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ORIGINAL

Design, Development and Validation of an Educational Methodology Using Immersive Augmented Reality for STEAM Education

Santiago Delgado-Rodríguez[1], Silvia Carrascal Domínguez[2] and Rebeca Garcia-Fandino[3]

[1] Department of Education, Faculty of Languages and Education, University of Nebrija, Spain
[2] Department of Teacher Training Centre, Faculty of Education, University Complutense of Madrid, Spain
[3] Departamento de Química Orgánica, Centro Singular de Investigación en Química Biolóxica e Materiais Moleculares (CiQUS), Universidad de Santiago de Compostela, Spain

ABSTRACT

The main objective of this study is the design and validation of an educational methodological model based on the use of immersive technological resources (Augmented Reality – AR) to improve learning processes in secondary education science subjects (Biology and Geology). The process was developed based on three main quantitative studies: an exploratory study, a study of performance divided into three cases studies, and an attitudinal study. The information obtained was completed with a fourth qualitative study of the training of teachers who participate in educational technology. This research provides empirical evidence that allows validation of the methodological model developed to explain key concepts and to improve the level of motivation and acceptance of AR technology by students. The proposed model can induce improvements in educational processes in the field of STEAM when used with an immersive AR technological resource and an adapted digital evaluation system. It also demonstrates that teachers require specific training in connection with the creation and the adequate use of AR educational resources, and of digital evaluation systems as well. The results of this study have important implications for the field of education, demonstrating the potential of AR technology to improve learning outcomes and the need for teacher training in its use.

Keywords TEACHING METHODOLOGY, STEAM, AUGMENTED REALITY, EVALUATION METHODS, TEACHER TRAINING

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Corresponding Author
Santiago Delgado-Rodríguez,
sdelgadoro@nebrija.es

Department of Education, Faculty of Languages and Education. University of Nebrija, Spain.

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1 INTRODUCTION

Emerging technologies are causing a change of paradigm in traditional education in the direction of innovative teaching geared towards providing students with skills adapted to present-day society. Together with the digital revolution of recent decades, the global Covid-19 pandemic has highlighted the relevant role of technology in education for both teacher training and for students, and in the teaching-learning process in general. In order to respond to this need, different international STEAM (Science, Technology, Engineering, Arts and Mathematics) initiatives are underway to promote the acquisition of 21st century competences, such as creative thinking, team work, communication and problem solving (Allina, 2017; Haesen & Van De Put, 2018; Perignat & Katz-Buonincontro, 2019).

Technology is a key aspect of all STEAM projects and is essential in almost all professional sectors. The conclusions of several recent studies have suggested that the adequate use of technology has a significant impact in education (Hattie & Yates, 2014; H. Johnson et al., 2019). Moreover, some international reports have revealed the importance of how technological resources are used in educational settings in order to achieve the intended results (Brown et al., 2020). Therefore, involving students in STEAM educational projects is as important as researching how technological advances and mobile devices affect the process of learning (Bulman & Fairlie, 2016; Cabero & Barroso, 2016; Fombona, Pascual, & Pérez, 2020). From a theoretical point of view, it should be mentioned that the current literature lacks studies on the most adequate and effective approach in respect to technological resources, and mode of use, in the field of education (Berlinski & Busso, 2017). However, from an empirical point of view, the educational sector requires practical and verified models to guide teachers regarding the most suitable types of technologies and methodologies and the most adequate and efficient evaluation systems, as well as the most effective manner of integrating the latter in order to maximise their effects and achieve optimum student performance. Indeed, the ultimate objective is to connect technology with the improvement of learning processes in an effective manner.

In recent years, the majority of emerging technologies have gained momentum. The latest Horizon Reports that analyse technologies that will have a significant impact on teaching and learning processes (Alexander et al., 2019; Becker et al., 2018; Brown et al., 2020; L. Johnson et al., 2016) have emphasised the great potential of immersive technologies in the field of education, in particular Augmented Reality (AR) and Virtual Reality (VR). However, more research is still needed to determine their real, specific reach, and the extent of their significance in teaching and learning processes (Brown et al., 2020). In this sense, studies carried out in recent years by Huang and Liaw (2018) and Liu, Li, Cai, and Li (2018) have concluded that VR and AR will be decisive in improving the degree of perceived utility in the first instance and, secondly, in developing positive attitudes amongst teachers and students in connection with the use of technological resources in science subjects.

In general, the use of AR resources in education is more suitable for teachers than the use of resources based on VR (Alalwan et al., 2020). Hence, there is great potential for the effective implementation of AR, in particular for STEAM (Meletiou-Mavrotheris, En, Peters, & Heraud, 2019). AR technology entails the superposition of digital information (images, audio, videos, 3D models, etc.) in a register that is displayed in the existing surroundings, depending on an operator's location or perspective (Garzón & Acevedo, 2019; Sirakaya & Sirakaya, 2018). The combination of real-world elements with virtual information is performed in real time and allows interaction of all senses (Azuma et al., 2001). AR's interactive digital content makes learning more significant and improves academic performance (Cai, Chiang, Sun, Lin, & Lee, 2017). Additionally, the use of multiple senses simultaneously by users favors the processes that strengthen memories and retention of acquired knowledge, which represents a significant improvement in learning processes (Cheng & Tsai, 2013). By means of AR, teachers can materialise abstract concepts to help students visualise and understand challenging subjects (Laine, Nygren, Dirin, & Suk, 2016; Moorhouse, Dieck, & Jung, 2019).

However, it is fundamental important to introduce teachers to the field of AR. Through teacher training, a greater understanding of the practical educational use of this immersive technology can be achieved (Marques & Pombo, 2021). Research on the use of AR in different educational areas has grown in the last few decades. Despite this, its incorporation into the classroom as a teaching resource and as a tool to assist STEAM educational practices has not always been the focus of analysis. Not many teachers currently implement this new tool in their classes and, consequently, only a few select students benefit from AR-enriched learning. Some recent studies have focused on the effects that the generation of learning objects with technologies based on AR could have on students. Findings indicate increased interest in the content, together with an increase in the degree of motivation and academic performance attained by students (Cabero, Barroso, & Gallego, 2018). At present, one of the areas that has been less studied is how the use of AR-based technological resources (Pellas, Fotaris, Kazanidis, & Wells, 2019) improves the acquisition of functional skills by students with special educational needs (SEN). Although results in this area have shown a possible positive impact, it is still necessary to research how to adapt these technological resources for their effective use in education (Sulaiman, Al-Samarraie, Moody, & Zaqout, 2020).

More studies must be carried out with a more significant and representative sample in order to determine the exact effects that can be produced by the different variants of AR-based technologies (geo-localisation, markers, etc.). It is also necessary to specify the pedagogical designs that are most adequate for use, along with their nature and the contexts in which they should be used in order to maximise their possible educational effects (Gandolfi, Ferdig, & Immel, 2018). It is important that these educational STEAM projects are linked to the development of innovative methodologies that include theoretical models and specify evaluation systems and methods that are compatible with AR resources for their efficient implementation in educational environments (Pellas et al., 2019). In this way, it should be possible to establish the methodologies, mechanisms and specific processes needed to effectively integrate the different immersive AR-based technologies into educational contexts (Cabero & Barroso, 2016; Garzón, Pavón, & Baldiris, 2019).

This research study analyses the impact of the use of AR-based technological resources in explaining and understanding certain key concepts in science subjects (Biology and Geology) in obligatory Secondary Education. The study attempts to determine whether an innovative methodology, based on the combination of AR technological elements (used as complementary educational resources), can be effective in the teaching-learning process, as established in the main research objectives shown in Figure 1. The results allow determination of the general characteristics that this methodology must include and the technological resources on which to base it. They also enable identification of the most adequate processes to ensure their effective application, such as a specific digital evaluation.

2 METHODS

Given the nature and the complexity of the empirical research carried out, it is based on four main types of studies (Figure 1): i) exploratory study, ii) performance study, iii) attitudinal study and iv) teacher training study. The selection of the four types of studies was conditioned by the limited bibliographical background and resources, and by the benefits of data triangulation in order to improve the quality of the results obtained. The research entails a mixed methodology that combines qualitative and quantitative studies (León & Montero, 2015). The data were analysed with IBM® SPSS® *Statistics* v.22 software.

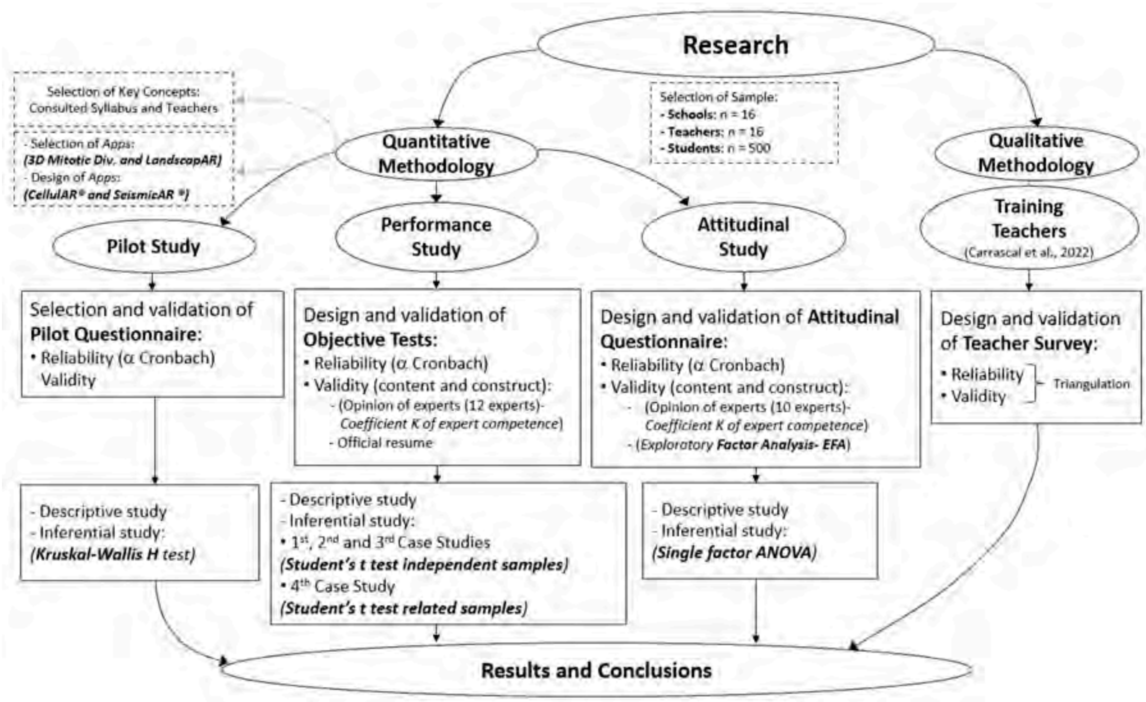

Figure 1 General diagram of the methodology used in the research

2.1 Design of the Research

To carry out the research, experts in the field of education selected four AR-based educational applications that represent four key concepts of the subjects of Biology and Geology, two for each one. The technological resources were (Table 1): *3D Mitotic Division* and *LandscapAR*, available free of charge from Android and iOS stores, and *CellulAR*® and *SeismicAR*® (developed *ad-hoc* by the authors for this study). This approach was aimed at avoiding possible biases provoked by the acquisition of previous knowledge. Additionally, the selection of two pre-existing educational applications, along with the creation of two more *ad hoc*, would avoid the introduction of potential extraneous variables related to design factors. This would also provide participating teachers with the ability to choose from a wider range of key concepts.

Table 1 Technical characterístics of the technological resources based on AR used in this research

Technical Characteristics	Applications Developed				Applications Selected			
	CellulAR®		SeismicAR®		LandscapAR		División Mitótica 3D	
Compatibility	Android 6.0	iOS 8.0	Android 5.0	iOS 11.0	Android 2.3	-	Android 4.4	iOS 7.0
Version	1.2	1.1	1.2	1.1	1.5	-	1.2.4	-
Size	91 MB	200.1 MB	43 MB	80.1 MB	2.5 MB	-	60 MB	162 MB
Location	Google Play	App Store	Google Play	App Store	Google Play	App Store	Google Play	App Store
Availability	Available	Available	Available	Available	Available	Not available	Available	Available
Trademark	Yes		Yes		Yes		Yes	
Developer	MD.USE Innovative Solutions, S.L.		Aumentaty, S.L.		Weekend Labs UG.		LIITEC-ULS Universidad de La Serena	

The different designs used in each type of study are summarised in Figure 2.

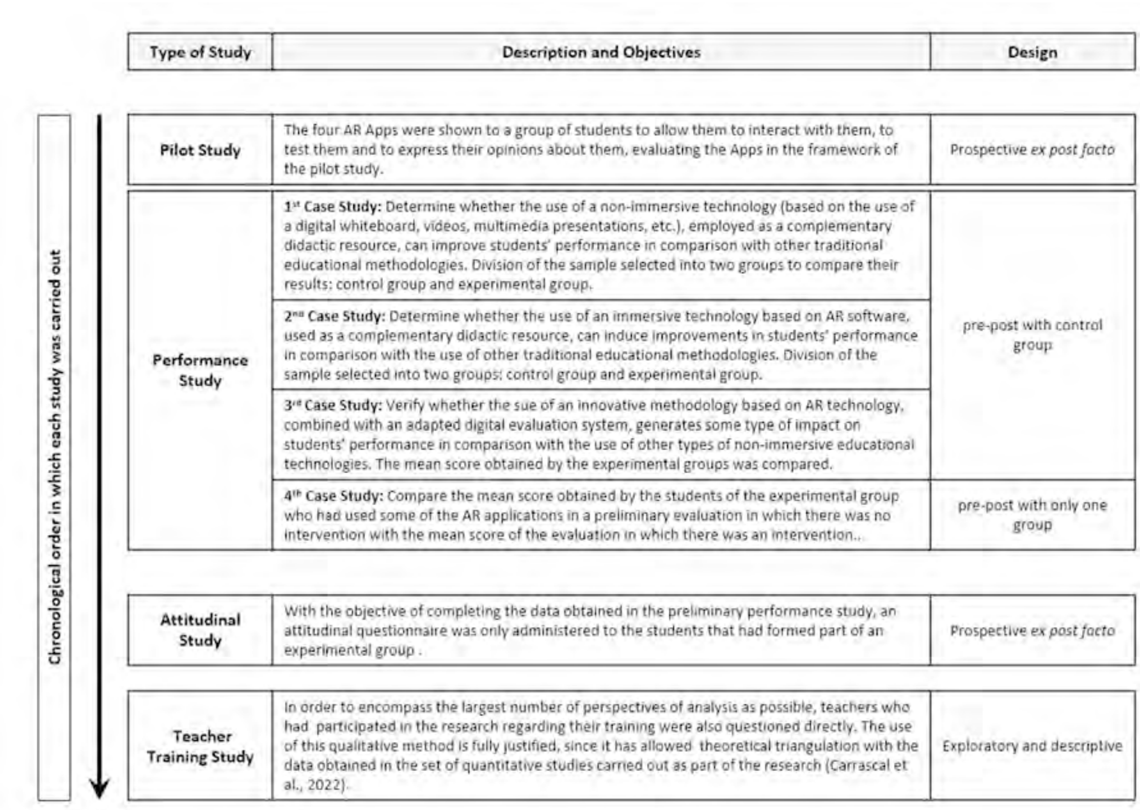

Figure 2 Diagram of the designs used in each type ofstudy

2.2 Design of Instruments

In order to guarantee the full functionality and technical quality of the four AR applications selected and developed *ad-hoc*, they were subject to a process of technical and didactic evaluation (Barroso et al., 2017). The technical evaluation included verifying specific aspects connected to the functioning of and interaction with the virtual objects generated, optimising the modes of visualisation and sequencing between scenes, accessibility of the digital information and ease of navigation. The didactic evaluation was geared at determining students' assessment so as to guarantee its reliability and validity. For this purpose, a ***pilot study*** was carried out, in which students were asked their opinion regarding the technical and aesthetic aspects of the four AR applications, as well as their perception of ease of use. The basic structure of a previously validated questionnaire prepared for the evaluation of virtual educational and training resources in prior research Cabero-Almenara, Llorente-Cejudo, and Gutiérrez-Castillo (2017) was used as a reference, thus ensuring the validity of the content of the questionnaire used (Sáez, 2017).

The instrument designed for the ***study of academic performance*** consists of an objective test prepared *ad-hoc*. Its purpose is to assess the knowledge acquired by the students regarding content taught in accordance with the objectives of the subject's syllabus. All of the items were designed on the basis of the levels of cognitive domain, knowledge and comprehension in the framework of Bloom's Taxonomy (Bloom, 1956). Each one of the four performance tests designed on paper, intended to be used by the control groups, was also designed in digital format as an electronic questionnaire intended for the experimental groups. To determine the validity of the content, a draft of the tests designed was sent to a group of twelve education experts for revision, analysis and evaluation.

An instrument based on an ***attitudinal questionnaire*** was created *ad-hoc* to ask the students belonging to experimental groups about specific aspects in connection with the AR methodology and technology used in the classroom. The instrument was adapted from two models previously proposed by other authors:

1. the *"Technology Acceptance Model" (TAM),* used as a reference to determine the ***Degree of Acceptance*** of the technology by the students in respect to the use of an innovative methodology. This model, proposed by Davis (1989), continues to be used in different research within the framework of the applicability of educational technology (Cabero et al., 2018). Including a study related to the acceptance of AR technology in this research is justified, taking into account that authors such as Scherer, Siddiq, and Tondeur (2020) advocate the need to assess the level of acceptance of the technology in each study, highlighting the importance of not taking it for granted in a general manner.
2. the model proposed by Keller (2010), used as a reference to determine the ***Level of Motivation*** generated in students by the application of the innovative methodology proposed. The *"Instructional Materials Motivation Survey" (IMMS)* was adapted and applied to the specific case study.

In addition to collecting information regarding the main dimensions, i.e. Level of Motivation and Degree of Acceptance, a third dimension was added, initially called ***Degree of Comprehension***.

Initially, the instrument comprised three dimensions, seven indicators and 26 items, to which nine categorical variables were added: *sex, age, student with SEN, name and type of school (public or private with public funding), school's geographic location, experience in the use of AR, habitual use of non-immersive technology in the classroom, habitual use of AR-based technology in the classroom and habitual use of an adapted evaluation system*.

The initial attitudinal questionnaire was sent to a group of 10 scale design experts to ensure the validity of the content. Subsequently, following the recommendations and the criteria established, the initial attitudinal questionnaire was modified and finally consisted of a three dimensional structure, seven indicators and 35 items (Table 2).

Table 2 Final structure of the attitudinal questionnaire designed for the research

Dimensions	Indicators	Items
Degree of Motivation	Attention	1-7
	Confidence	8-11
	Satisfaction	12-16
	Relevance	17-21
Level of Acceptance of AR Technology	Perceived Utility	22-26
	Perceived Ease of Use	27-30
Degree of Comprehension of Key Concepts	Perceived Ease for Comprehension of Key Concepts	31-35

The instrument to assess the ***Level of teacher training*** was designed *ad-hoc*, with the objective of asking each one of the 16 teachers participating in the different phases of the research about their use of educational technology in general (immersive and non-immersive) and about adapted digital evaluation systems. In order to determine the validity of the content, a group of three experts was consulted. Taking into account their opinions and recommendations, the final questionnaire consisted of the following three questions: (1) *As a teacher, had you ever taken, prior to the month of January 2019, a training course related to the use of non-immersive educational technology (use of educational platforms such as Classroom, use of digital boards, programs such as PowerPoint, etc.)?;* (2) *As a teacher, had you ever taken, prior to the month of January 2019, a training course related to immersive educational technology, specifically based on Augmented Reality?*; (3) *As a teacher, had you ever taken, prior to the month of January 2019, a training course related to the use of digital evaluation systems specifically adapted to the use of immersive technology in the classroom?*

In the design of all instruments administered to students for the study, ethical and legal issues covered by the applicable legislation at that time were taken into consideration. The data protection and digital rights legislation was applied, specifically in relation to obtaining the necessary approval from the educational centres to conduct the study in their classrooms, as well as informing the participants about the objectives of the study and the guarantees established to maintain their anonymity and confidentiality.

2.3 Selection of the sample and the participants

Participants in the research consisted of students (n = 500) and teachers (n = 16) of the science subjects of Biology and Geology in fourth year of obligatory Secondary Education. All of the students and teachers were from either public schools (n = 10) or private schools with public funding (n = 6) within the Autonomous Community of Cantabria, in Spain (Table 3). Of the 500 students, 2.2% (n = 11) participated in the pilot study and 97.8% (n = 489) participated in the performance study. In turn, 40.7% (n = 199) of these students who participated in the performance study also participated later in the attitudinal study, having been in the experimental groups that used the AR applications.

The sampling used in this study is probabilistic, random, and multi-stage. First, we selected the educational centres that voluntarily agreed to participate in the study. Then, we chose the course, science subject and, finally, the units of participating students who were already grouped in their respective educational centres.

3 RESULTS

Different statistical analysis techniques were selected depending on each design.

3.1 Quantitative Studies

3.1.1 Exploratory Study

In order to establish the reliability of the instrument administered in the pilot study, Cronbach's Alfa procedure was used to determine the internal consistency index. Alfa values of 0.685 and 0.681 were obtained for the Technical Aspects and Facility of Use aspects, respectively (total value for the questionnaire: 0.682).

In the two dimensions analyzed, the descriptive analysis of the students' answers to the questionnaire reflects scores that are much higher than 3.5, the scale's mean. The data reveal medium-high homogeneity of the answers, indicating evident uniformity of the students' opinions regarding the AR applications.

Given the small number of students that participated in the study, it is assumed that the sample does not present normality in respect to the sample populations, which is why the non-parametric Kruskal-Wallis test was applied (values shown in Table 3).

Table 3 Values obtained with the Kruskal-Wallis test

	Dimensions		
	Technical and Aesthetic Aspects	**Ease of Use**	**Group dimensions**
Chi-square	2,688	1,198	1,614
df	3	3	3
Sig.	0.442	0.753	0.656

It is possible to conclude that the students' assessments of the four AR applications do not present statistically significant differences from one to the other. Ultimately, the selected group of students considered all four selected digital technological learning resources equivalent in terms of their capacity to show the four key concepts selected. These resources were considered to have an equivalent conceptual level, ensuring their reliability and validity.

3.1.2 Study of Performance

Applying Kolmogrov-Smirno's and Shapiro-Wilk's normality tests, significance degrees of p >,05 (*sig.* = .200 and *sig.* = ,685 respectively), were obtained, confirming the normality of the student sample. The empirical data obtained from the field work on the performance tests carried out with the groups of students is summarised in Table 4.

Table 4 Empirical data obtained in the objective academic performance tests

PARTICIPATING SCHOOLS	No. of Groups	CASE STUDY 1		CASES STUDIES 2 and 4			
		Control Group	Experimental Group	Control Group	Experimental Group		
		Mean Score	Mean Score	Mean Score	Mean Score	Group's Mean Score in Preliminary Evaluation	Group's Mean Score in the Evaluation with Intervention
CEC2*	2	-	-	5,02	7,16	6,96	6,85
CEC3	2	-	-	6,67	7,44	-	-
CEC4	2	5,80	6,64	5,80	6,64	6,62	7,08
CEC5	1	-	-	5,33	4,55	6,27	6,64
CEC6	1	5,83	8,96	6,15	4,48	6,74	7,56
CEP7**	2	3,92	5,58	4,84	7,83	6,73	6,32
CEP8	2	-	-	4,49	4,67	5,72	5,52
CEP9	1	4,86	6,22	5,05	4,89	5,30	5,50
CEP10	2	7,56	6,33	6,74	6,44	5,19	5,05
CEP11	2	5,87	4,67	4,56	2,82	5,80	5,70
CEP12	2	3,78	5,87	1,40	2,00	4,38	3,70
CEP13	2	-	-	3,56	3,27	5,25	6,08
CEP14	2	4,95	7,19	5,79	3,73	5,91	5,73
CEP15	2	7,33	7,65	7,13	6,96	7,49	7,62
CEP16	2	6,28	5,79	-	-	-	-
TOTAL MEAN SCORES:		5,62	6,49	5,18	5,21	6,03	6,10

*CEC: Private School with Public Funding; **CEP: Public School

In order to carry out the performance test, four equivalent objective performance tests were created *ad-hoc* (one test for each of the key concepts used). Due to spatial and temporal determinants and limitations, finally only two performance tests were used, corresponding to the Biology and Geology concepts of *Cellular Division* and the *Earth's Internal Structure,* respectively.

Cronbach's Alfa procedure was used to obtain an approximation of the degree of reliability of the instruments used. A value of 0.969 was obtained in respect to Cellular Division, and of 0.956 in the case of the Earth's Internal Structure.

The statistical inference study of the data was structured into four different yet complementary case studies:

3.1.2.1 First Case Study The mean score (5.62) obtained by the ten control groups that used traditional complementary learning resources is compared with the mean score (6.49) obtained by the other ten experimental groups that used the non-immersive technological resource in the classroom. For that purpose, the parametric statistical test for quantitative data known as student's *t* test was used to determine if the means of independent samples are equal (Pardo & San Martín, 2015; Sáez, 2017) (Table 5).

Table 5 Results obtained in Levene's test (quality of variances) and Student's t test (equal means) - First performance case study

		Levene's test of quality of variances		Student's t test for equal means						
		F	Signif.	t	df	Signif. (bilateral)	Difference of means	Difference of standard error	95% confidence interval of difference	
									Lower	*Higher*
Mark Written Performance Test	Equal variances are assumed	0,086	0,773	-1,574	18	0,133	-0,872	0,55414	-2,03621	0,29221
	Equal variances are not assumed			-1,574	17,948	0,133	-0,872	0,55414	-2,03646	0,29246

These results suggest that there are no statistically significant differences between the mean score of the control groups and the experimental groups: t (18) = 1.57, $p > .05$.

3.1.2.2 Second Case Study The mean score (5.22) obtained by the control groups that used traditional complementary learning resources is compared with the mean score (5.08) obtained by the experimental groups that used the AR-based immersive technological resource in the classroom, in combination with a digital evaluation system. In this case, the student's *t* test was applied. Following an analysis of the data obtained, shown in Table 6, it is possible to conclude that there are no statistically significant differences between the mean score of the control groups and that of the experimental groups: t (26) = .22, $p > .05$

3.1.2.3 Third Case Study As a particular case study, the mean score (6.49) obtained by the experimental groups that used non-immersive technology as a technological educational resource was compared with the mean score (5.08) obtained by the experimental groups that used AR-based immersive educational technology combined with a digital evaluation system. Once again, the student's *t* test was applied, with the results shown in Table 7, leading to the conclusion that there are statistically significant differences between the mean scores of the two sets of experimental groups: t (22) = 2.12, $p > .05$. In addition, the effect size calculated is .93, which indicates a large effect in accordance with the criteria established

Table 6 Results obtained in Levene's test (quality of variances) and Student's t test (equal means) - Second performance case study

		Levene's test of quality of variances		Student's t test for equal means						
		F	Signif.	t	df	Signif. (bilateral)	Difference of means	Difference of standard error	95% confidence interval of difference	
									Lower	*Higher*
Mark Written Performance Test	Equal variances are assumed	1,149	0,294	0,224	26	0,825	0,14143	0,63156	-1,15676	1,43962
	Equal variances are not assumed			0,224	25,039	0,825	0,14143	0,63156	-1,15919	1,44205

by Cohen (1992), and a minimum-moderate effect in accordance with criteria established by Ferguson (2009).

Table 7 Results obtained in Levene's test (quality of variances) and Student's t test (equal means) - Third performance case study

		Levene's test of quality of variances		Student's t test for equal means						
		f	Signif.	t	df	Signif. (bilateral)	Difference of means	Difference of standard error	95% confidence interval of difference	
									Lower	*Higher*
Mark Written Performance Test	Equal variances are assumed	2,584	0,122	2,122	22	0,045	1,40786	0,66341	0,03203	2,78369
	Equal variances are not assumed			2,273	21,915	0,033	1,40786	0,61948	0,12284	2,69288

3.1.2.4 Fourth Case Study For the purpose of completing the data obtained in the second case study, the mean scores (6.03) obtained by the students of the experimental groups to which the innovative methodology was applied and who were tested with an adapted digital system (post-test mean) were compared with the mean scores (6.10) obtained by those same students in the evaluation performed prior to the study and the intervention (pre-test mean). The student's *t* test was then applied; however, since related groups were involved, prior application of Levene's test was not an essential requirement. The analysis did not reveal any statistically significant differences between the experimental groups' pre-test and post-test mean scores: t (12) = .61, $p > .05$. (Table 8).

Table 8 Results obtained in the Student's t test - Fourth performance case study

	Mean	Standard deviation	Standard error of mean	95% confidence interval of diference		t	df	Signif. (bilateral)
				Inferior	*Superior*			
Mark Pre - Post Evaluation (AR Intervention Group)	-0.07615	0.45055	0.12496	-0.34842	0.19611	-0.609	12	0.554

3.1.3 Attitudinal Study

The attitudinal study was geared towards trying to answer the following questions:

1. Whether the use of an innovative AR-based methodology and a digital evaluation system has an impact on motivation and the degree of acceptance of the technology;
2. Whether the use of an AR-based technology as a complementary educational resource favours comprehension of any key concept by the students of science subjects in general and by SEN students in particular;
3. What specific variables have a significant impact on factors such as motivation and the degree of acceptance of the technology; and whether these variables have an influence on other possible related factors.

The instrument's internal consistency was determined by means of Cronbach's Alfa coefficient, obtaining a global value of .980.

Considering the questions formulated and in order to establish the possible relationships between the variables and the factors, an Exploratory Factor Analysis (EFA) was carried out (Hair, Black, Babin, & Anderson, 2018). This type of analysis was selected because one of the study's objectives is to verify in an exploratory manner the questionnaire's internal structure by means of its main components, and to determine the possible existence of other factors in the underlying structure (López-Aguado & Gutiérrez-Provecho, 2019). Previously, the coefficients of the correlation matrix were calculated, determining the relationships between the pairs of variables. Barlett's test of Sphericity and the Kaiser Meyer Olkin (KMO) test were used to measure sampling adequacy, obtaining the values shown in Table 9, which verified that the conditions required to carry out the exploratory factor analysis were satisfied.

Table 9 KMO and Bartlett's test for EFA

Kaiser-Meyer-Olkin measure of sampling adequacy		0.956
Bartlett's sphericity test	Aprox. Chi-square	5794,370
	df	595
	Signif.	0,000

Note: Sample N = 199

The exploratory factor analysis was performed using the Principal Components method with ***Varimax*** rotation. For the selection of the specific number of factors and following the criteria established by Abad, Olea, Ponsoda, and García (2011), sedimentation graph analysis (Scree Test) (Figure 3) was chosen as the complementary method. The data obtained from the analysis enabled the suitability of extracting three main factors to be established. This number is considered to be sufficient because it notably reduces the number of initial factors and explains 69.2% of the variance (61.0%, 5.1% and 3.1% for each factor, respectively). The results permitted grouping of the items and designation of the factors (components) as follows: (1) *Level of Motivation:* 18 items; (2) *Degree of Acceptance of the AR Technology:* 15 items; and (3) *Degree of Acceptance of the Adapted Digital Evaluation System:* 2 items.

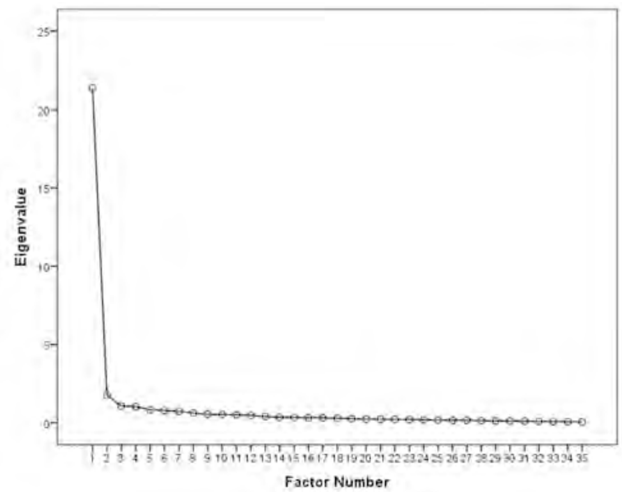

Figure 3 Sedimentation Graph or Scree Test obtained from the Principal Components method

The descriptive analysis of the data obtained from students' answers to the questionnaire reflects mean score values higher than the scale's theoretical mean, i.e. 3.0, in the three dimensions that comprise the attitudinal questionnaire, items 1 to 35.

It should be noted that analysis of the data shows low typical deviations in the assessments carried out by the students, at both the individual and the global level (1.17) of the item, which indicates an average homogeneity and evident uniformity in the answers obtained.

The following independent variables were used to perform the inferential study: *Sex, Student's Age, Condition of Students with Special Educational Needs, Type of School, School's Geographic Location, Habitual Use of Non-Immersive Technology, Habitual Use of AR Tools in the Classroom, Use of VR Tools in the Classroom and Habitual Use of Evaluation Systems Adapted to New Technologies*. The three factor scores obtained were used as dependent variables: *Level of Motivation, Degree of Acceptance of the Technology* and *Degree of Acceptance of an Adapted Digital Evaluation System*. To compare quantitative data with more than two groups, a fully randomised *one-way* ANOVA parametric test was used, obtaining the following results:

The ***Age of Students*** has a statistically significant impact on the level of acceptance of an adapted evaluation system: F (2.157) = 3.03, p = .05 with low-medium strength of association (0.025) (Cohen, 1988). The results of the *post hoc* analysis of the data obtained show that the groups of students aged 16 and 17 or more have higher scores than the other students in the statistic F corresponding to the factor *Degree of Acceptance of an Adapted Digital Evaluation System*. Thus, the students aged 16-17 or more present a greater degree of acceptance of adapted evaluation systems than the other, younger students.

The condition of ***Student with Special Educational Needs*** has a statistically negative impact on the *Degree of Acceptance of Augmented Reality Technology*: F (1.158) = 5.47, p < .05 with low-medium strength of association (.027). A *post hoc* analysis reveals that *Student with Special Educational Needs* has higher scores in the statistic F corresponding to the factor *Degree of Acceptance of Technology* than the other students, suggesting that they present a higher degree of acceptance of AR-based technology in comparison with the other students.

The ***School's Geographic Location*** has a statistically significant impact on both the *Degree of Acceptance of the Technology* and the *Degree of Acceptance of an Adapted Digital Evaluation System,* respectively: F (5.154) = 3.39, p < .05 with a medium strength of association (.07). A more detailed analysis of the data obtained reveals that the students of schools located in towns of more than 10,000 inhabitants and big urban environments obtain higher mean scores in factor F, corresponding to the *Degree of Acceptance of the Technology,* in comparison with students of schools located in towns with fewer inhabitants and environments of smaller municipalities. One hypothesis which may explain these results is the existence of a possible digital gap between urban centres with a high population density and rural centres or areas with a low population density.

The ***Habitual Use of Educational Resources based on AR technology in the Classroom*** has a statistically significant impact on the *Degree of Acceptance of an Adapted Digital Evaluation System*: F (1.158) = 6.37, p < .05 with low-medium strength of association (.033). Moreover, a *post hoc* analysis reveals that the students who use AR resources in class obtain a higher score than the other students in statistic F corresponding to the factor *Degree of Acceptance of an Adapted Digital Evaluation System.* In consequence, it is possible to conclude that students who use AR resources in class have a greater degree of acceptance of adapted evaluation systems in comparison with other students.

3.2 Qualitative Studies

3.2.1 Study Regarding the Teachers' Level of Training

In qualitative research studies, confidence in the results obtained and the security of the conclusions depends on the instrument's reliability and validity (León & Montero, 2015). As a consequence, it is possible to conclude that the security of the results obtained is high, which in turn justifies the high level of confidence in the data offered by the teachers by means of the triangulation process.

The results of the questionnaire administered to the teachers (n = 16) participating in the study reveal the following information:

1. 75.0% of the teachers (n = 12) answered that they had had a training course in connection with the use of a non-immersive educational technology (Item 1).
2. 100.0% of the participating teachers (n = 16) answered that they had never had any training course in connection with an immersive technology applied to education specifically based on AR technology (Item 2).
3. 93.8% of the teachers (n = 15) answered that they had never had any training course in connection with the use of digital evaluation systems adapted to the use of immersive technology in the classroom (Item 3).

4 DISCUSSION AND CONCLUSIONS

This study investigated the impact of an innovative educational methodology using Augmented Reality (AR) technology, combined with an adapted digital evaluation system, on fourth-grade students studying Biology and Geology in secondary education. The study also examined the factors that influence the teaching-learning process in these subjects.

The results are based on the statistical treatment and analysis of the data obtained in each one of the four principal studies into which the research is structured. This procedure, structured in different phases, enabled triangulation of the resulting data to complete the information in order to obtain the final conclusions.

The analysis of students' assessments carried out in the pilot study confirms that the instrument utilised presents adequate technical characteristics for use in the preliminary evaluation of the AR applications employed during the research process. These results support the data obtained in other related studies, such as the one conducted by Cabero-Almenara et al. (2017) in which a similar instrument was used.

The data obtained in the first phase of the performance study reveal a positive improvement in the scores obtained, although it is not significant from a statistical point of view. This supports rejection of the hypothesis that the use of a methodology based on non-immersive educational technology can have a significant impact on students' performance. The analysis of the data obtained in the second phase of the performance study suggests rejecting the hypothesis that the use of an innovative methodology, based on the combination of AR technology and an adapted digital evaluation system can have a significant impact on students' general performance. These results apparently differ from other recent studies that suggest that the use of AR-based technology in Secondary Education led to improvements in the learning process and academic performance (Garzón et al., 2019).

It should be noted that the data analysed show that the students who formed part of the experimental groups, to whom the key concept had been explained with the help of non-immersive technological resources, obtained significantly higher scores, with a large effect size in comparison with the ones obtained by the students in the experimental groups who had had the key concept explained with the help of the AR-based application. This result suggests rejection of the hypothesis that the use of an innovative methodology based on the combination of AR technology and an adapted digital evaluation system can have a positive and significant impact on students' performance in general, in comparison with the use of other non-immersive technologies.

The analysis of students' evaluations, carried out by means of the attitudinal questionnaire, indicates uniformity and reliability. The evaluations provide an argument of validity to determine the acceptance of AR technology by the students, in accordance with the results obtained by other researchers in this field (Scherer et al., 2020). The data obtained from the analysis of the answers indicate that an innovative AR-based methodology to explain key concepts of a subject, combined with an adapted digital evaluation system, has a positive influence on students' level of motivation in general. These data complement the results obtained from quantitative and qualitative data by other researchers in similar studies conducted in the field of Secondary Education (Serio, Ibáñez, & Delgado, 2013).

A positive impact is also generated on the degree of acceptance of AR-based technology in students in general, and it is very significant in the specific case of students with special educational needs, with an effect of low-medium strength. These findings coincide with the conclusions of similar studies carried out in this field (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014; Baragash, Al-Samarraie, Ibrahim, & Alfarraj, 2020; Cabero-Almenara, Barroso-Osuna, Llorente-Cejudo, & Fernández, 2019; Wu, Lee, Chang, & Liang, 2013).

The data analysed in this study regarding the factor structure of the attitudinal questionnaire reveal the existence of a third factor relating to the degree of acceptance of digital evaluation systems adapted to AR-based educational technology, which is positively valued by students in general. The set of three factors, i.e. the level of motivation, the degree of technological acceptance and the degree of acceptance of an adapted digital evaluation system, better represents the structure of the data as a construct. These data suggest the need to incorporate adapted digital evaluation systems as part of educational methodological strategies based on the use of AR immersive technology. This finding is consistent with the hypothesis proposed by some digital technology experts, such as Livingstone (2012) and upheld by Nieto (2016) and Blázquez, Alonso, and Yuste (2017) whereby the use of an innovative methodology in combination with an adapted digital evaluation system enables a positive effect that generates deep methodological changes. These changes are based on specific skills and strategies related to the educational technological resources, which cannot otherwise be effectively produced or quantified with traditional evaluation systems.

The students from schools located in urban environments and towns of more than 10,000 inhabitants show a positive level of acceptance of the adapted digital evaluation system. These students show a greater degree of acceptance than the others of AR technology as an educational resource, suggesting the possible existence of a digital gap between students from urban areas and students from rural areas (Alalwan et al., 2020).

The data obtained indicate that students can understand better key concepts explained by the teacher with the help of an AR application used as an educational resource, upholding the hypothesis that an AR-based technology used as a complementary educational resource can generate a positive impact on students' academic performance and comprehension.

The results of the analysis of the data indicate the existence of a statistically significant effect between the personal use of AR-based applications by some students in their personal environment and their willingness to use this technology for educational purposes. These data extend the results obtained in similar research and are also in line with the research carried out in this field by Cai et al. (2017), Ibáñez, Serio, Villarán, and Delgado (2014), and Sahin and Yilmaz (2020) to determine the possible impact the use of this technology could generate on learning and on improvements in associated cognitive processes in comparison with other traditional non-immersive didactic methods and resources.

From a theoretical point of view, the proposed methodological design should generate gains in the learning processes. However, in light of the empirical results obtained, the fact that there is no impact on the performance of the students of the sample in comparison with the use of non-immersive technology, or even in comparison with a traditional classroom, requires consideration.

Hence, it should be noted that the results obtained that are related to teachers' level of training reveal that the majority of the teachers who participated in the study had prior training in non-immersive educational technology. In contrast, none of the participating teachers had ever received any kind of specific training related to AR-based immersive technology, and only one had received previous training specifically related to adapted digital evaluation systems.

These data coincide with those of other researchers such as Alalwan et al. (2020), who reported a generalised lack of comprehension of the appropriate manner in which immersive technology should be used in order to optimise its effects in learning, and the lack of specific teacher training on the correct use of said technology. In this sense, Scherer et al. (2020) contemplated the need to analyse the principal causes that condition acceptance of the technology by teachers in educational environments. Marques and Pombo (2020) revealed a positive disposition on the part of teachers towards the use of this type of educational technology, and indicated that they must be given specific training to develop concrete skills to enable the correct use of technological resources and the specific attitudes and knowledge to apply them. The analysis of the data obtained supports the hypothesis that teachers' specific training in immersive educational technology has a significant impact on teaching and learning processes that integrate innovative methodologies based on immersive technological resources and adapted digital evaluation systems. Said data coincide with the opinion of educational experts who have found improvements in students' performance linked to their use of technological resources depending, in turn, on the specific training of teachers in connection with the specific use of educational technology (Blázquez et al., 2017).

The results of this research coincide with those obtained by Nieto (2016) and by Spiteri and Rundgren (2020), who concluded that technology in general and immersive technology in particular cannot, on its own, generate a greater impact on students' learning experience. Similar conclusions have been reflected in international reports, such as Brown et al. (2020).

On the basis of the results of this multidisciplinary study, the findings obtained allow the empirical validation of the theoretical-educational model proposed, provided that the teachers involved in the educational processes have specific training for its implementation and development in the framework of STEAM education.

5 AUTHOR'S CONTRIBUTIONS

S. D and S. C. conceived of the study. R. G.-F. and S. D. developed the Augmented Reality applications. S. D. performed the study. S. C. and R. G.-F. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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REFERENCES

Abad, F., Olea, J., Ponsoda, V., & García, C. (2011). *Medición en ciencias sociales y de la salud*. Síntesis.

Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Alzahrani, A., & Sarsam, S. (2020). Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective. *Studies in Educational Evaluation*, *66*(100876). https://doi.org/10.1016/j.stueduc.2020.100876

Alexander, B., Ashford-Rowe, K., Barajas-Murphy, N., Dobbin, G., Knott, J., Mccormack, M., … Weber, N. (2019). *EDUCAUSE Horizon Report 2019: Higher Education Edition*. EDUCAUSE. Retrieved from https://library.educause.edu

Allina, B. (2017). The development of STEAM educational policy to promote student creativity and social empowerment. *Arts Education Policy Review*, *119*(2), 77–87. https://doi.org/10.1080/10632913.2017.1296392

Azuma, R., Baillot, Y., Baillot, Y., Feiner, S., Julier, S., & Macintyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, *21*(6), 34–47. https://doi.org/10.1109/38.963459

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented Reality Trends in Education: A Systematic Review of Research and Applications. *Educational Technology & Society*, *17*(4), 133–149.

Baragash, R., Al-Samarraie, H., Ibrahim, A. A., & Alfarraj, O. (2020). Augmented reality in special education: a meta-analysis of single-subject design studies. *European Journal of Special Needs Education*, *35*(3), 382–397. https://doi.org/10.1080/08856257.2019.1703548

Barroso, J., Cabero, J., García, F., Calle, F., Gallego, Ó., & Casado, I. (2017). *Diseño, producción, evaluación y utilización educativa de la Realidad Aumentada*. Sevilla, Anadalucía, España. Retrieved from https://grupotecnologiaeducativa.es

Becker, A., Brown, S., Dahlstrom, M., Davis, E., Depaul, A., Diaz, K., … J (2018). *NMC Horizon Report: 2018 Higher Education Edition*. EDUCAUSE. Retrieved from https://library.educause.edu

Berlinski, S., & Busso, M. (2017). Challenges in educational reform: An experiment on active learning in mathematics. *Economics Letters*(156), 172–175. https://doi.org/10.1016/j.econlet.2017.05.007

Blázquez, F., Alonso, L., & Yuste, R. (2017). *La evaluación en la era digital* (1st ed.). Síntesis.

Bloom, B. (1956). *Taxonomy of Educational Objectives, Handbook 1: Cognitive Domain* (2nd ed.). Addison Wesley Publishing Company.

Brown, M., Mccormack, M., Reeves, J., Brooks, C., Grajek, G., Alexander, B., … Weber, N. (2020). *2020 EDUCAUSE Horizon Report, Teaching and Learning Edition*. Retrieved from https://library.educause.edu

Bulman, G., & Fairlie, R. (2016). Technology and Education: Computers, Software, and the Internet. *Handbook of the Economics of Education*, *5*, 239–280.

Cabero, J., & Barroso, J. (2016). The educational possibilities of Augmented Reality. *Journal of New Approaches in Educational Research*, *5*(1), 44–50. https://doi.org/10.7821/naer.2016.1.140

Cabero, J., Barroso, J., & Gallego, Ó. (2018). La producción de objetos de aprendizaje en realidad aumentada por los estudiantes. Los estudiantes como prosumidores de información. *Ciencia y Educación*(11), 15–16.

Cabero-Almenara, J., Barroso-Osuna, J., Llorente-Cejudo, C., & Fernández, M. (2019). Educational Uses of Augmented Reality (AR): Experiences in Educational Science. *Sustainability*, *11*(18). https://doi.org/10.3390/su11184990

Cabero-Almenara, J., Llorente-Cejudo, C., & Gutiérrez-Castillo, J. (2017). Evaluación por y desde los usuarios: objetos de aprendizaje con Realidad Aumentada. *Revista De Educación a Distancia (RED)*, *17*(53). Retrieved from https://revistas.um.es

Cai, S., Chiang, F. K., Sun, Y., Lin, C., & Lee, J. (2017). Applications of augmented reality-based natural interactive learning in magnetic field instruction. *Interactive Learning Environments*, *25*(6), 778–791. https://doi.org/10.1080/10494820.2016.1181094

Carrascal, S., Delgado-Rodríguez, S., & García-Fandiño, R. (2022). Retos del profesorado en los nuevos contextos de enseñanza-aprendizaje. Innovación educativa en asignaturas de ciencias de Educación Secundaria con recursos tecnológicos inmersivos. *Docencia y Aprendizaje. Competencias, identidad y formación de profesorado* (pp. 727–746). Tirant Humanidades.

Cheng, K. H., & Tsai, C. C. (2013). Affordances of Augmented Reality in Science Learning: Suggestions for Future Research. *Journal of Science Education and Technology*, *22*(4), 449–462. https://doi.org/10.1007/s10956-012-9405-9

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. Lawrence Erlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340.

Ferguson, C. (2009). An effect size primer: A guide for clinicians and researchers. *Professional*

Psychology: Research and Practice, *40*(5), 532–538. https://doi.org/10.1037/a0015808

Fombona, J., Pascual, M. A., & Pérez, M. (2020). Analysis of the Educational Impact of M-Learning and Related Scientific Research. *Journal of New Approaches in Educational Research*, *9*(2), 167–180. https://doi.org/10.7821/naer.2020.7.470

Gandolfi, E., Ferdig, R., & Immel, Z. (2018). Educational Opportunities for Augmented Reality. In J. Voogt, G. Knezek, R. Christensen, & y K.-W. Lai (Eds.), *Second Handbook of Information Technology in Primary and Secondary Education* (pp. 967–979). Springer. Retrieved from https://doi.org/10.1007/978-3-319-53803-7_112-1

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review*, *27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta analysis of augmented reality. *Virtual Reality*, *23*, 447–459. https://doi.org/10.1007/s10055-019-00379-9

Haesen, S., & Van De Put, E. (2018). *STEAM Education in Europe: A Comparative Analysis Report*. EuroSTEAM. Retrieved from http://www.eurosteamproject.eu http://www.eurosteamproject.eu

Hair, J., Black, W., Babin, B., & Anderson, R. (2018). *Multivariate Data Analysis* (8th ed.). Cengage Learning, EMEA.

Hattie, J., & Yates, G. (2014). *Visible Learning and the Science of How We Learn*. Routledge.

Huang, H. M., & Liaw, S. S. (2018). The International Review of Research in Open and Distributed Learning. *An Analysis of Learners' Intentions Toward Virtual Reality Learning Based on Constructivist and Technology Acceptance Approaches*, *19*(1). https://doi.org/10.19173/irrodl.v19i1.2503

Ibáñez, M., Serio, A. D., Villarán, D., & Delgado, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education*, *71*, 1–13. https://doi.org/10.1016/j.compedu.2012.03.002

Johnson, H., Mcnally, S., Rolfe, H., Ruiz-Valenzuela, J., Savage, R., Vousden, J., & Wood, C. (2019). Teaching Assistants, Computers and Classroom Management. *Labour Economics*, *58*, 21–36. https://doi.org/10.1016/j.labeco.2019.02.006

Johnson, L., Becker, A., Cummins, S., Estrada, M., Freeman, V., Hall, A., & C. (2016). *NMC Informe Horizon 2016 Edición Superior de Educación*. The New Media Consortium.

Keller, J. (2010). *Motivational Design for Learning and Performance. The ARCS Model Approach*. Springer.

Laine, T., Nygren, E., Dirin, A., & Suk, H. J. (2016). Science Spots AR: a platform for science learning games with augmented reality. *Educational Technology Research and Development*(64), 507–531. https://doi.org/10.1007/s11423-015-9419-0

León, O., & Montero, I. (2015). *Métodos de investigación en Psicología y Educación. Las tradiciones cuantitativa y cualitativa*. McGraw-Hill.

Liu, E., Li, Y., Cai, S., & Li, X. (2018). The Effect of Augmented Reality in Solid Geometry Class on Students' Learning Performance and Attitudes. In M. Auer & R. Langmann (Eds.), *Smart Industry & Smart Education. REV 2018. Lecture Notes in Networks and Systems* (Vol. 47, pp. 549–558). Springer. https://doi.org/10.1007/978-3-319-95678-7_61

Livingstone, S. (2012). Critical reflections on the benefits of ICT in education. *Oxford Review of Education*, *38*(1), 9–24. https://doi.org/10.1080/03054985.2011.577938

López-Aguado, M., & Gutiérrez-Provecho, L. (2019). Cómo realizar e interpretar un análisis factorial exploratorio utilizando SPSS. *REIRE Revista d'Innovació i Recerca en Educació*, *12*(2), 1–14. https://doi.org/10.1344/reire2019.12.227057c

Marques, M., & Pombo, L. (2020). Game-Based Mobile Learning with Augmented Reality: Are

Teachers Ready to Adopt It. *Project and Design Literacy as Cornerstones of Smart Education*, *158*, 207–218.

Marques, M., & Pombo, L. (2021). The Impact of Teacher Training Using Mobile Augmented Reality Games on Their Professional Development. *Education Sciences*(404), 11–11. https://doi.org/10.3390/educsci11080404

Meletiou-Mavrotheris, M., En, M., Peters, Y. R., & Heraud. (2019). Augmented Reality in STEAM Education. *Encyclopedia of Educational Innovation* (pp. 1–6). Springer. https://doi.org/10.1007/978-981-13-2262-4_128-1

Moorhouse, N., Dieck, M., & Jung, T. (2019). An experiential view to children learning in museums with Augmented Reality. *Museum Management and Curatorship*, *34*(4), 402–418. https://doi.org/10.1080/09647775.2019.1578991

Nieto, E. (2016). El papel de las tecnologías en el desarrollo de los aprendizajes y en la mejora del rendimiento académico. In M. Rodríguez, E. Nieto, & R. Sumozas (Eds.), *Las tecnologías en educación. Hacia la calidad educativa* (pp. 17–33). Síntesis.

Pardo, A., & San Martín, R. (2015). *Análisis de datos en ciencias sociales y de la salud II*.

Pellas, N., Fotaris, P., Kazanidis, I., & Wells, D. (2019). Augmenting the learning experience in primary and secondary school. *Virtual Reality*, *23*(4), 329–346. https://doi.org/10.1007/s10055-018-0347-2

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*(43). https://doi.org/10.1016/j.tsc.2018.10.002

Sáez, J. (2017). *Investigación educativa. Fundamentos teóricos, procesos y elementos prácticos*. UNED.

Sahin, D., & Yilmaz, R. (2020). The effect of Augmented Reality Technology on middle school students. *Computers & Education*, *144*(103710). https://doi.org/10.1016/j.compedu.2019.103710

Scherer, R., Siddiq, F., & Tondeur, J. (2020). All the same or different? Revisiting measures of teachers' technology acceptance. *Computers & Education*, *143*.

Serio, A., Ibáñez, M., & Delgado, C. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education*, *68*, 586–596. https://doi.org/10.1016/j.compedu.2012.03.002

Sirakaya, M., & Sirakaya, D. (2018). Trends in Educational Augmented Reality Studies: A Systematic Review. *Malaysian Online Journal of Educational Technology*, *6*(2), 60–74. https://doi.org/10.17220/mojet.2018.02.005

Spiteri, M., & Rundgren, S.-N. C. (2020). Literature Review on the Factors Affecting Primary Teachers' Use of Digital Technology. *Technology, Knowledge and Learning*, *25*, 115–128. https://doi.org/10.1007/s10758-018-9376-x

Sulaiman, R., Al-Samarraie, H., Moody, L., & Zaqout, F. (2020). Augmented Reality and Functional Skills Acquisition Among Individuals with Special Needs: A Meta-Analysis of Group Design Studies. *Journal of Special Education Technology*, *37*(1), 1–8. https://doi.org/10.1177/0162643420910413

Wu, H. K., Lee, S. Y., Chang, H. Y., & Liang, J. C. (2013). Current Status, Opportunities and Challenges of Augmented Reality in Education. *Computers and Education*, *62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024