

Framework for designing motivational augmented reality applications in vocational education and training

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One of the greatest advantages of augmented reality (AR) in education is that AR increases student motivation. Nevertheless, there is a gap between the research on student motivation in AR and the definition of frameworks to inform and guide the design and development of AR applications that effectively support student motivation. In this paper, we attempt to bridge that gap as we introduce and evaluate a framework for designing motivational AR applications. Our framework has been built upon three theoretical foundations: motivational design, universal design for learning and co-creation. The evaluation study was conducted with 58 chemistry students enrolled in the vocational education and training (VET) program for Laboratory Operations, and we found that the framework not only effectively supports the four dimensions of Keller's (2010) ARCS (attention, relevance, confidence and satisfaction) model of motivation, but also demonstrates exceptional results in the Attention and Confidence dimensions of motivation.

Introduction

Research on augmented reality (AR) in education is evolving quickly (Saidin, Abd Halim, & Yahaya, 2015; Santos et al., 2014). Many AR applications for learning have been created in a wide variety of learning domains and for every educational level from early childhood through to higher education. Moreover, AR applications have also been developed for informal educational settings. At the same time, while some guidelines for designing AR applications for education have been defined (Kourouthanassis, Boletsis, & Lekakos, 2015), they do not fully set out strategies for designing motivational AR applications (i.e., AR applications that effectively increase student motivation).

Apart from design guidelines, frameworks can also provide information on how to design AR applications. Based on a review of the literature, we found that a considerable number of frameworks for AR in education have been defined. Surprisingly, however, only three out of the 35 frameworks analysed considered motivational factors in their design. Consequently, there is a lack of research on defining frameworks to inform the design of AR applications that effectively support student motivation. This is surprising, because many studies in the literature highlight the fact that one of the most important advantages of AR in educational settings is that AR increases student motivation (Akçayır & Akçayır, 2017; Chiang, Yang, & Hwang, 2014; Radu, 2014). This in turn suggests that there is gap that needs to be bridged between current research on the effect AR applications have on student motivation and existing framework definitions providing the information required to design AR applications that support student motivation. Moreover, Akçayır & Akçayır (2017) suggest that more research needs to be conducted to determine the real advantages of AR for increasing student motivation.

Motivation is a human dimension that explains why people make an effort to pursue a goal and why people actively work to attain that goal (Keller, 2010). While there are many models that study human motivation, the ARCS (attention, relevance, confidence and satisfaction) model introduced by Keller (2010) is one that explains this concept in relation to learning processes. The ARCS model is based on extensive research into motivational design and the general theory of motivation in relation to learning. The model's four dimensions provide an overview of the major categories of learning motivation. In this paper, we have adopted the ARCS model of motivation. Many studies in the literature, such as those by Chiang et al. (2014), Ibanez, Di-Serio, Villaran-Molina, and Delgado-Kloos (2015), and Chen, Chou, and Huang (2016), report a positive impact of AR on the ARCS dimensions of student motivation.

Motivation is one of the key aspects that contributes to and influences learning (Linnenbrink & Pintrich, 2002). In this regard, design guidelines need to be developed to improve motivation in learning settings and so contribute to understanding how motivation influences learning (Pintrich, 2003) from the perspective of a positivist research paradigm. However, the lack of frameworks or design guidelines force developers and other stakeholders involved in developing AR applications to conduct multiple user studies to inform the design of AR applications (Santos et al., 2015), and this increases the complexity of their development. Akçayır and Akçayır (2017) point out that holistic models and design principles for AR learning environments are needed.

In line with these research issues, we address the following research question: which are the components that an AR application should have to support the four dimensions of the ARCS model of motivation? We hypothesise that a framework for designing and developing motivational AR applications might contribute to creating AR learning experiences that effectively support student motivation.

Thus, in this paper we introduce and validate a framework for designing motivational AR applications. The framework is built upon three theoretical foundations: motivational design (Keller, 2010), universal design for learning (UDL; Meyer, Rose, & Gordon, 2014; Rose & Meyer, 2002) and co-creation (Sanders & Stappers, 2008). Our framework describes the modules that an AR application should have to effectively support student motivation; it was defined based on the literature on AR in education and on two exploratory studies conducted in a car maintenance course in a VET program (Bacca, Baldiris, Fabregat, Clopés, & Kinshuk, 2016; Bacca, Baldiris, Fabregat, Kinshuk, & Graf, 2015). The framework was then evaluated in the VET program of Laboratory Operations with chemistry students. This study is framed in the positivist research paradigm (Scotland, 2012), which means that the methodology for understanding reality is purely experimental and the research method is entirely quantitative.

The remainder of this paper is organised as follows: after the Introduction, the related work is presented. Following the related work, the framework is described and then the evaluation study is presented. Finally, the results of the evaluation are presented, and the last section discusses the results, draws conclusions, describes implications, future work and limitations of this study.

Related work

A review of frameworks for AR and mobile AR in education was conducted to obtain an overview of the current state of research on frameworks for AR in education. In total, 35 frameworks for AR and mobile AR in education were identified. After reading the articles for each framework, we identified that they greatly differ from one another, thus making it difficult to compare them according to their characteristics or purposes. However, we identified a number of categories that all the frameworks did have in common: type of AR used (marker-based AR, marker-less AR, location-based AR), learning domain, pedagogical and didactical approach and educational level addressed. We also analysed whether or not the framework considered motivational aspects. Next, we used these categories to classify the frameworks. A table with all the frameworks can be found at <http://piranya.udg.edu/quimica/files/TableOfFrameworksComparison.pdf>

Figure 1 shows a synthesis of the literature review process and the main conclusion obtained. Table 1 shows the results concerning educational levels. Of the 35 frameworks, 12 were designed for multiple educational levels. The results also reveal that many efforts have been made to define frameworks for AR in higher education (8 out of 35 frameworks). Surprisingly, only one framework (Syberfeldt, Danielsson, Holm, & Wang, 2016) has been defined for VET. Thus, more research is needed on AR frameworks that set out how to design and develop AR applications for VET programs.

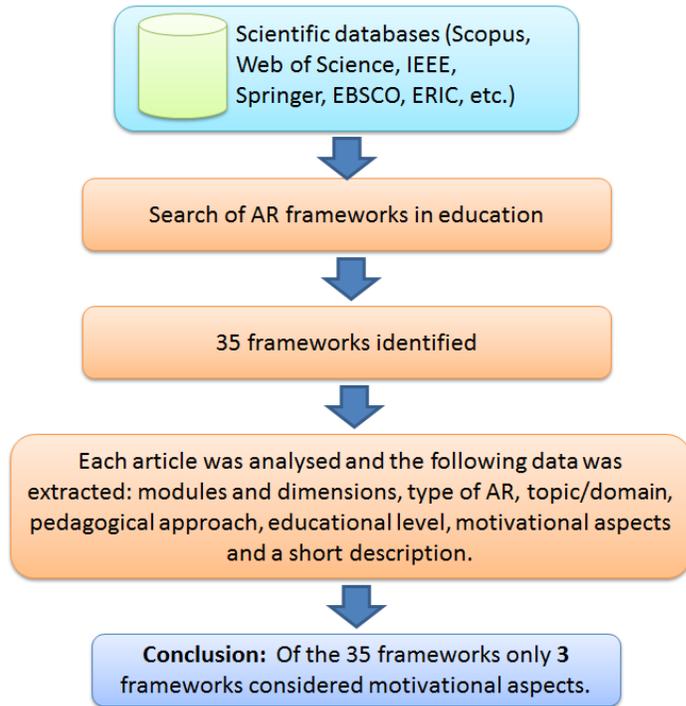


Figure 1. Synthesis of the literature review process and main conclusion

Table 1
Educational level considered in the frameworks analysed

Educational level	Number of frameworks
Multiple	12
Higher education	8
Primary education	4
Informal learning	3
College	2
Secondary education	2
Not reported	2
Preschool education	1
VET	1

Even though one of the advantages of AR in education is that it increases motivation, surprisingly none of the frameworks defines the components that an AR application should have to effectively increase student motivation. Only three of the 35 frameworks considered factors related to motivation. These studies are by Jamali, Shiratuddin, and Wong (2014), Bujak et al. (2013), and Colpani and Homem (2015). However, the authors do not provide any guidelines for designing and developing AR applications to support student motivation.

Together, these results provide an overview of the current state of AR frameworks in education. One of the conclusions drawn from this review is that very few frameworks have considered motivational aspects in their

definitions. Thus, this is an open issue that requires further research to contribute to the design of AR applications that effectively support student motivation, in particular in VET programs.

There are other studies that also describe guidelines for designing AR applications, such as those by Dünser, Grasset, Seichter, and Billinghamurst (2007); Juan, Furió, Seguí, Aiju, and Cano (2011); Cuendet, Bonnard, Dolenh, and Dillenbourg (2013); and Ko, Chang, and Ji, (2013). However, while applying these principles to AR application designs might increase user experience in AR-based settings and might indirectly increase student motivation, these design principles are not grounded in a theory of motivation nor are they specifically defined to guide the design and development of AR learning experiences that will successfully support student motivation. Thus, more research is needed on defining guidelines and frameworks to ensure effective motivational AR application design.

Framework for designing motivational AR learning applications

Our framework aims to inform the design and development of motivational AR learning applications. Thus, it defines the components recommended for supporting student motivation and, in particular, for supporting the four dimensions in the ARCS model of motivation. Our framework is based on three theoretical foundations that are summarised as follows:

- Motivational design is the systemic process of “arranging resources and procedures to bring about changes in people’s motivation” (Keller, 2010, p. 22). Some recommendations provided in the framework come from such motivational design theory.
- UDL is a validated framework for addressing student variability (Meyer et al., 2014); it aims to avoid barriers in the learning process so that students become expert learners. The UDL framework is based on modern neuroscience research, the learning sciences and cognitive psychology, which have identified that the human brain consists of three networks: affective, recognition and strategic. The three UDL principles are based on the three networks; these principles are (1) provide multiple means of engagement, (2) provide multiple means of representation, and (3) provide multiple means of action and expression. Some recommendations provided in our framework come from these principles.
- Co-creation is defined as “any act of collective creativity, i.e., creativity that is shared by two or more people” (Sanders & Stappers, 2008, p. 2). To effectively support student motivation, our framework recommends collaborating with teachers and students to create the AR applications.

The framework can be used for developing AR applications from scratch or for creating AR learning experiences by using one or more existing third-party applications that implement the components defined in the framework. Figure 2 shows an overview of the framework. A detailed description of each component along with all the recommendations can be found at <http://piranya.udg.edu/armotid/index.php>

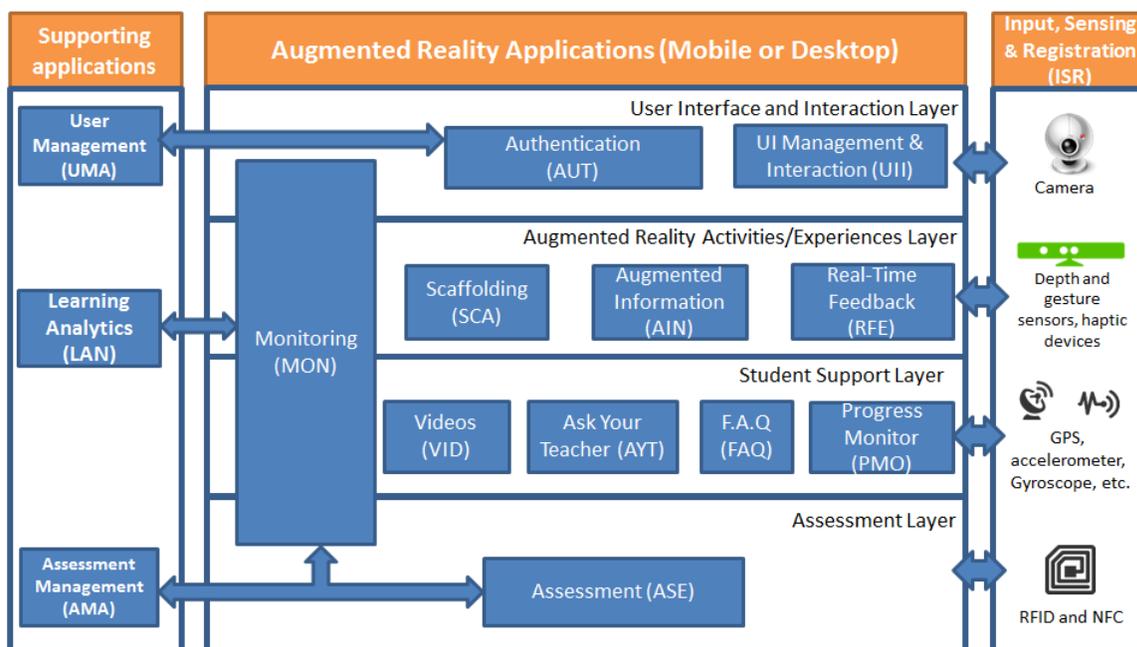


Figure 2. Expanded set of components of the framework for designing and developing motivational AR applications

Supporting applications

This section of the framework includes mobile or web-based applications that manage information and services externally (i.e., outside the AR application). Supporting applications receive output from or provide input to the AR application.

AR (mobile or desktop)

This is the main section of the framework and is divided into four layers. Each layer is described in the following sub-sections:

- User interface and interaction layer
- AR activities/experiences layer
- Student support layer
- Assessment layer.

User interface and interaction layer

Authentication (AUT), UI management & interaction (UII): This module manages authentication, user interface (UI) and the interaction mechanisms required to show the information to students. By its nature, AR interfaces are immersive. According to Dede (2009), immersive interfaces enhance learning because they provide multiple perspectives (exocentric and egocentric) of a phenomenon. In that regard, exocentric and egocentric perspectives are key aspects in the development of AR applications. Egocentric perspectives enable motivation through embodied and concrete learning because they provide a view of the phenomenon from inside the phenomenon (Dede, 2009), for instance, looking the molecules that form an inorganic compound and interacting with them. The exocentric perspective allows a phenomenon to be observed from outside the phenomenon, for instance, to observe the result of a chemical reaction when combining two chemical compounds. Dede (2009) also claims that one of the advantages of immersive interfaces is that they improve *near-transfer*; that is, students transfer the knowledge learned in a specific context to solve real-world problems in similar contexts. This is particularly important in VET.

In some models, architectures and frameworks for AR applications in education, the AR interface and interaction have been considered as modules with well-defined functions (Chao, Lan, Kinshuk, Chang, & Sung, 2014; Margetis et al. 2015). The use of interaction metaphors and natural interactions are also recommended (Dünser et al., 2007).

AR activities/experiences layer

Scaffolding (SCA): This is a strategy for helping students so that they can complete a learning activity. We suggest that AR applications should include a scaffolding mechanism to support student motivation. The relationship between scaffolding and motivation is established through a concept known as *success opportunities*. Success opportunities are the opportunities that learners have to succeed in activities that are challenging (Keller, 2010). The scaffolding strategy helps to create success opportunities (by using scaffolds) so that students can achieve in the learning activities. Thus, scaffolding strategies might be key components for sustaining student motivation in AR applications. Scaffolding is a strategy recommended in UDL to assist students in the learning task. Scaffolding strategies have been extensively used in AR applications in education (Chen et al., 2016; Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos, 2016; Yin, Song, Tabata, Ogata, & Hwang, 2013) and have a positive effect on motivation (Ibanez et al., 2015). The use of scaffolding is consistent with the design principles introduced by Dunleavy (2014).

Augmented information (AIN): Augmented information is inherent to AR technology. One of its features that typically captures the attention of students is when the augmented information is superimposed onto real objects. Thus, we feel that this aspect is relevant in sustaining student motivation. Indeed, capturing the attention of learners is one of the strategies for sustaining student motivation (Keller, 2010). The possibility of displaying augmented information in the form of images, videos, 3D objects or audio might help to provide multiple means of representation, which is one of the guidelines in the UDL framework (Meyer et al., 2014). Some guidelines for developing AR applications emphasise the need for carefully designing the presentation of the content (Anastassova & Burkhardt, 2009) and the usability of the system (Ko et al., 2013).

Real-time feedback (RFE): This module manages the feedback that the system provides in response to a student's interaction with the AR application. Some studies have reported that the provision of feedback might have a positive effect on student motivation (Chakraborty & Muya Nafukho, 2014; Chao et al., 2014). Thus, we suggest that providing real-time feedback might support student motivation. According to Keller (2010), the levels of challenge in learning activities need to be combined with positive and attributional feedback to help students to succeed and/or confirm their success in the learning tasks. Feedback is closely related to the confidence and satisfaction dimensions of the ARCS model of motivation (Keller, 2010). Moreover, according to UDL, providing feedback is one of the key strategies in helping students to maintain perseverance and to support the executive functions (Meyer et al., 2014). Feedback should be mastery-oriented, which means that the feedback helps students to reach mastery rather than just confirming their success or pointing out errors (Meyer et al., 2014). The provision of real-time feedback has been found to be relevant in AR applications (Nadolny, 2016).

Student support layer

Videos (VID): The aim of this module is to show videos with the learning content to provide an alternative way of presenting information, as recommended by the UDL guidelines. For those students who prefer audio and video to textual information, this module might be helpful. The videos included in this module convey information that complements the information transmitted through other mechanisms in the AR applications. In the literature, using video podcasts has been widely recognised as an effective strategy to motivate students (Bolliger, Supanakorn, & Boggs, 2010; Kay, 2012). In some AR applications, videos have been used to present examples and/or to provide additional content (Wang, Vincenti, Braman, & Dudley, 2013). Thus, we suggest that AR applications might provide videos about the learning content to support student motivation.

Ask your teacher (AYT): This module provides a mechanism by which students can send questions to their teacher as and when their doubts arise during the AR learning experience. Each question is sent to a server,

and the teacher is notified by a web or mobile application that a new question has been posted by a student. This module was inspired by UDL guidelines, and teachers suggested creating this module during the co-creation of an AR application for VET (Bacca et al., 2015).

Frequently asked questions (FAQ): This module provides, in advance, answers to questions that are common to the learning domain or questions that are typically asked by students for a particular learning task. This module is updated with new questions and their corresponding answers when teachers decide to post the questions sent by students through the AYT module. Together, the FAQ and the AYT modules can be considered as a question and answer (Q&A) system, which has been found to be relevant in the interaction between teacher and student in online learning (Na, Choi, Lim, & Kim, 2008). Q&A systems have also been integrated with AR systems (Lin & Chen, 2015). We suggest that the FAQ and AYT modules might support student motivation.

Progress monitor (PMO) and Monitoring (MON): The PMO is a module that monitors student activity in and the interaction with the application. It works in conjunction with the MON module. The MON module captures a student's interaction within the four layers of the framework and also sends this information to the PMO to generate reports.

By using the data provided by the MON module, the PMO measures a student's progress using variables such as overall progress in the content, learning outcomes, and/or time spent using the application. The PMO should be able to report information to the students in a comprehensible way so that they are aware of their progress and performance in the learning task. Students need to know whether they are making progress or not in the learning activities (Meyer et al., 2014). Furthermore, monitoring progress and showing this information to students is useful for increasing motivation (Meyer et al., 2014). Thus, we suggest that the PMO and MON might support student motivation. Moreover, the PMO should be able to provide the teacher with reports about general course performance as well as detailed performance metrics for each student.

Assessment layer

Assessment (ASE): This module manages the assessment process in the AR application. For instance, if the assessment strategy is based on tests, then this module should present the test to students, collect their answers and any data that might be relevant for the teacher; for example, the time that the students spent answering the question or data about any other student interaction with the module. The ASE module may have different types of tests, such as multiple-choice, true or false, open ended or fill-in-the-blank questions. Whenever possible, it should automatically correct the answers so that students have immediate automated feedback. The use of assessment mechanisms has been considered in some AR applications (Chao, Chang, Lan, Kinshuk, & Sung, 2016; Ternier, Klemke, Kalz, van Ulzen, & Specht, 2012).

Input, Sensing & Registration (ISR)

This section of the framework represents the input of information from a wide variety of devices that can be used to register information from the real world to overlay the digital information. The information from these devices facilitates the AR experience.

Evaluating the framework

The aim of evaluating the framework is to identify if the modules defined within it support student motivation when instantiated in an AR application that is used as part of the learning process. The framework was evaluated in the VET program of Laboratory Operations for chemistry students. In VET programs, motivation is a key aspect not only in the traditional classroom, but also in the workplace, where students acquire practical skills in a specific domain (Pineda-Herrero, Quesada-Pallarès, Espona-Barcons, & Mas-Torelló, 2015; Schaap, Baartman, & de Bruijn, 2012).

Together with the teachers, we identified that the topic in which AR may offer better advantages and support was “Inorganic nomenclature”. Teachers stated that this is an abstract topic in which students often face difficulties when they have to learn the rules to analyse each chemical compound and provide its corresponding name. Thus, AR may provide an enhanced learning experience to facilitate students’ understanding of this abstract subject matter.

Since the framework can be used to create motivational AR learning experiences with existing third-party applications or by developing an AR application from scratch, for the purposes of this evaluation and after consulting with the teachers, we decided to use two existing mobile AR applications: Popar Interactive Periodic Table (Popar Toys, 2017) and Arloon Chemistry (Arloon, 2017). Moreover, together with the teachers we co-created a mobile application called Chemistry Videos and Assessment and a web-based supporting application. In total, the four applications cover 11 of the framework’s 14 components (i.e., 80% of the framework) as shown in Table 2. These applications were used to create a motivational AR learning experience as a support for teaching the topic of inorganic nomenclature, in particular, for teaching about cations and anions, hydrides, oxides, binary compounds with nonmetals, hydroxides and acids.

Table 2
Modules of the framework implemented by the four applications

Module	Application			
	Popar	Arloon Chemistry	Chemistry videos and assessment	Supporting application
UMA				X
LAN				
AMA				X
AUT			X	
UII	X	X		
SCA	X	X		
AIN	X	X		
RFE	X	X		
VID			X	
AYT				
FAQ				
PMO			X	
MON			X	
ASE		X	X	

Research design

The research design was defined according to the positivist research paradigm. Thus, a quasi-experiment research design was adopted for this evaluation because it was not possible to randomly allocate participants to the control and experimental conditions (Coolican, 2014).

To evaluate student motivation, the post-test only pre-experimental research design (Cohen, Manion, & Morrison, 2007) was selected. In our evaluation, this research design was adopted because it was not possible to obtain a reliable measure of the students’ initial levels of motivation before the intervention with the AR applications that could be compared to the post-test levels. Other studies in the literature, such as those from Chiang et al. (2014), Chen et al. (2016) and Ibanez et al. (2015), adopted similar approaches and did not measure initial levels of motivation either.

Participants

Students from a VET institute in Spain participated as the experimental group ($N = 26$), and the control group for this study ($N = 32$) came from a VET institute in Colombia. Content equivalence was ensured for both groups, because the subject matter was similar in both institutions and teachers from both institutes agreed

that the learning content was the same. Most of the participants fell within a 17- to 19-year-old age range, and none of them had used AR applications before. It is important to note that participants came from two different cultural backgrounds. Consequently, cultural factors might influence the results of this study, but that aspect was out of the scope of this study.

Instruments

The instructional materials motivation survey (IMMS) (Keller, 2010) measures motivation levels in accordance with the ARCS motivation model. Other studies have successfully applied this survey (Cronbach $\alpha = 0.96$) to measure students' levels of motivation in AR learning experiences (Chiang et al., 2014; Chin, Lee, & Chen, 2015). However, unlike other studies in the literature, in our study all 36 survey questions were maintained to avoid affecting the reliability of the instrument. The questions were, however, slightly adapted to ask about the experience using the AR applications and traditional learning materials. The instrument uses a 5-point Likert scale. Informed consent was obtained from the participants in this study.

Procedure

Figure 3 shows the procedure for the evaluation. The control group followed a traditional learning experience using the materials that teachers usually employ and without any changes in the instruction. As mentioned before, the content equivalence was ensured for the control group because the subject matter contained the same topics as that of the experimental group. This learning phase lasted for seven weeks (20 hours in total). At the end of this period, the IMMS motivation questionnaire was distributed to collect information about students' levels of motivation after learning with traditional learning materials such as books, photocopies. Completing the questionnaire took 50 minutes.

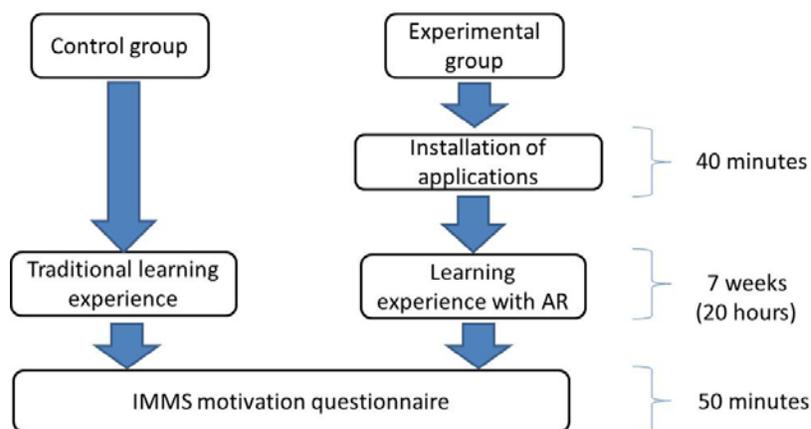


Figure 3. Experimental procedure for the evaluation of the framework

In contrast, for the experimental group the first phase was *installation of applications*, in which students were guided through the process of installing the applications. Students were shown how to use the applications, and the basic concepts of AR and objectives of the activity were explained to them. Teachers already knew how to use the applications because they learnt how to use them when they selected the applications to be used together with the application that we developed. A booklet containing the AR markers was given to each student. This phase took 40 minutes. Then, the learning experience with AR took place. During the intervention, the students used the applications in class under the guidance of their teacher and at home as part of their homework. This phase lasted for seven weeks (20 hours). This longer intervention helps avoid the Hawthorne effect (Looi et al., 2009) so that by the end of the intervention the levels of motivation have been affected as little as possible by the novelty of the technology. The Hawthorne effect, also known as the novelty of technology effect, occurs when students are not used to using a particular technology and their engagement can be higher just because of the novelty created by the new experience with that technology. In our study, this effect was diminished with a longer intervention so that students get used to the AR

technology. Finally, as in the control group, the same IMMS motivation questionnaire was distributed to collect information about the students' level of motivation; this took 50 minutes to complete.

Data analysis and results

The results for student motivation came from the data collected from the IMMS that had been distributed to the control and experimental groups. The study results are based on statistical analysis, because the study was framed under the positivist research paradigm.

Firstly, to select the statistical test accordingly, we analysed whether or not the data followed a normal distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests in SPSS; the results are presented in Table 3.

Table 3

Tests for normality of data gathered from the IMMS motivation instrument

Dimension	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	degrees of freedom	Sig.	Statistic	degrees of freedom	Sig.
Attention	0.098	58	0.200*	0.974	58	0.234*
Relevance	0.161	58	0.001	0.927	58	0.002
Confidence	0.105	58	0.179*	0.958	58	0.043
Satisfaction	0.091	58	0.200*	0.965	58	0.090*

* $p > 0.05$

As Table 3 shows, data collected for relevance and confidence dimensions do not follow a normal distribution, and so to analyse this data we used the Mann-Whitney U test. For attention and satisfaction dimensions we used the standard parametric t-test.

For the relevance dimension, the results showed that the participants in the control group reported higher levels of relevance than the participants in the experimental group did. However, this difference was not significant ($U = 354.5$, $p > 0.05$, $Sig. = 0.33$).

The results for the confidence dimension showed that participants in the experimental group reported higher levels than those in the control group. This difference was significant ($U = 638$, $p < 0.05$, $Sig. = 0.001$), effect size was moderate (Cohen's $r = 0.46$) and post-hoc power was 0.51.

The standard parametric t -test was applied to attention and satisfaction dimensions to identify if there were any differences in the levels of motivation between the control group and the experimental group in these dimensions. The results from the t -test for the attention dimension showed that the participants in the experimental group reported higher levels of attention ($M = 3.56$; $SD = 0.44$) than the participants in the control group did ($M = 3.2$; $SD = 0.44$). The difference between the means was significant: $t(37.149) = 2.070$, $p < 0.05$, $Sig. = 0.045$, while the effect size was medium (Cohen's $d = 0.56$) and post-hoc power was 0.55.

The results of the t -test for the satisfaction dimension showed that the participants in the control group reported higher levels of satisfaction ($M = 3.7$; $SD = 0.7$) than those in the experimental group ($M = 3.1$; $SD = 1$). The difference between the means was significant: $t(56) = 2.472$, $p < 0.05$, $Sig. = 0.016$; effect size was medium (i.e., Cohen's $d = 0.67$) and post-hoc power was 0.71.

Table 4 shows a summary of the results and whether the statistical difference was significant or not and specifies the group in which the difference was significantly higher. Values in bold indicate the results that were significant.

Table 4
Summary of the results of student motivation in the quasi-experiment

Dimension	Result in the experimental group		Result in the control group		Summary of the result from the statistical test
	Mean	SD	Mean	SD	
Attention	3.56	0.44	3.2	0.44	Significant difference in favour of the experimental group
Relevance	3.44	0.55	3.57	0.5	No significant difference
Confidence	3.64	0.51	3.18	0.5	Significant difference in favour of the experimental group
Satisfaction	3.1	1	3.7	0.7	Significant difference in favour of the control group

Discussion and conclusions

The framework introduced in this paper is an empirically supported foundation that contributes to the design and development of motivational AR applications that effectively support student motivation. The framework addresses, in part, the need expressed by Pintrich (2003) and Akçayır and Akçayır (2017) for more design guidelines and holistic models to improve motivation in learning settings. In particular, our framework defines the components that an AR application should include to effectively support the four dimensions of motivation so that software developers, educational technology researchers, teachers and other stakeholders can create effective motivational AR learning experiences.

In terms of motivation, the results show a positive impact in the four dimensions for the control and experimental groups. This means that students reported positive levels of motivation after learning with both the AR applications and traditional materials such as textbooks, photocopies and written exercises. However, it is worth noting that higher levels of motivation were reported by students in attention and confidence dimensions when learning with the AR applications (experimental group) compared to the learning process with the traditional materials (control group). These results are consistent with those obtained by Di Serio, Ibáñez, and Kloos (2013) with respect to the positive impact that AR has on attention and confidence dimensions.

In terms of the attention dimension, students in the experimental group reported higher levels of attention than those in the control group. This might suggest that the learning experience based on our framework captured student interest, created curiosity and helped students to focus on the key information of the learning content. This result supports previous studies reporting the positive impact AR applications have on the attention dimension (Chen et al., 2016; Chiang et al., 2014; Chin et al., 2015; Ibanez et al., 2015).

As for the confidence dimension, students in the experimental group reported higher levels than those using the traditional learning materials. This result is in agreement with other studies that have demonstrated that AR applications are useful for supporting the confidence dimension of motivation (Chen et al., 2016; Chiang et al., 2014; Chin et al., 2015), and may suggest that students perceived that they can succeed in the learning activities and that they have greater control over their learning process. This result might be explained by the fact that the components of the framework implemented in the AR applications allowed students to learn at their own pace and allowed them, in this particular learning domain of chemistry, to explore multiple possibilities for solving problems and obtain automatic feedback, which is something that is not possible to achieve directly with traditional learning materials. This result demonstrates that the components defined in our framework are useful for supporting the confidence dimension at a higher level than the use of traditional learning materials do.

In contrast, the results for the relevance dimension, showed there was no statistically significant difference between the control group and the experimental group. In general, it seems that students perceived both the AR learning experience and the traditional learning experience as being relevant for their learning process;

albeit with a slight preference for the traditional learning experience. However, this result also suggests that the AR learning experience created with the framework was as equally relevant for students as the traditional learning experience was; therefore, this may demonstrate that the AR learning experience was not negatively affecting relevance dimension. On the other hand, this result may have been affected by the learning domain or the applications selected for the evaluation study. Subsequently, further research may be needed to identify the causes of these differences.

Finally, in terms of satisfaction, participants in the control group reported higher levels of satisfaction than those in the experimental group. A potential explanation for the result in the control group is that students are very used to learning with traditional learning materials as they have been using them for most of their schooling. Consequently, students prefer traditional learning materials because they have not had any other type of learning experience. Although students in the experimental group reported a lower level of satisfaction, this may be explained by the fact that the AR applications available for creating the AR learning experience vary in terms of their design and, therefore, these applications might not have been fully adjusted to the precise needs of the learning domain in question. These slight differences between the third-party application designs and the requirements of this specific learning domain might have had a negative impact on student motivation. This is a risk that teachers always run when using third-party applications that have not been specifically designed for their exact requirements. However, it is worth noting that this might not have a substantial impact if the application is selected by the teachers according to their precise requirements and clearly defined learning objectives or when the applications are co-created with the teachers.

Another interpretation of the results obtained in the Satisfaction dimension in the experimental group comes from observing the intervention. During the intervention, we observed that some students had negative perceptions about the subject itself (Inorganic nomenclature) because of its high amount of theoretical content which seems to make this topic difficult to assimilate. This situation might have diminished the levels of motivation in all four dimensions, but it may have affected Satisfaction dimension in particular.

It is worth noting that to take full advantage of the possibilities AR offers, developing AR applications not only entails applying design principles or a framework (Dünser et al., 2007), but also involves a process of co-creation, instantiating a framework (like the one introduced in this paper), and developing, building and testing prototypes until the tool is deemed ready to be deployed in the classroom.

Implications for stakeholders and future work

The results and contributions of this study have some implications for different stakeholders:

- Teachers may use the framework for creating motivational AR learning experiences by using existing AR applications that implement components of the framework. In this paper, we showed how to use existing applications to create a motivational AR experience. Moreover, teachers may use the framework for evaluating existing AR applications or as a guide for co-creating AR applications with other collaborators. Knowledgeable end users and students could participate in the co-creation of AR applications as key stakeholders.
- Educational technology software developers may use the recommendations provided in the framework for designing and developing motivational AR applications and may co-create with teachers new modules and interaction mechanisms to extend our framework.
- Together, researchers and educational technology experts may create AR learning experiences by using the framework and conducting field studies in other educational levels. New components may be defined and tested to determine whether these components together support student motivation. To the best of our knowledge, our framework is the first framework that informs the design of motivational AR learning experiences, so our framework can be extended to support other learning dimensions such as learning outcomes, learning attitudes, usability.
- Students might participate in early stages of co-creation processes and in user studies to identify more accurate students' needs and to consider their valuable input in the design and development.

- VET institutions may use the results of this study to make decisions on how to integrate AR applications in their curriculums, development of new policies and support projects for the development of new AR applications.

Future research directions include:

- Future research might consider other variables that impact AR learning experiences, such as usability, ergonomics, user context, and preferences, and map them to new dimensions or components in the framework.
- Personalisation mechanisms might be considered, so that AR applications detect the aspects that better motivate students and can offer a more personalized motivational experience. For instance, artificial intelligence techniques can be used to adapt scaffolding and real-time feedback according to students' levels of motivation and level of knowledge in the topic. Moreover, according to their learning style, the AR application could show appropriate learning content to increase students' motivation.
- The framework could be tested in other educational levels and in other topics in VET education.
- Other models of motivation can be considered to have an overview of other dimensions of motivation.
- Other data collection methods different from self-report instruments can be used to have a more reliable measure of student motivation.

Limitations of the study

The use of a self-report instrument (IMMS) might not reflect all the aspects of student motivation, and the information reported by students might be influenced by other factors, such as cultural background. Consequently, the results need to be interpreted with some caution. Moreover, the evaluation study was conducted in the VET level of education and only in the VET program of Laboratory Operations with marker-based AR, so the results might not be generalised to other educational levels or types of AR. The control and the experimental groups came from two different cultural backgrounds (Colombia and Spain respectively). In this study, the cultural factors were not considered because they were out of scope, but they might have influenced the results. Finally, although interactivity is an important aspect of AR applications, in the review of AR frameworks in education this aspect was not considered.

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