagana, & Engida, 2014; O'Dwyer & Childs, 2017). Some reasons for that could be that traditional materials have two dimensions to represent the chemical concepts, and the understanding of these concepts implies the 3D representation of the spatial structure of the molecules (Maier & Klinker, 2013). The use of AR technology for teaching chemistry can improve the understanding of the spatial structure of molecules (Maier, Tönnis, & Klinker, 2009, pp. 943–6114) since it allows the visualization of abstract elements from different angles (Arvanitis et al., 2007; Dunleavy, Dede, & Mitchell, 2009).

## 2. Related work

### 2.1. AR technologies in education

According to Wang et al. (2018), AR devices can broadly be divided into three categories: (1) wearable, (2) handheld, and (3) fixed.

(1) Wearable AR technologies are related to portable personal electronic devices with processing power that can record an activity done by the wearer, including head-mounted displays and gesture-recognition devices. Head-mounted displays are technologically complex devices worn on the head, which allow the user to see an augmented view of reality through a digitally-enhanced viewfinder (Novak-Marcincin, Barna, Janak, & Novakova-Marcincinova, 2013). Gesture-recognition devices interpret the motions of a human body interface, augmenting the real world using natural gestures.

(2) Handheld technology includes mobile devices like tablets and smartphones. In recent years, mobile technology has become more accessible and available; it has increased its processing power and multimedia capabilities, allowing AR learning experiences to become increasingly accessible in various educational settings.

(3) Fixed technology refers to AR technology displayed on a computer screen. Although this technology has some disadvantages, such as a lack of portability, this type of AR display is an economically low-cost alternative. In addition, a fixed-screen display can be an ideal entry point to AR learning possibilities for the classroom by utilizing an existing computer monitor.

### 2.2. AR in educational settings

The main advantages reported in research studies using AR in educational settings are L*earning gains* and *motivation* (Di Serio et al., 2013; Erbas & Demirer, 2019; Furió et al., 2015; Hung et al., 2017; Ibáñez et al., 2014; Ibáñez et al., 2020; Qingtang et al., 2021). Regarding *Learning* gains, several studies reported that students improved their academic performance using AR technology compared to traditional approaches (Ibáñez et al., 2020; Qingtang et al., 2021). In addition, several studies stated that students felt more motivated using AR applications than other pedagogical tools (Di Serio et al., 2013; Erbas & Demirer, 2019; Furió et al., 2015; Hung et al., 2017; Ibáñez et al., 2014). For example, a review of AR applications in educational settings (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014) shows that 30% of the studies (from 30 studies) reported *motivation* as one of the main advantages of AR in educational settings. In the same way, Garzón, Pavón, and Baldiris (2019) present a systematic review of AR in educational settings, where the authors found that the second most commonly reported advantage of using AR in educational settings is *motivation.* Other advantages reported in the literature are long-term memory retention, improved collaboration, increased attention, and enhanced problem-solving skills (Diegmann, Schmidt-Kraepelin, Eynden, & Basten, 2015; Guntur, Setyaningrum, Retnawati, & Marsigit, 2020; Radu, 2014).

Most studies using AR in education have been in primary, high school, and higher education (Garzón, J., Pavón, J., & Baldiris, S., 2019; Bacca et al., 2014). In primary education, AR systems allow students to learn while playing, motivating them to learn complex concepts. In high school, AR allows teachers to explain different concepts. Finally, in Bachelor's students, AR allows students to learn abstract concepts that are difficult to understand without the help of AR.

For example, Xiao, Xu, Yu, Cai, and Hansen (2016) present the Starry Sky Exploration AR system to teach astronomy to primary school students using AR technologies. The system has an observation module, where students use mobile devices to scan an AR identification card to view the distinguishing characteristics of the planets. Then, students see a 3D planet using the camera on a mobile device to capture the image on a symbol card. A pilot test of the system showed that students' attention indicators increased gradually, and follow-up student interviews revealed high student satisfaction (Xiao et al., 2016).

The work of Santana, Juárez, and Magaña (2013) proposes a mobile augmented reality system for Mexican high school students, allowing students to access additional educational content related to their textbooks. The AR application recognizes the augmented tags in the book and shows multimedia (3D models, video, and text) content to complement the topics covered in the class. Results from a usability evaluation with 29 high school students show that 79% prefer 3D models as their preferred augmented content, followed by video content with 21%. In addition, 62% of participants commented that AR systems could improve their learning.

On the other hand, the work of Ibáñez, Di Serio, Villarán & Delgado Kloos (2014) presents an AR application for teaching the basic concepts of electromagnetism in high school. Students use a tablet to see superimposed information, such as electromagnetic forces or circuit behavior. This research shows that AR improved academic achievement and provided instant feedback.

This body of literature shows how mobile AR technology can increase motivation and support academic achievement in different subjects and at several educational levels, such as primary and high school. Next, we describe how AR technology can support teaching chemistry topics.

### 2.3. AR in chemistry topics

Since learning chemistry depends on understanding the spatial structures of the chemical compounds and require to visualize specific microstructures (Singhal, Bagga, Goyal, & Saxena, 2012) several studies have explored the effect of AR technology on learning chemistry topics. For example, Fjeld et al. (2007) developed an AR application that uses a Tangible User Interface for organic chemistry education. The authors compared the application's learning effectiveness and user acceptance versus the ball-and-stick model (BSM), a molecular model of a chemical compound that represents in 3D the position of atoms and the bonds between them. They found that learning effectiveness was almost the same for both learning environments. Regarding user acceptance of the application, they found that the ease of learning the system, ease of use, helpfulness in problem-solving, and comfort of use, the participants preferred the ball-and-stick model to the application. In terms of enjoyability, visualization, content availability, future use, and learning effectiveness, the students chose the application versus the BSM.

Iordache, Pribeanu, and Balog (2012) developed an AR Teaching Platform. Students in seventh grade tested the tool and answered a questionnaire of 10 questions about the capabilities of the platform that support understanding and learning of several chemistry concepts and their perceived utility. They found that students could better understand

and learn chemistry with less effort by using the AR platform.

Singhal et al. (2012) developed an AR system to increase the understanding of 3-D Chemistry modeling and spatial arrangement of molecular structures in space to school-level students. Based on observation during exhibitions, the authors reported that they could conclude that the students enjoy the system and gain more knowledge of molecular structures.

Cai, Wang, and Chiang (2014) examined the effect of an AR tool on the learning of chemistry of high school students. The authors conducted a pre-post-test design study. Participants answered a quiz on microparticles before and after using the AR tool. The students' scores after using the AR tool were higher than those obtained before the learning activity. The author also measured the attitude toward the AR tool and found that students generally have positive attitudes.

Vega Garzón, Magrini, and Galembeck (2017) developed an AR application to promote acquiring the necessary skills to understand the basic concepts of the biochemistry of university students. The app has two modes: the Study and the Game modes. The authors presented results of the glycolysis study mode. The percentage of students who answered the test without mistakes was above 50 for 9 of 10 questions.

Another body of literature shows that in several studies that use AR technology to teach chemistry, the attitude of students and teachers towards using this type of technology is overall positive. For example, Núñez, Quirós, Núñez, Carda, and Camahort (2008) explored the students' opinions about an AR system for teaching Inorganic Chemistry at university-level. In general, the students thought AR was useful for understanding crystalline structures. However, half of the students complain about not having the system installed in the classroom permanently.

Wojciechowski and Cellary (2013) conducted a study with second-grade secondary school participants. Participants performed chemical experiments using an AR system. In addition, the authors explored the students' attitudes toward using the AR system. They found that perceived usefulness and enjoyment had a similar effect on attitudes toward using AR, and perceived enjoyment was a more significant factor than perceived usefulness regarding the intention to use the AR system.

Crandall, Engler III, Beck, Killian, O'Bryan, Jarvis, and Clausen (2015) found similar results with students of a chemistry course at the senior level and faculty members. After a week of using an AR-based game, the participants completed a questionnaire on the game's usability and user experience. There was a preference for the game instead of the standard lecture format.

Yang, Mei, and Yue (2018) explored teachers' perceptions of mobile augmented reality-assisted chemical education. The authors found that the teachers generally had a positive attitude toward the immersive chemistry learning experience.

In other studies, the development of AR-based technology for teaching chemistry has been described, but its effect has not been reported (Chen, 2006; Fjeld & Voegtli, 2002; Taçgin, Uluçay, & Özüağ, 2016).

Some limitations of the previous studies focused on teaching chemistry topics using AR technology include the lack of a control group (Cai et al., 2014; Iordache et al., 2012; Vega Garzón et al., 2017), the lack of a dependent variable measurement before the use of the AR technology (Fjeld et al., 2007; Iordache et al., 2012; Vega Garzón et al., 2017), and the subjective measures of learning (Singhal et al., 2012).

Furthermore, the success of AR technology in a learning setting could be determined by the students' and teachers' acceptance and intention to use the technology. Although AR is not a new technology, it could be different from the materials commonly used by education professionals. Thus, one of the challenges related to using AR could be the resistance to change of teachers and staff (Kerawalla, Luckin, Seljeflot, & Woolard, 2006).

Finally, most studies captured the qualitative perception of the AR technology acceptance, asking open questions to participants. However, few studies explore technology acceptance using standardized questionnaires such as the Technology Acceptance Model (TAM) (Wojciechowski & Cellary, 2013).

The purpose of the current research was to explore the effect of an AR mobile application on the academic level, motivation, and technology acceptance in university students of a chemistry course.

The research questions that guided the present research are:

- What is the effect of an AR application on the academic performance of university students in a chemistry course?
- What is the effect of an AR application on university students' motivation in a chemistry course?
- How do university students perceive the acceptance of the AR application regarding usefulness and ease of use in a chemistry course?

## 3. Materials and methods

### 3.1. Participants

This study involved 95 university students in Colombia: Fifty-four males and 41 females (min age = 16, max age = 20). The students took a chemistry course at three universities; two were public schools, and one was private.

### 3.2. Data collection instruments

#### 3.2.1. Academic test

Two chemistry professors developed two academic tests to explore the AR app's effect on students' academic performance.

The different tests were developed in two phases. First, two professors created sixteen multiple-choice items on carbon bonds. Second, three chemistry experts reviewed the items. Based on the feedback, some questions were edited. Eight questions were included in test A, and the other eight were included in test B. Test scores ranged from 0 to 8 based on the number of correct answers.

Four chemistry experts evaluated the clarity, coherence, and relevance of each item of the two academic tests using a Likert scale from 1 to 4 (one is completely disagree and four is completely agree). In addition, each expert evaluated each item's writing style and difficulty, and the considered adjustments were made.

#### 3.2.2. Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis (1989), is a standardized questionnaire commonly used in technology acceptance studies (Marangunic, N. & Granic, A., 2015; Sun & Cheng, 2009; Teo, 2009). The TAM suggests that the acceptance of a technological system is related to the intention to use, determined by the evoked user's perceptions of the usefulness and ease of use of the technology and cognitive and emotional states. Perceived usefulness and ease of use impact the attitude, leading to technology adoption behavior (Davis, 1989). The TAM evaluates the technology's perceived usefulness and ease of use using a Likert scale from 1 to 7 (one is completely disagree and seven is completely agree). Higher scores reflect higher perceived usefulness and ease of use (Appendix 1).

#### 3.2.3. Instructional materials motivation survey (IMMS)

The Instructional Materials Motivation Survey (IMMS) (Keller, 2010) is a 36-item scale ranging from 1 (not true) to 7 (very true). The total score ranges from 36 to 180 points, higher scores indicate a higher motivation. The scale consists of four subscales, attention (α: 0.83), relevance (α: 0.81), satisfaction (α: 0.92), and confidence (α: . 90). Twelve items focus on attention, specifically how the material attracts and maintains attention. Nine items focus on relevance, how well the information links to the learner's prior knowledge and experience, perceived needs, and potential future applications. Nine items focus on confidence and how the materials assure the terming will succeed. Finally, six items focus on satisfaction and perceived enjoyment during and after the course (Appendix 2).

#### 3.2.4. System usability scale (SUS)

The System Usability Scale (SUS) (Brooke, 1996) is a 10-item scale that uses a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The final score is on a scale of 0–100. The goal of the SUS is to evaluate a system's usability. The questions focus on the user's level of agreement with statements about the characteristics of the technology, such as the system's complexity. The SUS questionnaire is an inexpensive standardized method that allows researchers to uncover usability problems in the initial stage of technology design (Lewis, 2018). See Appendix 3.

### 3.3. App design

Chemical bond models were developed in Blender, a free and open-source 3D creation software for rendering, modeling, sculpting, animation, and rigging. Those 3D models were exported from Blender to FBX format, an open, platform-independent 3D data file format, which is the most compatible format for Unity, a platform for creating cross-platform games and interactive experiences. 11 objects were modeled on the Blender platform. With these inputs, the construction stage of the AR scenario begins, linking QR codes with the models. An apk file was generated; this allows the installation of the app on a smartphone, allowing students to view each of the models in AR through the QR codes using the smartphone. The apk file was exported from Unity; the apk file contains everything related to the scene; it is compatible with Android systems, IOS, Tizen, PS4 PSVita, and Samsung TV, among others.

Finally, 11 models of chemical bonds were obtained, using AR for their visualization. The AR app is shown in Fig. 1.

After the app implementation, 33 students (not part of the final sample) used it to explore its functionality. After the app's use, students answered the SUS questionnaire. The mean SUS score was 64 (SD = 14.9), indicating that the app had some issues to improve (a SUS score of 68 is required for a system to have a usability score above the average). The main issues found during this process were that the app worked slowly and should include more information about carbon bonds. These results helped us to improve the app's implementation.

### 3.4. Research design

A quasi-experimental design was used with an experimental and a control group. Since the school administration had arranged the groups, the researchers randomly chose the experimental and control groups. Forty-eight students were assigned to the control group and 47 to the experimental group.

### 3.5. Experimental process

Before the experimental procedure, three universities in Colombia were selected, and the first author met with the school authorities to expose the study's objective and method. The permissions to implement the procedure were received. Two chemistry teachers agreed to participate in the study, and the researchers explained to the teachers the research's purpose and process and answered all their questions. The app was shown to the teachers to familiarize themselves with it. To assure the fidelity of the intervention, the researcher and the teachers developed a class guide that consisted of step-by-step instructions to conduct the carbon bonds lesson. The guide included the instructions to apply the academic test A before the lecture, information related to the carbon bonds, instructions to perform the activities by students, which consisted of developing three models of carbon bonds using modeling clay, and instructions to apply the academic test B after the lecture.

The experimental process began with participants answering the pre-test, the academic test A. Then, the lecture on carbon bonds was conducted based on the class guide on different days for both groups. At the end of the lesson, the students performed three activities, which consisted of developing three models of carbon bonds using modeling clay. The experimental group used the AR app, while the control group used 2D pictures. The models are shown in Fig. 2.

After the lecture, the participants answered the academic test B, the TAM (only for the experimental group), and the IMMS. The experimental process of the study is shown in Fig. 3.

### 3.6. Data analysis

The data were analyzed using SPSS software. A descriptive analysis was conducted to calculate the mean and standard deviation of the pre and post-test scores on the academic test and the post-test scores on the IMMS for the control and the experimental groups.

**Fig. 1.** AR app for teaching carbon bonds.

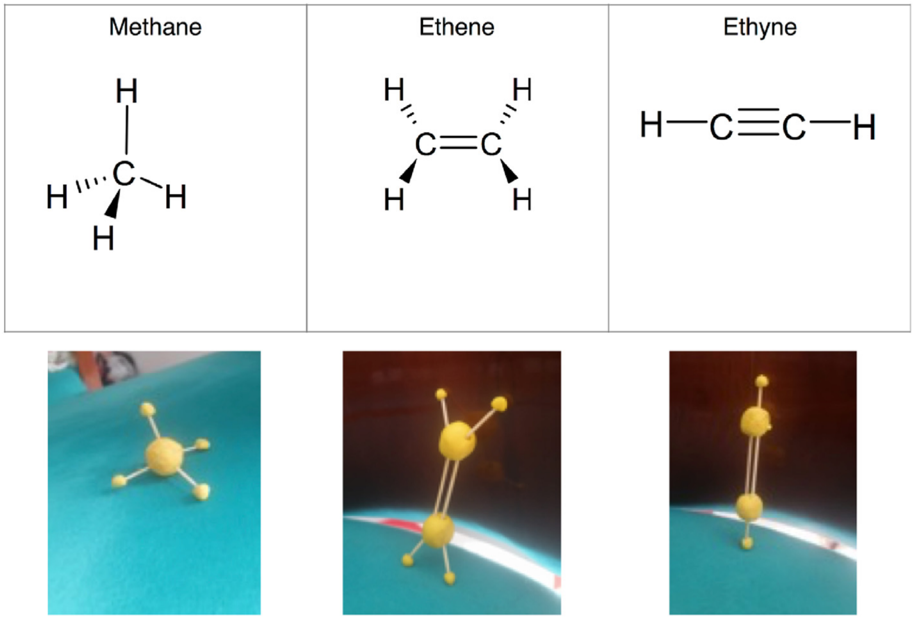


**Fig. 2.** Models of carbon bonds developed by students using modeling clay. The experimental group used the AR app, while the control group used 2D pictures.

A Shapiro-Wilk test was conducted to calculate the normal distribution assumption required for the parametric statistics tests. Based on the results, the normal distribution assumption was not met; therefore, nonparametric tests were applied (Field, 2013; Wasserman, 2006).

A Mann-Whitney-U Test (U) at the 0.05 significance level was performed to compare the experimental and control groups' academic tests, the TAM and the IMMS scores.

A Wilcoxon Signed Rank Test (W) was performed to compare the pre and post-test scores on the academic test of the experimental and control groups.

## 4. Results

### 4.1. Academic test scores

The mean score on the academic test for the control group before the experimental process was 2.5 (SD = 1.90), and for the experimental group was 2.1 (SD = 1.7). A Mann-Whitney-U Test between the pre-scores of the control and experimental groups did not show a significant difference (U = 986, p = .284).

The mean score on the academic test for the control group after the experimental process was 3.1(SD = 1.5), and for the experimental group was 4.4 (SD = 1.7). In addition, a Mann-Whitney-U Test between the post-scores of the control and experimental groups showed a significant difference (U = 601, p = .00006).

The results of the Mann-Whitney-U test analysis are shown in Table 1.

A Wilcoxon Signed Rank Test analysis between the pre (2.5) and post (3.1) scores on the academic test for the control group did not show a significant difference (p = .14).

A Wilcoxon Signed Rank Test analysis between the pre (2.1) and post (4.4) scores on the academic test for the experimental group showed significant improvement (p = .000000).

Table 2 shows the results of the Wilcoxon Signed Rank Test analysis.

### 4.2. Number of models developed correctly

Regarding the number of models developed correctly, 11 students of the control group developed 0 models of carbon bonds correctly, 21 students developed one accurate model, 16 students developed two correct models, and 0 students developed three correct models. Conversely, six students developed 0 correct models for the experimental group, four developed one accurate model, ten designed two correct models, and 27 developed three correct models. These results are shown in Table 3.

### 4.3. IMMS scores

The mean score on the IMMS test for the control group after the experimental process was 4.6 (SD = 0.86), and for the experimental group was 4.8 (SD = 0.73). A Mann-Whitney-U Test between the post-scores of the control and experimental groups did not show a significant difference (U = 977, p = .225). Each dimension's scores were calculated for the experimental and control group. The mean on the attention scale for the control group was 4.4 (SD = 0.79) and for the experimental group was 4.8 (SD = 0.79). The mean on the relevance scale for the control group was 4.7 (SD = 0.97) and for the experimental group was 5.1 (SD = 0.88). The mean on the satisfaction scale for the control group was 5.1 (SD = 1.2) and for the experimental group was 5.5 (SD = 1). The mean on the confidence scale for the control group was 4.3 (SD = 0.88), and for the experimental group was 4.7 (SD = 0.75). A Mann-Whitney-U Test showed a significant difference between the experimental and control group on the attention (U = 887, p = .048) and relevance scales (U = 840, p = .025). These results are shown in Table 4.

### 4.4. TAM scores

The mean score on the TAM test for the experimental group after the experimental process was 5.4 (SD = 1.33). The mean score of the perceived usefulness was 5.6 (SD = 1.3), and for the perceived ease was 5.4 (SD = 1.4). These results indicate that the overall technology acceptance of the AR application was positive.

## 5. Discussion

The objective of the current research was to explore the effect of an augmented reality app on the academic level, motivation, and technology acceptance of students of a university-level chemistry course.

Regarding the effects of an AR app on the academic performance of university students in a chemistry course, the results showed that the mean scores on the academic test of the students who used the AR

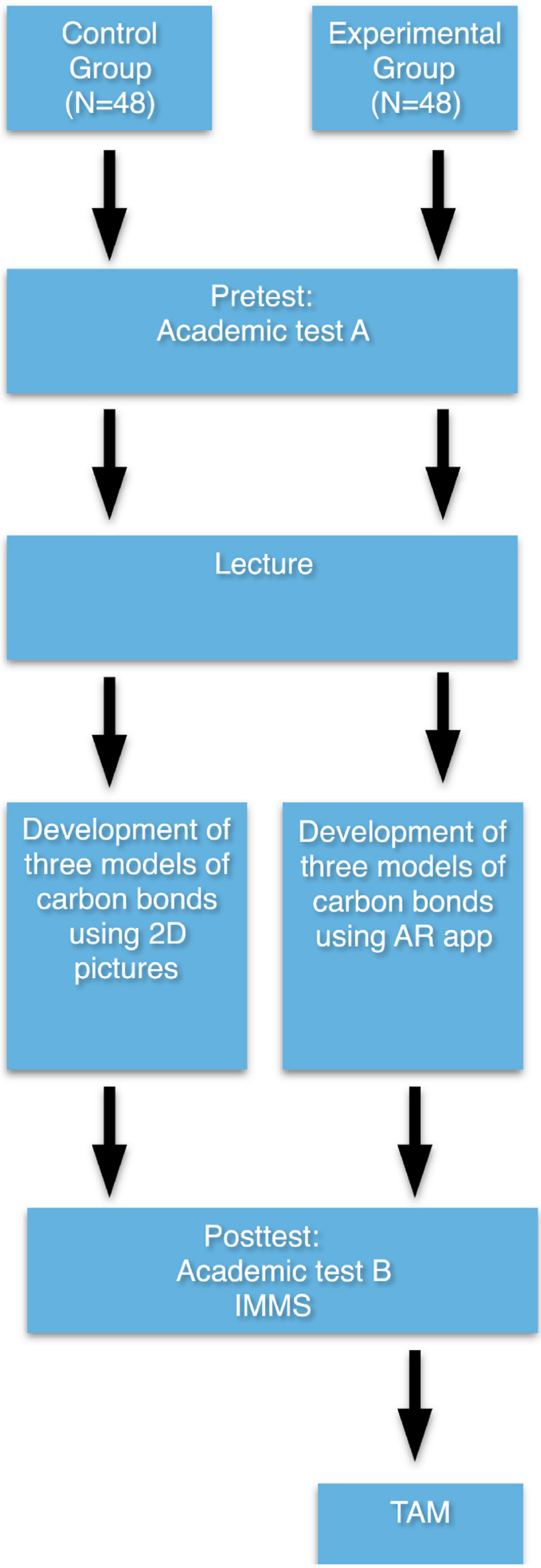


**Fig. 3.** Illustration of the phases of the study.

**Table 1**
Results of the *U* test between the pre and post-scores of the control and experimental group.

| | Control group | | Experimental group | | *U* | *p* |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Academic test | | | | | | |
| Pre-scores | 2.5 | 1.9 | 2.1 | 1.7 | 986 | .284 |
| Post-scores | 3.1 | 1.5 | 4.4 | 1.7 | 601 | .00006* |

**Table 2**
Results of the W test between the pre and post-scores of the control and experimental group.

| | Pre-scores | | Pos-scores | | *p* |
|---|---|---|---|---|---|
| | M | SD | M | SD | |
| Academic test | | | | | |
| Experimental group | 2.1 | 1.7 | 4.4 | 1.7 | .0000* |
| Control groups | 2.5 | 1.9 | 3.1 | 1.5 | .14 |

**Table 3**
Number of models developed correctly by the students in the control and experimental group.

| | Control group | Experimental group |
|---|---|---|
| | N | N |
| 0 models | 11 | 6 |
| 1 model | 21 | 4 |
| 2 models | 16 | 10 |
| 3 models | 0 | 27 |

**Table 4**
IMMS dimension scores of the experimental and control groups.

| | Control group | | Experimental group | | *U* | *p* |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Attention | 4.4 | 0.79 | 4.8 | 0.79 | 887 | 0.048* |
| Relevance | 4.7 | .97 | 5.1 | .88 | 840 | 0.025* |
| Satisfaction | 5.1 | 1.2 | 5.5 | 1 | 927 | .124 |
| Confidence | 4.3 | 0.88 | 4.7 | 0.75 | 899 | 0.067 |
| Total scores | 4.6 | 0.86 | 4.8 | 0.73 | 977 | 0.225 |

application were higher than the control group's mean scores. These results are similar to previous studies that show that AR increases academic levels compared to other methods (Ibáñez et al., 2020; Qingtang et al., 2021). In addition, the results are also consistent with studies that reported a positive effect on chemistry learning using AR-based tools, although academic performance was not directly measured in those studies (Cai et al., 2014; Iordache et al., 2012; Fjeld et al., 2007; Vega Garzón et al., 2017; Singhal et al., 2012).

Concerning the effect of an AR app on university students' motivation in a chemistry course, this study shows that the scores on the IMMS were not significantly different between the control and the experimental group after the experimental phase.

This may be because students knew they were participating in a study, which led to a reactivity effect (Haynes & Horn, 1982); future studies could test this hypothesis.

Concerning university students' acceptance of the AR app, we found that the mean scores on the TAM questionnaire's perceived usefulness and ease of use dimensions were above average. The TAM postulates that technology usage is determined by the behavioral intention to use it. Therefore, perceived usefulness and perceived ease of use are predictors of intent to use technology (Davis, 1989; Marangunic & Granic, 2015; Pynoo et al., 2012; Smarkola, 2007; Wahid, 2007).

Perceived usefulness refers to the user's belief that the technology would increase performance (Davis, 1989). Perceived ease of use refers to how individuals believe using the technology would be effortless (Davis, 1989).

Previous research shows that technology acceptance and usage in distance education represented a significant challenge for teachers and educational institutions (Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014; Straub, 2009). Besides, Davis (1993) found that the perceived usefulness was 50% more influential than ease of use in determining technology usage. Hence, it is essential to develop and provide training, support, and resources for students and teachers to increase the perception of usefulness and the use of technology.

## 6. Conclusions

In conclusion, AR technology could be helpful in an academic setting by allowing the student to be more active in the learning process and therefore be more motivated, resulting in better performance and generalization of knowledge to the real world.

The use of AR in educational settings has pedagogical implications; AR can impact the learning process in three dimensions, physical, cognitive, and contextual. Physical refers to manipulating objects; physical control of the environment can lead to a better understanding of spatial concepts and better recall of the learning content. Cognitive refers to the spatiotemporal contiguity of information; AR could facilitate learning abstract information and symbolic associations because it presents information associated with physical objects and locations. Finally, Contextual refers to three general factors: collaboration, contextual relevance, and personal relevance, which can improve the learning process (Bujak et al., 2013).

### *6.1. Limitations*

One limitation of the present study is that the school administration arranged the groups, so it was impossible to select participants for each group randomly. Another possible limitation is that the students' motivation could be due to the novelty of the AR technology. Finally, this study was conducted only during one class; maybe more long-term interventions could lead to a more positive effect.

## Statements on open data and ethics

The participants were protected by hiding their personal information in this study. They were voluntary and they knew that they could withdraw from the experiment at any time. The data can be provided upon requests by sending e-mails to the corresponding author.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cexr.2023.100022.

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