FRAMEWORK FOR THE DESIGN AND DEVELOPMENT OF MOTIVATIONAL AUGMENTED REALITY LEARNING EXPERIENCES IN VOCATIONAL EDUCATION AND TRAINING

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Universitat de Girona

Doctoral Thesis

Framework for the Design and Development of Motivational Augmented Reality Learning Experiences in Vocational Education and Training

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That the thesis entitled "Framework for the design and development of motivational augmented reality learning experiences in vocational education and training" to obtain a doctoral degree, has been completed under my supervision / co-supervision and meets the requirements to opt for an International Doctorate.

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List of acronyms

6-VARLE – 6 Variables of an AR Learning Experience
ACM – Association for Computing Machinery
ALT – Academic Learning Time
ANOVA – Analysis of variance
AR – Augmented Reality
ARAVET – Augmented Reality in the field of Vocational Education and Training
ARCS – Attention, Relevance, Confidence, Satisfaction
ARMotiD – Augmented Reality Motivational Design
AST - Automotive Service Technicians
BCDS – Comunicasions i Sistemes Ditribuits Research Group
Co-Creation – Collaborative Creation
GPS – Global Positioning System
HDM – Head-mounted displays
IA-OER – Inclusive and Accessible Open Educational Resources
IMMS – Instructional Materials Motivation Survey
JCR – Journal Citation Reports
LARGE – Learning Augmented Reality Global Environment
MARAELS – Mobile AR Assisted English Learning System
MOA – Motivation-Opportunity-Ability
MOOC – Massive Open Online Courses
MR – Mixed Reality
OM – Optimal Matching
Paint-cAR – Augmented Reality Paint Car application
PC – Personal computer
PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QR code - Quick Response code
QUORUM – Quality of Reporting of Meta-analysis
SSCI – Social Sciences Citation Index
SCI – Sciences Citation Index
TAM – Technology Acceptance Model
TMH – Telepresence Mediation Hypothesis
UDI – Universal Design of Instruction
UDL – Universal Design for Learning
UD – Universal Design
UID - Universal Instructional Design
VET – Vocational Educational and Training
VIF – Variation Inflation Factor
VR – Virtual Reality

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Abstract

The concept of AR (Augmented Reality) was coined in contexts of training and maintenance when the first Head-mounted display was designed to assist maintenance operations of aircrafts. Since that moment, there has been an increasing interest in using AR in a wide variety of fields such as marketing, architecture and construction, entertainment, medical and military applications, tourism, and education among others. In the field of education, AR has been applied to create learning experiences in almost every educational level from early childhood education to higher education.

Consequently, research on AR in education has reported that one of the most important advantages of AR in education is that AR applications increase student motivation. Hence, if AR applications increase motivation, AR applications have been designed with components or modules that create a learning experience that positively affect student motivation. However, from a systematic literature review that we conducted we identified that current research on AR in education falls short in clearly reporting which are the components or modules of AR applications that may increase student motivation. The identification of these components or modules of AR applications that increase student motivation may help to identify the predictors of student motivation in AR learning experiences. Moreover, we identified that current research fall short in providing guidelines to inform the design and development of AR learning experiences that increase motivation or what we call *motivational AR learning experiences* in the context of the Vocational Education and Training level of education. Finally, we identified that little has been done in the identification of the possibilities for using AR in the VET level of education. Consequently, in this thesis we focused on these open issues and the research questions that drive this thesis are: 1) Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education? 2) Can the design and development of motivational AR learning experiences based on the framework positively impact student motivation?.

Aligned with these research questions, we hypothesize that the identification of the modules or components of AR applications that increase motivation and the subsequent identification of the predictors of student motivation in AR learning experiences may help to identify the components that should be considered in a framework for the design and development of motivational AR learning experiences for the VET level of education. We also hypothesize that the provision of guidelines in a framework to inform the design and development of motivational AR learning experiences may help to create learning experiences with AR for the VET level of education that effectively support student motivation.

To address these research questions and as a major contribution of this thesis, we defined a framework for the design and development of motivational AR learning experiences for the VET level of education. This framework provides guidelines for the design and development of AR applications to effectively support student motivation. The framework is based on three theoretical underpinnings: motivational design, Universal Design for Learning (UDL) and Co-creation.

To define the framework, first we conducted two exploratory studies in which we designed and developed a mobile AR application called Paint-cAR that was co-created with teachers and tested in the VET programme of Car's Maintenance. From these exploratory studies we gained insights into the impact that an AR application may have on student motivation and we ensured that the application effectively sustained student motivation. Then, we identified the predictors of student motivation with data gathered in the second exploratory study from two sources: the interaction of students with the modules of the Paint-cAR application and the Instructional Materials Motivation Survey (IMMS). The five predictors of student motivation that we identified are: *Use of scaffolding*, *Degree of success*, *Real-time feedback*, *Time on-task* and *Watching videos*. We also identified the relationships between these five predictors and the four dimensions of the ARCS (*Attention*, *Relevance*, *Confidence* and *Satisfaction*) model of motivation. Thus, the predictors of student motivation were one of the inputs for defining the framework together with findings in the literature and our experience in the development of the Paint-cAR application. The framework was validated in the VET programme of Laboratory Operations in the context of the Chemistry learning domain. The results showed that the framework is a decoupled framework and demonstrated that the framework allows creating motivational AR learning experiences.

Consequently, this thesis contributes to the knowledge in the field of AR in VET education in the following aspects:

1) We identified the predictors of student motivation in AR learning experiences in the VET level of education, some variables associated to an AR learning experience in VET were identified and we described the implications of these predictors for the design and development of AR learning experiences.

2) We defined a framework to inform the design and development of motivational AR learning experiences for the VET level of education.

3) We confirmed that AR positively impact on student motivation in VET.

4) We defined a methodology for the co-creation of AR applications and we showed how we applied the methodology for creating two AR applications in the VET level of education.

Resumen

El concepto de RA (Realidad Aumentada) fue acuñado en contextos de formación y mantenimiento cuando el primer visor de realidad aumentada fue diseñado para asistir operaciones de mantenimiento de aviones. Desde aquel momento ha habido un creciente interés en usar la RA en una amplia variedad de campos tales como el marketing, la arquitectura y la construcción, el entretenimiento, aplicaciones médicas y militares, turismo y educación. En el campo de la educación, la RA ha sido aplicada para crear experiencias de aprendizaje en casi todos los niveles educativos desde la educación infantil hasta la educación superior.

En consecuencia, la investigación sobre RA en educación ha reportado que una de las ventajas más importantes de la RA en educación es que las aplicaciones de RA incrementan la motivación del estudiante. Por tanto, si las aplicaciones de RA incrementan la motivación, entonces las aplicaciones de RA han sido diseñadas con módulos y componentes que afectan de forma positiva la motivación del estudiante. Sin embargo, a partir de una revisión sistemática de literatura que realizamos, hemos identificado que la investigación actual en RA en educación no reporta claramente cuáles son los componentes o módulos de las aplicaciones con RA que incrementan la motivación del estudiante. La identificación de estos componentes o módulos de las aplicaciones con RA que incrementan la motivación puede ayudar a identificar los predictores de la motivación del estudiante en experiencias de aprendizaje con RA. Además, hemos identificado que los estudios existentes no proveen pautas que orienten el diseño de experiencias de RA que incrementen la motivación (que hemos denominado como *experiencias de aprendizaje con RA motivadoras*). Finalmente, hemos identificado que se ha hecho muy poco respecto a la identificación de posibilidades de uso de la RA en entornos de formación vocacional. En esta tesis nos enfocamos en estas preguntas abiertas y por tanto las preguntas de investigación que guían esta tesis son: 1) ¿Cuáles son los componentes que deberían ser considerados en un framework para el diseño y desarrollo de experiencias de aprendizaje con RA motivadoras para el nivel educativo de formación vocacional? 2) ¿El diseño y desarrollo de experiencias de aprendizaje con RA motivadoras basadas en el framework puede impactar de forma positiva en la motivación del estudiante?

Alineados con estas preguntas de investigación, planteamos la hipótesis de que la identificación de los módulos o componentes de las aplicaciones con RA que incrementan la motivación y la identificación de los predictores de la motivación del estudiante en experiencias con RA pueden ayudar a identificar los componentes que deberían ser considerados en un framework para el diseño y desarrollo de experiencias de aprendizaje con RA motivadoras para el nivel educativo de formación vocacional. También hemos planteado la hipótesis de que la generación de pautas en un framework para el diseño y desarrollo de experiencias de aprendizaje con RA motivadoras puede ayudar a crear experiencias de aprendizaje con RA para el nivel educativo de formación vocacional que apoyan de forma efectiva la motivación del estudiante.

Para responder a estas preguntas de investigación y como contribución más importante de esta tesis, hemos definido un framework para el diseño y desarrollo de experiencias de aprendizaje con RA motivadoras para el nivel educativo de formación vocacional. Este framework provee las pautas para el diseño y desarrollo de aplicaciones de RA que apoyan de forma efectiva la motivación del estudiante. El framework propuesto está basado en tres fundamentos teóricos: diseño motivacional, Diseño Universal para el Aprendizaje (DUA) y Co-creación.

Para definir el framework, en primer lugar llevamos a cabo dos estudios exploratorios en los cuales se diseñó y desarrolló una aplicación móvil de RA denominada Paint-cAR que fue co-creada con profesores y probada en el programa de formación vocacional en mantenimiento de vehículos. En estos escenarios exploratorios hemos identificado indicios sobre el impacto que tiene una aplicación de RA en la motivación del estudiante y nos aseguramos que la aplicación mantenía la motivación del estudiante. Posteriormente, identificamos los predictores de la motivación del estudiante con datos recopilados a partir del segundo estudio exploratorio obtenidos de dos fuentes de información: la interacción de los estudiantes con los módulos de la aplicación de RA y la encuesta IMMS (Instructional Materials Motivation Survey). Los cinco predictores de la motivación del estudiante que hemos identificado son: Uso del andamiaje (Scaffolding), grado de éxito, retroalimentación en tiempo real, tiempo en la actividad y visualización de videos. También identificamos las relaciones entre estos cinco predictores y las cuatro dimensiones del modelo de motivación ARCS (Atención, Relevancia, Confianza, Satisfacción). Así, los predictores de la motivación del estudiante fueron una de las fuentes para la definición del framework junto con los hallazgos en la literatura y con nuestra experiencia durante el desarrollo de la aplicación Paint-cAR. El framework fue validado en el programa de formación vocacional en Operaciones de Laboratorio. Los resultados obtenidos muestran que el framework es desacoplable y que permite la creación de experiencias de aprendizaje con RA motivadoras.

En consecuencia, esta tesis contribuye al conocimiento en el área de la RA en educación en los siguientes aspectos:

1) Identificación de los predictores de la motivación del estudiante en experiencias de aprendizaje con RA en el nivel educativo de formación vocacional. Además, hemos descrito las implicaciones de estos predictores para el diseño y desarrollo de experiencias de aprendizaje con RA.
2) Definición de un framework para orientar el diseño y desarrollo de experiencias de aprendizaje con RA motivadoras para el nivel educativo de formación vocacional.
3) Confirmación de que la RA afecta de forma positiva la motivación del estudiante en formación vocacional.
4) Definición de una metodología para la co-creación de aplicaciones de RA y aplicación de la metodología para la creación de dos aplicaciones de RA para el nivel educativo de formación vocacional.

Resum

El concepte de RA (Realitat Augmentada) va ser acunyat en contextes de formació i manteniment quan el primer visor de realitat augmentada va ser dissenyat per assistir operacions de manteniment d'avions. Des d'aquell moment hi ha hagut un creixent interès a usar la RA en una àmplia varietat de camps com ara el màrqueting, l'arquitectura i la construcció, l'entreteniment, aplicacions mèdiques i militars, turisme i educació. En el camp de l'educació, la RA ha estat aplicada per crear experiències d'aprenentatge en gairebé tots els nivells educatius des de l'educació infantil fins a l'educació superior.

En conseqüència, la investigació sobre RA en educació ha reportat que un dels avantatges més importants de la RA en educació és que les aplicacions de RA incrementen la motivació de l'estudiant. Per tant, si les aplicacions de RA incrementen la motivació, llavors les aplicacions de RA han estat dissenyades amb mòduls i components que afecten de manera positiva la motivació de l'estudiant. No obstant això, a partir d'una revisió sistemàtica de literatura que vam realitzar, hem identificat que la investigació actual en RA en educació no reporta clarament quins són els components o mòduls de les aplicacions amb RA que incrementen la motivació de l'estudiant. La identificació d'aquests components o mòduls de les aplicacions amb RA que incrementen la motivació pot ajudar a identificar els predictors de la motivació de l'estudiant en experiències d'aprenentatge amb RA. A més, hem identificat que els estudis existents no proveeixen pautes que orientin el disseny d'experiències de RA que incrementin la motivació (que hem anomenat experiències d'aprenentatge amb RA motivadores). Finalment, hem identificat que s'ha fet molt poc pel que fa a la identificació de possibilitats d'ús de la RA en entorns de formació vocacional. En aquesta tesi ens enfoquem en aquestes preguntes obertes i per tant les preguntes de recerca que guien aquesta tesi són: 1) Quins són els components que haurien de ser considerats en un framework per al disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores per al nivell educatiu de formació vocacional? 2) El disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores basades en el framework pot impactar de manera positiva en la motivació de l'estudiant?

Alineats amb aquestes preguntes d'investigació, vam plantejar la hipòtesi de que la identificació dels mòduls o components de les aplicacions amb RA que incrementen la motivació i la identificació dels predictors de la motivació de l'estudiant en experiències amb RA poden ajudar a identificar els components que haurien de ser considerats en un framework per al disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores per al nivell educatiu de formació vocacional. També hem plantejat la hipòtesi de que la generació de pautes en un framework per al disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores pot ajudar a crear experiències d'aprenentatge amb RA per al nivell educatiu de formació vocacional que donen suport de manera efectiva la motivació del estudiant.

Per respondre a aquestes preguntes d'investigació i com contribució més important d'aquesta tesi, hem definit un framework per al disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores per al nivell educatiu de formació vocacional. Aquest framework proveeix les pautes per al disseny i desenvolupament d'aplicacions de RA que donen suport de manera efectiva la motivació de l'estudiant. El framework proposat està basat en tres fonaments teòrics: disseny motivacional, Disseny Universal per a l'Aprenentatge (DUA) i Co-creació.

Per definir el framework, en primer lloc vam dur a terme dos estudis exploratoris en els quals es va dissenyar i desenvolupar una aplicació mòbil de RA anomenada Paint-cAR que va ser co-creada amb professors i provada en el programa de formació vocacional en manteniment de vehicles. En aquests escenaris exploratoris hem identificat indicis sobre l'impacte d'una aplicació de RA en la motivació de l'estudiant i ens assegurem que l'aplicació mantenia la motivació de l'estudiant. Posteriorment, vam identificar els predictors de la motivació de l'estudiant amb dades recopilades a partir del segon estudi exploratori obtingudes de dues fonts d'informació: la interacció dels estudiants amb els mòduls de l'aplicació de RA i l'enquesta IMMS (Instructional Materials Motivation Survey). Els cinc predictors de la motivació de l'estudiant que nosaltres identifiquem són: Ús de la bastida (Scaffolding), grau d'èxit, retroalimentació en temps real, temps en l'activitat i visualització de vídeos. També vam identificar les relacions entre aquests cinc predictors i les quatre dimensions del model de motivació ARCS (Atenció, Rellevància, Confiança, Satisfacció). Així, els predictors de la motivació de l'estudiant van ser una de les fonts per a la definició del framework amb les troballes en la literatura i amb la nostra experiència durant el desenvolupament de l'aplicació Paint-cAR. El framework va ser validat en el programa de formació vocacional en Operacions de Laboratori. Els resultats obtinguts mostren que el framework és desacoplable i que permet la creació d'experiències d'aprenentatge amb RA motivadores.

En conseqüència, aquesta tesi contribueix al coneixement en l'àrea de la RA en educació en els següents aspectes:

1) Identificació dels predictors de la motivació de l'estudiant en experiències d'aprenentatge amb RA en el nivell educatiu de formació vocacional. A més, hem descrit les implicacions d'aquests predictors per al disseny i desenvolupament d'experiències d'aprenentatge amb RA.

2) Definició d'un framework per a orientar el disseny i desenvolupament d'experiències d'aprenentatge amb RA motivadores per al nivell educatiu de formació vocacional.

3) Confirmación de que la RA afecta de forma positiva la motivación del estudiante en formación vocacional.

4) Definició d'una metodologia per a la co-creació d'aplicacions de RA i aplicació de la metodología per a la creació de dues aplicacions de RA per al nivell educatiu de formació vocacional.

PART 1
CONTEXTUALIZATION

CHAPTER 1
INTRODUCTION

1.1 MOTIVATION

The concept of Augmented Reality (AR) was coined in context of training and maintenance when Caudell and Mizell, (1992) introduced a Head-mounted display for assisting maintenance in the aircraft industry. Since that moment, AR has been extensively used for assisting maintenance and repairing tasks in a wide variety of fields in industry (Ong, Yuan, & Nee, 2008). AR is defined as a technology that “allows the user to see the real world, with virtual objects superimposed upon or composited with the real world” (Azuma, 1997). Nowadays, AR technology is still a topic of increasing interest in manufacturing and industrial maintenance (Syberfeldt *et al.*, 2016; Borsci, Lawson and Broome, 2015). However, AR has also spread to many other fields such as marketing, architecture and construction, entertainment, medical and military applications, tourism, education and others (Yuen, Yaoyuneyong, & Johnson, 2011; Yang, 2015). AR technology is rapidly evolving and research on AR in education is also evolving quickly (Santos et al., 2014; Saidin, Abd Halim, & Yahaya, 2015; Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014).

The increasing interest in using AR in education has led to the creation of *AR learning experiences*, i.e. learning experiences that are supported by AR (M. E. C. Santos et al., 2014). Research on AR has created AR learning experiences for almost any educational level from early childhood education to higher education in which many studies have been conducted. The results of this large and growing body of literature on AR in education are the identification of many advantages, opportunities, limitations and challenges of this technology in education. The landscape of research on AR in education shows that two of the most important advantages of AR in education are that AR increases students’ learning outcomes and that AR increases student motivation (Radu, 2014; Chiang, Yang, & Hwang, 2014; Bacca et al., 2014). 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).

Therefore, if AR increases student motivation, AR applications have been designed with components or modules that create a learning experience that positively affect student motivation. However, according to the literature review reported in CHAPTER 2, current research on AR in education fall short in explaining which are those components or modules that positively affect student motivation and does not explain how and why motivation is increased. Moreover, we identified that current research does not provide guidelines to inform the design and development of *motivational AR learning experiences* in the VET level of education. By *motivational AR learning experiences* we refer to AR learning experiences that are motivating by themselves and to those experiences that have been carefully designed to increase and sustain student motivation. Consequently, these aspects require more attention from the research community and therefore further research is needed. From this context, we identified the need of deepening the research on motivation in AR learning experiences to contribute to the knowledge in the design and development of motivational AR learning experiences for the VET level of education. This open issue was another motivation of the research conducted in this thesis and this issue is aligned with the need expressed by Akçayır & Akçayır (2017) of further research in terms of motivation and student engagement to have a better understanding of these aspects in AR-based educational settings.

Furthermore, another aspect that motivated the research conducted in this thesis was that, in the literature review that we conducted (see CHAPTER 2), we did not identified frameworks that inform or guide the design and development of motivational AR learning experiences. Thus, taking into account the context discussed earlier in this section, in this thesis we focus on the definition of a framework to inform the design and development of motivational AR learning experiences for the VET level of education. We hypothesized that the definition of a framework for the design and development of motivational AR learning experiences is a major contribution in terms of providing guidelines for software developers, educational technology experts and teachers in terms of the design and development of effective and authentic motivational AR learning experiences in VET.

Notwithstanding the fact that AR has been extensively used in almost every level of education, according to the literature review that we conducted (see CHAPTER 2), we concluded that the educational level of Vocational Education and Training (VET) is one of the levels in which AR has not been extensively applied. Therefore, the advantages and opportunities for using AR at this level remain still unexplored.

VET is defined as: “education programmes that are designed for learners to acquire the knowledge, skills and competencies specific to a particular occupation, trade or class of occupations or trades” (UNESCO, 2012, p. 14). At this educational level students are prepared to supply the needs of the labour market in some specific occupations. In the Spanish Educational System, some examples of VET programmes are: logistics, transport, manufacturing, building, electricity, and tourism among others.

Students that enrol in VET programmes have completed secondary education or at least most of it. After finishing the VET programme they can go to university or to the labour market in order to work in a particular occupation. Some students also enrol in VET programmes after finishing secondary education when they need to obtain a certification for a particular occupation. According to the statistics of the Spanish Ministry of Education, Culture and Sport, 68,1% of the students enrolled in VET programmes in 2013 came from secondary education, 1,5% came from special education schools, 13,9% had dropped out of other educational levels and 16,5% enrolled due to other reasons (Ministerio de Educación Cultura y Deporte, 2014). Moreover, according to the results of the Survey of Adult Skills conducted by the OECD, in Spain and Italy, 3 out of 10 adults perform at or below the level 1 (in a scale from 1 to 5) of literacy and numeracy. Besides that, only 1 out of 20 adults is proficient at the highest level of literacy (levels 4 or 5). The report also states that “large proportions of young people leave school with poor skills in literacy, numeracy and problem solving” (OECD, 2013, p. 30).

Consequently, in VET programmes there is a wide variety of students with different backgrounds, needs, interests, motivation, preferences, etc. By talking with expert teachers of VET programmes we identified that teachers often perceive student’s lack of: motivation, concentration, attention, confidence and background knowledge among other aspects and this is what is often called students’ variability (Meyer, Rose, & Gordon, 2014).

Students’ variability is not a problem indeed, it is in fact a norm because all students are as different as their fingerprints. Students are unique and all them learn in different ways and all of them have different needs, preferences, interests, motivations, etc. The problem in fact relies on the curriculum, which is designed for the “average” student and therefore those students who are not in the average are excluded. One of the causes of this exclusion is that some of the methods and materials used in the learning process create some barriers that make difficult for some students to fully participate in the learning process. In that regard, from a pedagogical perspective there is an approach to overcome barriers in the learning process, to create curriculums that are inclusive and to deal with students’ variability. This approach is the Universal Design for Learning (UDL) (Meyer et al., 2014). The UDL is a validated framework and is one of the most common approaches in inclusive education. The UDL defines three main principles: 1) provide multiple means of engagement 2) provide multiple means of representation and 3) provide multiple means of action and expression. The first principle of this framework is directly connected with the topic of motivation that we were discussing earlier. In fact, this principle was placed first in the UDL framework because recent research in emotions has demonstrated that cognition and emotions are not separated functions (Meyer et al., 2014). In this regard, emotions and affect are crucial in a learning process and therefore deserve attention in learning design.

Within this context, in this thesis we decided to focus on the VET level of education and we conducted two exploratory studies with the aim of exploring the advantages and possibilities that AR may provide to increase student's motivation and to explore how and why student motivation is affected in AR learning experiences. Moreover, the UDL framework was taken as a pedagogical underpinning to address students' variability and avoid barriers in the learning process.

On the other hand, our research group have consolidated solid expertise in these topics as we have been working previously in other projects related to the topics of inclusive education and AR. For instance, we conducted some research on the attention to students' diversity with technology in the areas of mathematics, science and language as part of the ALTER-NATIVA European project (ALTER-NATIVA Project, 2013) (ALFA III - DCI-ALA/19.09.01/10/21526/245-575/ALFA III (2010)88). Moreover, we worked in the Inclusive Learning Project (Supporting Trainers for an Inclusive Vocational Education and Training) (2012-1-ES1-LEO05-49449) in which we conducted some research in inclusive education at the VET level of education (Inclusive Learning Consortium, 2015). We also worked in the ARrelS (Augmented Reality in Adaptive Learning Management Systems for All) (TIN2011-23930) national funded project in which we worked on research on AR, mobile learning, personalization and accessibility in e-Learning. Finally, we are currently working in the Open Co-creation (TIN2014-53082-R) national funded project in which we are working in the co-creation of Inclusive and Accessible Open Educational Resources (IA-OER). The expertise gained from the work in these projects is a solid background and also motivated the research conducted in this thesis.

In summary and based on the discussion presented earlier in this section, the motivation of this thesis focused on the latent need of studying student motivation in AR learning experiences in VET. In particular we focused on the identification of the components or modules that positively affect student motivation and therefore we defined a framework to inform the design and development of motivational AR learning experiences as a major contribution of this thesis in the field of AR in education.

The rest of this chapter is organized as follows: The research questions that drove the research process and were answered during the research process are posed in section 1.2. The objectives that oriented the research are presented in section 1.3. Moreover, a description of the research methodology adopted in this thesis is described in section 1.4 and finally the outline and some comments on the style of writing of this thesis are presented in section 1.5.

1.2 RESEARCH QUESTIONS

As discussed in section 1.1 and according to the conclusions from the literature review presented in section 2.8, we identified that many studies have reported that one of the advantages of AR in education is that it increases motivation (Di Serio, Ibáñez, & Kloos, 2013; Chiang et al., 2014; Radu, 2014; Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos, 2015). However, current research on motivation in AR learning experiences does not clearly define which are the components or modules that positively affect student motivation. Therefore, we still do not know why and how these components or modules of AR learning experiences positively affect student motivation. This is connected with the open issue **OI1** defined in section 2.8.

We hypothesize that the identification of the components or modules of AR learning experiences that increase motivation may contribute to define the components or modules that an AR application should have to support student motivation. Therefore, the following research question drives the research process of this thesis:

RQ1: Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?

Moreover, as discussed in section 1.1 and in section 2.8, we identified that very few of the AR frameworks in education have considered aspects or features of student motivation and therefore these frameworks do not provide guidelines or recommendations for the design of motivational AR learning experiences. This aspect addresses the open issue **OI3** defined in section 2.8. So we hypothesize that the provision of recommendations and guidelines in the form of a framework for the design of motivational AR learning experiences may contribute to the design and development of authentic and effective AR learning experiences that positively affect and sustain student motivation in VET. Moreover, we may contribute to the knowledge in the design and development of AR learning experiences in which we will really know which aspects are the ones that better sustain student motivation. Therefore, the following research question drives the research process of this thesis:

RQ2: Can the design and development of motivational AR learning experiences based on the framework positively impact student motivation?

Moreover, open issue **OI2** was covered in this thesis during the process of answering **RQ1** by conducting the first and second exploratory studies (described in CHAPTER 3 and CHAPTER 4) and open issue **OI4** was covered in this thesis also as part of the **RQ2** by conducting the two exploratory studies in the VET level of education.

1.3 OBJECTIVES

The motivation of this work (described in section 1.1) together with the research questions (described in section 1.2) allowed us to define the following Main Objective (**MO**):

- **MO:** To define a framework for the design and development of motivational AR learning experiences for the VET level of education.

This main objective was supported by the following Specific Objectives (**SO**):

- **SO1:** To conduct a systematic literature review to identify the current state of AR in education
- **SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education.
- **SO3**: To identify the predictors of student motivation in AR learning experiences.
- **SO4:** To define the modules of the framework and specify the recommendations for the design and development of motivational AR learning experiences in VET.
- **SO5:** To validate the framework for the design and development of motivational AR learning experiences for the VET level of education.

1.4 RESEARCH METHODOLOGY

To reach the specific objectives (**SO1**, **SO2**, **SO3**, **SO4** and **SO5**) defined for this thesis and therefore reach the main objective **MO**, the research process in this thesis was designed by adopting two approaches in research: the exploratory or discovery-oriented approach (Barker, Pistrang, & Elliott, 2002) and the explanatory or hypothetico-deductive approach (Coolican, 2014). Thus, the research process in this thesis was divided into three major phases: The **Exploratory Phase,** the **Hypothetico-deductive and Explanatory Phase** and the **Validation Phase** which are described as follows:

Exploratory Phase: in this phase, an exploratory or discovery-oriented approach was adopted to have a better understanding of the current landscape of research on AR in education, to identify the open issues, define the research questions and to have a first approach to the research question **RQ1** and to reach the specific objectives **SO1** and **SO2**.

In particular the following Activities in the Exploratory Phase (**AEP**) were carried out:

- **AEP1:** Conduct a systematic literature review to have a better landscape of current research on AR in education. From this literature review, we identified four open issues (**OI1, OI2, OI3 and OI4** described in CHAPTER 2) that required further analysis.
- **AEP2:** The open issues were further analysed by conducting specific literature reviews that were not systematic but that allowed to search in many sources of information. As a result, we gained a better understanding of current state of research with respect to the four open issues. The results of the reviews of literature are presented in CHAPTER 2. Moreover, with a better understanding of the open issues, the research questions were defined to focus the research process. The research questions are explained in section 1.2. Both **AEP1** and **AEP2** addressed the specific objective **SO1.**
- **AEP3:** Based on the open issues, the literature review (as a result of **AEP1** and **AEP2**) and the research questions, two exploratory studies were conducted to analyse the impact of AR on student motivation. The two exploratory studies are described in CHAPTER 3 and CHAPTER 4. As a result, this activity provided insights into student motivation in AR learning environments at the VET level of education. **AEP3** addressed the specific objective **SO2**.

As a result of the **Exploratory Phase**, we had a better understanding of the research issues with respect to the impact of AR on student motivation. The next phase was to identify how and why AR positively affect student motivation and therefore an approach based on the explanation on how a phenomenon unfolds was needed. This led us to the next phase in the research methodology: the **Hypothetico-deductive and Explanatory Phase.**

Hypothetico-deductive and Explanatory Phase: This approach has an explanatory approach which means that the purpose is to explain how the studied phenomenon unfolds and to explain the causes of the phenomenon. The general purpose of this phase was to identify the predictors of student motivation in AR learning experiences. To do that, a set of hypotheses derived from the literature and derived from the design of the Paint-cAR application with respect to the predictors of student motivation were empirically validated with data gathered from the second exploratory study (described in CHAPTER 4). Moreover, based on the predictors of student motivation identified and based on a theoretical background, the framework for the design and development of motivational AR learning experiences was defined. This phase addressed the research question **RQ1** and the research question **RQ2**. Moreover this phase addressed the specific objective **SO3** and **SO4**.

In particular the following Activities in the Hypothetico-deductive and Explanatory Phase (**AHEP**) were carried out:

- **AHEP1:** The main purpose of this activity was to identify the predictors of student motivation in AR learning experiences. With that aim, we defined a group of hypothesis from the literature and we empirically validated these hypotheses (see CHAPTER 5) with data gathered from the second exploratory study (see CHAPTER 4). A validated model of hypotheses allowed us to identify the predictors of student motivation. This activity addressed the specific objective **SO3**.
- **AHEP2:** The main purpose of this activity was to define the framework for the design and development of motivational AR learning experiences for the VET level of education. The framework was defined based on the predictors identified in **AHEP1** and based on the literature on AR in education (see CHAPTER 6). This framework is the core of this thesis and is also the main contribution of this work. This activity addressed the specific objective **SO4**.

As a result of the **Hypothetico-deductive and Explanatory Phase** the predictors of student motivation in VET were identified and the framework for the design and development of motivational AR learning experiences was defined. Then, the next phase in the research process was to validate if the framework defined is valid to inform the design and development of motivational AR learning experiences. This led us to the next phase in the research methodology: the **Validation Phase.**

Validation Phase: The main purpose of the Validation Phase was to evaluate if the framework defined fits its purpose. This means, to evaluate if the framework supports the design and development of motivational AR learning experiences. This phase addresses the research question **RQ2** and the specific objective **SO5**.

In particular the following Activities in Validation Phase (**AVP**) were carried out:

- **AVP1:** The validation of the framework for the design and development of motivational AR learning experiences was specified. In this activity, the validation adopted an approach based on components and not a holistic approach as detailed in CHAPTER 7. This activity included the selection of the applications used in the creation of the AR learning experience for the validation process as well as the design of an application to validate five components of the framework.
- **AVP2:** The validation was carried out with a group of students and data gathered was analyzed and the conclusions were reported.

As described in this section, the research approach followed and the activities for each one of the three major phases followed in this research allowed us to reach the five objectives defined (**SO1, SO2, SO3, SO4** and **SO5**) and allowed us to answer the two research questions posed **RQ1** and **RQ2** and therefore allowed us to reach the main objective **MO** of this thesis.

1.5 OUTLINE AND WRITING STYLE OF THIS THESIS

This thesis is divided into four parts that contain eight chapters including the present chapter and the references and appendixes at the end of the document. Each part and chapter is organized as follows:

- **PART I – CONTEXTUALIZATION**
  - **CHAPTER 1 – INTRODUCTION:** This chapter presents the motivations of this thesis, together with the research questions that drove the research process and the objectives defined. Moreover, in this chapter a description of the research methodology followed and the outline of the thesis are also presented.
  - **CHAPTER 2 – STATE OF THE ART:** This chapter describes the systematic literature review conducted on the topic of AR in education. The methodology followed in this systematic literature review and the results obtained together with the open issues identified are also described. Furthermore, this chapter describes the findings of four reviews of literature that we conducted in the following topics with the aim of having a better understanding of the landscape on AR in education: predictors of student motivation, AR and special educational needs, AR frameworks in education and AR in VET. Moreover, we present the theoretical underpinnings that we used as rerefence in this thesis.
- **PART II – EXPLORATORY STUDIES:**
  - **CHAPTER 3 – FIRST EXPLORATORY STUDY:** In this chapter, we first present the design of the mobile AR Paint-cAR application by following the methodology that we defined for the co-creation of AR applications in education. Then, we present the research design, results and discussion of the study that sought to identify the impact of the Paint-cAR application on student motivation in the VET programme of Car's Maintenance.
  - **CHAPTER 4 – SECOND EXPLORATORY STUDY:** In this chapter, we present another iteration of the co-creation process to improve the design of the Paint-cAR application taking into consideration the results obtained from the first exploratory study (described in CHAPTER 3). Moreover, the research design,

results and discussion of a study conducted to evaluate the impact of an improved version of the Paint-cAR application on student motivation and learning outcomes for a longer period of time are presented.

- **PART III – DEFINITION AND VALIDATION OF THE FRAMEWORK:**
  - **CHAPTER 5 – PREDICTORS OF STUDENT MOTIVATION:** In this chapter we present a study that sought to identify the predictors of student motivation in VET when students use a mobile AR application for learning. We first present the hypotheses that we defined from the literature and then we present the validation of these hypotheses together with the discussion. Finally, we present the implications of these predictors in the design and development of motivational AR learning experiences.
  - **CHAPTER 6 – FRAMEWORK FOR THE DESIGN AND DEVELOPMENT OF MOTIVATIONAL AR LEARNING EXPERIENCES:** In this chapter we present the definition of the framework for the design and development of motivational AR learning experiences in VET. First, we present the theoretical underpinnings of the framework, followed by the framework definition detailed for each layer and module and finally the conclusions of the chapter are presented.
  - **CHAPTER 7 – VALIDATION OF THE FRAMEWORK:** In this chapter we first define what do we understand by validation of a framework and we define a methodology for the validation. After that, we develop the methodology and we present the research design of a quasi-experiment in which we validated a motivational AR learning experience created with the framework. The results of the validation are also presented and discussed. Finally the conclusions of the chapter are presented and the recommendatios for stakeholders with respect to the results of this thesis are described.
- **PART IV – CONCLUDING**
  - **CHAPTER 8 - CONCLUSIONS, CONTRIBUTIONS AND FUTURE WORK:** This chapter describes the general conclusions of this thesis, together with a description of the contributions to the knowledge in the design and development of motivational AR learning experiences. Finally, some future research directions are described.

Regarding the writing style of this thesis, we adopted the use of the first person of the plural “we” when we refer to the author of this thesis (Jorge Luis Bacca Acosta) hereinafter together with his supervisors (Dr. Ramon Fabregat, Dr. Silvia Baldiris and Dr. Kinshuk) in an effort to present the research in active voice instead of passive voice to facilitate reading. This choice is a matter of writing style. The aim of using the first person of the plural is also to avoid confusions when talking about the work of other authors or researchers and to maintain simplicity. This means that, within the text, any expressions like “authors” or “researchers” always refer to other authors and researchers that are neither the author of this thesis nor his supervisors.

Despite the fact that the use of the first person of the plural refers to the author and his supervisors, this research was completely conducted by the author of this thesis which means that the contributions of this thesis are the result of his work. The supervisors of this thesis guided, revised and provided suggestons, ideas and experience for the correct development and orientation of this thesis.

In short, some of the activities conducted in this thesis developed by the author with the guide, orientation, revision, suggestions and inputs of his supervisors are:

- The abstract, acknowledgements, motivation, the research questions, the objectives, the research methodology and the outline of this thesis are the result of the work of the author of this thesis. All of these are reported at the beginning of this thesis and in CHAPTER 1.

- The systematic literature review together with the specific literature reviews on the open issues identified that are reported in CHAPTER 2 together with the reporting of the results in the journal publication and in the chapter in this thesis are the result of the work of the author of this thesis.
- The development of the first and second prototype of the Paint-cAR application described in CHAPTER 3 and CHAPTER 4 and the execution of the first and second exploratory studies reported in the same chapters. The statistical analysis of data collected and the analysis of the results and discussion reported in these chapters are also the work of the author of this thesis.
- The design and development of the study of predictors of student motivation together with the statistical analysis of data and all the activities that this task implies. Moreover, the analysis of the results, discussion and the deduction of the implications of the study for the design and development of motivational AR learning experiences are also the work of the author of this thesis. All of these are reported in CHAPTER 5.
- The definition of the framework including all of its recommendations and suggestions are the result of the work of the author of this thesis. The definition of the framework is reported in CHAPTER 6.
- The validation of the framework was completely conducted by the author of this thesis together with the development of the "Chemistry Videos and Assessment" application that was used in the validation. The analysis of the results, discussion, conclusions and recommendations are also the work of the author of this thesis. All of these are reported in CHAPTER 7.
- The summary of the thesis, the general conclusions, the summary of the contributions, and the future work reported in CHAPTER 8 are also part of the work of the author of this thesis.

Regarding the citation style of this thesis, we followed the APA citation style.

CHAPTER 2

STATE OF THE ART

2.1 INTRODUCTION

Aligned with the motivation of this thesis presented in CHAPTER 1 and to address the first objective defined for this thesis: **SO1** – "To conduct a systematic literature review to identify the current state of AR in education", in this chapter we present the results of a systematic literature review of 32 journal papers from six major journals in educational technology and 18 papers from two major conferences in educational technology. This review was conducted to have a better landscape of the research on AR in education and to identify the open issues in this field. The timeframe selected for the systematic literature review was 2003 to 2013. Although the systematic literature review covers only the timeframe from 2003 on 2013, more specific reviews of literature were conducted on the open issues identified in the literature review and are updated until 2016. The specific literature reviews were conducted in the following topics that are aligned with the open issues identified: Predictors of student motivation and acceptance of AR in education, AR and special educational needs, AR frameworks in education and AR for the VET level of education. These specific literature reviews allowed us to have an updated landscape of the current state of AR in education in the open issues in which we focused while we conducted the research.

The systematic literature review addressed the first activity of the Exploratory Phase of the research methodology defined: **AEP1 –** Conduct a systematic literature review. Part of this literature review was published in the Journal of Educational Technology and Society (Q2 – SSCI – Impact factor: 1,104). The reference to the publication is (Bacca et al., 2014). More details on this publication are provided in section 2.9.

From this literature review we identified four open issues (OI) that are summarized as follows:

- **OI1:** Research studies on AR in education do not clearly define how and why AR increases student motivation.
- **OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences.
- **OI3:** Very little has been done in terms of the definition of AR frameworks in education.
- **OI4:** There is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education.

These open issues were further analyzed with more specific reviews of literature (that were not systematic but were updated until 2016) on the topic of each one of the issues identified. These specific reviews of literature are described in sections: 2.3, 2.4, 2.5 and 2.6. With respect to the research methodology, these specific reviews of literature correspond to the second activity of the Exploratory Phase in the research methodology: **AEP2** – Specific literature reviews. After analyzing the literature with respect to the OI, in summary we concluded that:

- Current research on AR in education does not clearly report which are the components or modules of AR applications that increase student motivation in AR learning experiences.
- There are some AR applications developed for addressing some particular students' educational needs but none of them have adopted a more generic inclusive perspective such as the UDL or other approaches of the Universal Design to create inclusive AR learning experiences.
- There are very few frameworks that define guidelines to inform the design and development of motivational AR learning experiences.
- Although AR has been extensively used in contexts of maintenance, there is a lack of research on the possibilities for using AR as a support for the learning process at the VET level of education.

Moreover, taking into account that in this thesis we focused in the topic of student motivation in AR learning experiences, section 2.7 presents the theoretical underpinnings of student motivation that define the conceptual frame in which this thesis is based.

The rest of this chapter is organized in eight sub-sections. Section 2.2 describes the systematic literature review conducted. Section 2.3 describes a review of literature on predictors of student motivation and acceptance of AR in education. Section 2.4 describes a review of literature on the support provided by AR to address special educational needs. Section 2.5 describes a review of literature on AR frameworks in education. Section 2.6 describes a review of literature on AR in VET and Section 2.7 presents the theoretical underpinnings of student motivation for this study. Finally section 2.8 presents the general conclusions of this chapter and section 2.9 presents the publication in the journal associated to the systematic literature review presented in section 2.2 of this CHAPTER.

2.2 SYSTEMATIC LITERATURE REVIEW

In this section we report the systematic literature review that we conducted with the aim of identifying open issues in research on AR in education and to have a better landscape of the current research in this field. This literature review corresponds to the first activity of the Exploratory Phase (**AEP1**) in the research methodology followed in this thesis. The literature review presented in this section differs from the one that was published in the Journal of Educational Technology & Society (Bacca et al., 2014) in the following ways:

- In this chapter we included the results of two additional Literature Review Research Questions (LRQ) that were not published in the journal: **LRQ2** and **LRQ6**.
- For each one of the six research questions of this literature review, the results of the analysis of conference papers were included. The results of the analysis of conference papers were not published in the journal article.

Thus, there is a substantial amount of results that were not published in the journal paper that are included in this section.

2.2.1 Research questions

There is a large volume of published studies on research on AR in education. However, since AR is an emergent technology, it is important to get an overview of the advances and real impact of its use in educational settings, describing how AR has been used for generate more student-center learning scenarios. Within this context the research questions addressed by this literature review are:

LRQ1 - What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?

LRQ2 - How did augmented reality evolve with the technological advances between 2003 and 2013?

LRQ3 - Have the inclusion of combined adaptive or personalized processes been considered in augmented reality applications?

LRQ4 - How has augmented reality addressed the special needs of access and people preferences in educational settings?

LRQ5 - What are the evaluation methods considered for augmented reality applications in educational scenarios?

LRQ6 - Which frameworks or architectures for augmented reality applications have been developed and tested in educational settings?

2.2.2 Method

For this review, we adapted the guidelines proposed by Kitchenham, (2004). We adopted these guidelines because these guidelines have been adapted to the field of computer science from the original guidelines for conducting systematic literature reviews in the medical domain. Thus, these guidelines are more appropriate for conducting a review from the perspective of the computer science field.

1. Planning: In this step the scope of the systematic review is defined. This step includes the definition of the methodology for selecting journals and conferences. The following activities are included:
    a) Selection of Journals and conferences
    b) Definition of inclusion and exclusion criteria of studies
    c) Definition categories for the analysis
2. Conduct the review: During this step searches in databases and journals are performed as well as the filtering of studies according to inclusion and exclusion criteria. This step also includes the data coding process. The activities in this step are:
    a) Study selection
    b) Data extraction (Content analysis method was applied)
    c) Data synthesis
    d) Data coding
3. Reporting the review: This step includes the analysis of results and discussion of findings.

Regarding step 3 (Reporting the review), we followed the recommendations of the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher, Liberati, Tetzlaff, & Altman, 2009). The PRISMA statement is the international and accepted updated version of the QUORUM statement (Quality of Reporting of Meta-analysis). Thus, we followed internationally accepted guidelines for reporting the literature review.

In the following sub-sections we describe the steps 1a, 1b and 1c according to the methodology and section 2.2.3 describes the results of the systematic literature review.

Step 1a: Selection of Journals and conferences

The aim of this step has been to choose the most relevant journals and conferences for this systematic literature review in a consistent way. To keep the process methodologically strong and scientifically consistent, the following method was defined in this literature review for selecting journals. After explaining the method for selecting journals, an explanation on how conferences were selected is provided.

The Google Scholar h5-index for the category "Educational technology" was used as the starting point. This starting point was selected since this category is more specific than "Education and educational research" category from the Journal Citation Report Social Science Citation Index

(JCR SSCI). In the later, most of the journals about educational technology are indexed jointly with journals about educational research in general.

We chose the top five journals from "Educational Technology" category from Google Scholar h5-index and we named this list "*GS list*". In order to validate our initial *"GS list",* we performed an iterative double check process using the JCR SSCI tool in order to consider the impact factor of each journal and its "relatedness" with others. The "relatedness" or most related journals is defined in the JCR taking into account the cited and citing relationship of the journals and is based on the number of citations from one journal to the other and the total number of articles. The iterative double check process was performed as follows: For each journal in the *GS list*, we searched the most related journals to that one using the option "Related Journals" in the JCR SSCI web application (Journal Citation Reports - ISI Web of Knowledge, 2012). As a result, we obtained one list of related journals for each journal in the *GS list*. In this way, we obtained five lists of related journals which were named as *RJ-GS1, RJ-GS2, RJ-GS3, RJ-GS4* and *RJ-GS5*, where *RJ* stands for "related journal" and *GS#* stands for the corresponding journal from the *GS list*.

We then independently sorted each of the lists *RJ-GS1* to *RJ-GS5* taking into account the impact factor. This process is somewhat similar (by analogy) to a precipitation process (Gooch, 2007) were the journals with major impact factor will "float" in each list. As a result, we obtained five independent lists of journals ordered by impact factor. Despite the fact that lists were organized by impact factor, we had some similar journals in each list but at different positions. For example, the British Journal of Educational Technology was at position 7 in the list *RJ-GS1* but at position 4 in *RJ-GS2.* In the remaining lists *(RJ-GS3, RJ-GS4* and *RJ-GS5)* the journal was also in different positions. In order to overcome this situation we combined all the elements of the lists (from *RJ-GS1* to *RJ-GS5*) by pondering the position occupied by each journal through the five lists. As a result, the definite list of journals ordered according to its position was obtained. This list was named *FL-JCR-SSCI list*.

We then analyzed each journal from the *FL-JCR-SSCI list* and discarded journals that did not cover topics about educational technology. This analysis was based on the "subject categories" reported for each journal in the JCR SSCI web application. If necessary we analyzed the aim and scope of each journal to see if the journal could be considered. As a result of this process, we had a new list of journals named *ET-FL-JCR-SSCI.* Where "*ET*" stands for Educational Technology. This list contains only journals that cover the topic of Educational Technology ordered by impact factor. Table 2-1 shows the first five journals of *ET-FL-JCR-SSCI* list that corresponds to the journals selected for this review. We have to point out that this method allowed us to find the most important journals in educational technology through a double check process considering impact factor and "relatedness" in the JCR SSCI.

Table 2-1. List of the first 5 journals of "ET-FL-JCR-SSCI list"

Journal Title	Impact Factor (JCR SSCI 2012)
Computers and Education	2,775
Internet and Higher Education	2,013
British Journal Of Educational Technology	1,313
Australasian Journal of Educational Technology	1,363
International Journal of Computer-Supported Collaborative Learning	1,717

In order to also consider the Journal Citation Reports Science Citation Index (JCR SCI), we repeated the iterative double check process with the journals indexed in the JCR SCI and obtained another list of journals, namely *ET-FL-JCR-SCI list.* Table 2-2 shows the first four journals of this list that corresponds to the journals from the JCR-SCI selected for this review. At this point we decided to include in the review, studies published in the first four journals of each list (*ET-FL-JCR-SCI and ET-FL-JCR-SSCI*). However, the "Internet and Higher Education" journal was not considered in the review since does not have studies published about AR in education.

As a result, we included one additional journal from the *ET-FL-JCR-SSCI* list so that the number of journals considered can be equal. Those journals are the most relevant journals in Educational

Technology according to our analysis. Those results were validated by comparing them with the SJR and SNIP indexes obtaining similar results.

Table 2-2. List of the first 4 journals of "*ET-FL-JCR-SCI list*"

Journal Title	Impact Factor (JCR SCI 2012)
Knowledge-based systems	4,104
Expert systems with applications	1,854
IEEE Transactions on education	0,95
IEEE Intelligent Systems	1,93

Since conference papers provide valuable insights about trending topics, research in progress and preliminary results which could be a good source of primary studies for this systematic review, we decided to include papers from recognized international conferences in this systematic review. For that purpose, we analyzed the number of papers published about augmented reality applied to educational settings for period 2008-2013 (the last five years of the period for the systematic literature review) in six major conferences in educational technology ("Computer Science Conference Rankings", 2011), ("CORE Ranking of Conferences and Jornals in Computer Science",2007). Table 2-3 shows the list of international conferences analyzed. Taking into account the number of papers that could be relevant for this systematic literature review, we selected the ISMAR and ICALT conferences (first two rows in Table 2-3) to be included in the systematic review.

Table 2-3. List of conferences analyzed.

Conference Title	Relevant papers for the systematic review
IEEE International Conference on Advanced Learning Technologies (ICALT)	23
International Symposium on Mixed and Augmented Reality (ISMAR)	16
International Conference on Computer Supported Collaborative Learning (CSCL)	9
International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI)	8
International Conference on Artificial Intelligence in Education (AIED)	2
Annual Conference on Integrating Technology into Computer Science Education (ITiCSE)	1
ACM Special Interest Group on Computer Science Education Conference (SIGCSE)	0

Step 1b: Inclusion and exclusion criteria

Taking into account the research questions, we considered general criteria that define the time frame for the study and the type of studies that are relevant. Accordingly, we defined the following criteria:

General Criteria:

a. Studies published between 2003 and 2013.
b. Studies that describe applications of AR in education.

Specific Criteria:

a. Studies that report advantages, disadvantages, affordances, limitations, features, uses, challenges and effectiveness of augmented reality in educational settings.
b. Studies that describe applications considering a user model and/or adaptive processes combined with augmented reality.
c. Studies that describe applications of augmented reality in education for people in contexts of diversity.
d. Studies describing the evaluation methods for augmented reality applications in educational scenarios.

The following exclusion criteria were defined and accordingly, studies meeting these criteria were excluded:

a. Studies not identified as "Articles" in the journals selected or not identified as "Conference Papers" (e.g., book reviews, books, editorial publication information, book chapters, etc.).
b. Studies that mention the term "augmented reality" but are actually about virtual reality or other topics because the term appears only in the references section or is mentioned sporadically.

Step 1c: Categories for the analysis and data coding

In this step, we defined a group of categories of analysis with their corresponding sub-categories according to each research question. Categories help us in grouping studies according to their shared characteristics. During the systematic review process, some sub-categories emerged and others were refined in order to cover all emerging information. The list of categories for the analysis classified by literature review research questions (LRQ) is as follows:

LRQ1 - What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?

1. Field of Education: Based on International Standard Classification of Education (UNESCO, 2012).
2. Target Group: Based on the International Standard Classification of Education (UNESCO, 2012).
3. Reported purposes of using AR: Subcategories emerged from the content analysis.
4. Reported advantages of AR: Subcategories emerged from the content analysis.
5. Reported limitations of AR: Subcategories emerged from the content analysis.
6. Reported effectiveness of AR: Subcategories emerged from the content analysis.

LRQ2 - How did augmented reality evolve with the technological advances between 2003 and 2013?

1. Type of AR (based on the classification introduced by Wojciechowski & Cellary (2013))
2. Device used for AR: Subcategories emerged from the content analysis.

LRQ3 - Have the inclusion of combined adaptive or personalized processes been considered in augmented reality applications?

1. Type of adaptation process: Subcategories emerged from the content analysis.
2. Type of user modeling: Subcategories emerged from the content analysis.

LRQ4 - How has augmented reality addressed the special needs of access and people preferences in educational settings?

1. Special Need addressed: Subcategories emerged from the content analysis.
2. Intervention method: Subcategories emerged from the content analysis.

LRQ5 - What are the evaluation methods considered for augmented reality applications in educational scenarios?

1. Research samples: Subcategories emerged from the content analysis.
2. Research method: Subcategories emerged from the content analysis.
3. Time dimension: Subcategories emerged from the content analysis.
4. Data collection method: Subcategories emerged from the content analysis.

LRQ6 - Which frameworks or architectures for augmented reality applications have been developed and tested in educational settings?

1. Purpose of the framework: Subcategories emerged from the content analysis.
2. Methodologies for framework generation: Subcategories emerged from the content analysis.

3. Methodologies for framework evaluation: Subcategories emerged from the content analysis.

Content analysis allows to find the research trends of a topic by analyzing the articles' content and grouping them according to the shared characteristics (Hsu, Hung, & Ching, 2013). This method was applied in order to extract the information of each paper. Two of the authors of the paper manually coded the studies separately according to their characteristics and classified them according to the categories and sub-categories defined. In case of discrepancy, the coders resolved it through discussion.

2.2.3 Results

In this section the results of conducting the review are described and discussed. In step 2a of the methodology we searched manually in the selected journals and applied the inclusion and exclusion criteria in order to select the studies for the review. As a result of this process we selected 32 studies from journals. Steps 2b and 2c were carried out by reading the papers completely and the data coding process was performed taking into account the categories defined in step 1c. In order to present the results this section was organized taking into account each research question addressed.

In total 30 studies were analyzed from the five journals selected from the JCR-SSCI and 2 studies were analyzed from the four journals selected from the JCR-SCI. Table 2-4 shows the number of studies analyzed by journal. It is important to note that in the table, the year 2013* includes the papers published until February 2014.

Table 2-4. Number of studies analyzed in this review by journal.

Journal	Studies analyzed (2003-2013*)
JCR-SSCI Journals	**Total: 30**
Computers & Education	23
Internet and Higher Education	0
British Journal of Educational Technology	4
Australasian Journal of Educational Technology	1
International Journal of Computer-Supported Collaborative Learning	2
JCR-SCI Journals	**Total: 2**
Knowledge-based systems	0
Expert systems with applications	1
IEEE Transactions on education	1
IEEE Intelligent Systems	0

By analyzing the year of publication of the studies considered we found that the number of published studies about AR in education has progressively increased year by year specially during the last four years. This means that many researchers are interested in exploring the features, advantages, limitations of AR in educational settings. This means that many researchers are interested in exploring the features, advantages, limitations and features of AR in educational settings. This finding is consistent with the prediction of Martin et al. (2011) that "AR will probably play a more important role on 2011-2012". According to these results, it seems that AR in education is an emerging topic and this finding corroborates the ideas of H.-K. Wu, Lee, Chang, & Liang (2013) and Cheng & Tsai (2012), who point out that the research on AR in education is in the initial phase. As Bujak et al. (2013) suggest: "Augmented reality (AR) is just starting to scratch the surface in educational applications". One of the issues that emerge from these findings is that more research needs to be undertaken in the topic of AR in education.

Regarding to the conference papers, **Table 2-5** shows the number of studies analyzed in this review by conference. As mentioned before, we analyzed 18 conference papers from the two major conferences that publish studies in the field of AR in education.

Table 2-5. Number of studies analyzed in this review by conference.

Conference name	Studies analyzed (2003-2013*)
IEEE International Conference on Advanced Learning Technologies (ICALT)	10
International Symposium on Mixed and Augmented Reality (ISMAR)	8

In the following subsections, our findings with respect to each research question are presented.

LRQ1 - What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?

a. Results obtained from journal papers in the category "Uses of AR in education"

With respect to the uses of AR in education, Table 2-6 presents the results obtained from the data coding process in the category of field of education for journal papers.

Table 2-6. "Uses of AR in education" by field of education in journal papers

Sub-Category	Number of Studies	Percentage (%)
Educational	0	0.0
Humanities & Arts	7	21.9
Social Sciences, Business and Law	4	12.5
Science	13	40.6
Engineering, Manufacturing and Construction	5	15.6
Agriculture	0	0.0
Health and Welfare	1	3.1
Services and Others	2	6.3

This table clearly shows the use of AR by each field of education. The most striking result to emerge from the data is that most of the studies (40.6%) were applied in the field of "Science" (which includes: mathematics, biology, ecology, physics, chemistry, geology, computer science and similar domains). This result indicates that most of the research done in AR applied to education has been concentrated on identifying the benefits of AR in science education. A possible explanation of this is that AR has demonstrated to be effective when applied to lab experiments (Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014; Lin, Duh, Li, Wang, & Tsai, 2013; Enyedy, Danish, Delacruz, & Kumar, 2012), ecology (Wrzesien & Alcañiz Raya, 2010), field trips (Kamarainen et al., 2013), mathematics and geometry (Blake & Butcher-Green, 2009), scientific issues (Chang, Wu, & Hsu, 2013) and in general, activities where students can see things that could not be seen in the real world or without a specialized device. Furió, González-Gancedo, Juan, Seguí, & Rando, (2013, p. 1) claim that students "do not have to use their imagination to envision what is happening. They can see it." which also means that AR is effective for teaching abstract or complex concepts.

A prior study has noted the importance of AR in science education. Cheng & Tsai (2012) carried out a literature review and identified many affordances of AR in science learning. However the authors pointed out that more research about learner characteristics, perceived social presence, user experience and interaction is needed. As a result of our analysis, the current state of research on AR in science learning has made evident some benefits and advantages of using AR for learning science.

Following "Science", "Humanities & Arts" was the second field of education in which AR was applied the most (21.9%). Studies in this field of education focused on language learning (Liu & Tsai, 2013; C. Chang, Lee, Wang, & Chen, 2010; Ho, Nelson, & Müeller-Wittig, 2011; T.-Y. Liu & Chu, 2010), visual art and painting appreciation (Di Serio, Ibáñez, & Kloos, 2013; K.-E. Chang et al., 2014), and culture and multiculturalism (David Furió et al., 2013). Interestingly, AR has been widely used in language learning due to the possibility of augment information and combining it with contextual information to provide new experiences in language learning. For instance AR provides the possibility of adding augmented information to real objects for practicing vocabulary. Moreover, AR has been applied in painting appreciation in order to provide an enhanced experience when looking at the details of a painting.

In "Social Sciences, Business and Law" and "Engineering, Manufacturing and Construction", AR is being explored. Only 12.5% of the studies reviewed applied AR in the field of "Social Sciences, Business and Law" and 15.6% applied AR in "Engineering, Manufacturing and Construction". In the field of "Social Sciences, Business and Law" the studies focused on library instruction (Chen & Tsai, 2012), management and sales (H.-W. Huang, Wu, & Chen, 2012), and business (Chen, Teng, & Lee, 2011). In the field of "Engineering, Manufacturing and Construction" and related disciplines AR has been applied in automatics and robotics for learning in virtual remote laboratories (Jara, Candelas, Puente, & Torres, 2011) and teaching concepts of computer networks (Ozcelik & Acarturk, 2011). In this field of education more research needs to be undertaken in order to identify the benefits of AR in engineering education and social sciences.

Finally the results of our review show that the less explored fields of education are "Health and Welfare" (3.1%) and "Services and Others" (travelling, transport, security services and hotel) with 6.3% of the studies reviewed. According to our review, no investigations have delved in the field "Educational" (teacher training in all levels of education) as well as the field of "Agriculture". The present results are significant in order to encourage researchers to explore the use of augmented reality in teacher training and agriculture, forestry, fishery, veterinary, etc.

b. Results obtained from conference papers in the category "uses of AR in education"

Table 2-7 shows the results obtained from the data coding process in the category of field of education for the conference papers.

Table 2-7. "Uses of AR in education" by field of education in conference papers

Sub-Category	Number of Studies	Percentage (%)
Educational	0	0,00
Humanities & Arts	6	33,3
Social Sciences, Business and Law	0	0,00
Science	5	27,7
Engineering, Manufacturing and Construction	2	11,1
Agriculture	0	0,00
Health and Welfare	2	11,1
Services and Others	3	16,6

Surprisingly, most of the studies reported in the conference papers are in the field of "Humanities & Arts" (33,3%). Although the difference with respect to the field of "Science" (the second field with the major number of studies) is of just 1 study, it shows that the interest of using AR in other areas have indeed reached the same interest that the "Science" field has. This also shows that researchers are starting to be more interested in exploring other topics in "Humanities & Arts" to apply AR and identify the unique affordances of AR in this field. By comparing this result in terms of the number of studies with the results of the journal papers it can be seen that in conference papers the field of "Science" does not have the same interest as in journal papers. This may suggest that on going and emerging research is moving to other fields of education apart from the "Science" field.

The fields of "Services and Others" (16,6%), "Engineering, manufacturing and construction" (11,1%) and "Health and Welfare" have also attracted the interest of researchers on AR. However, Unlike the number of studies published in journals in the field "Social Sciences, Business and Law" (12,5%), in the conference papers there were no studies in this field. This means that there was no on-going research on the use of AR in the field of "Social Sciences Business and Law". Likewise, the field "Educational" (0%) did not have any study published in this field.

c. Results obtained from journal papers in the category "Target Group"

Another category analyzed in this systematic review was the "Target Group". This category refers to the level of education of participants in the experiments or the research sample in which the study of AR in education was carried out. Table 2-8 summarizes the results.

Table 2-8. "Target group" in which AR studies were carried out in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Early childhood education	0	0.00
Primary education	6	18.75
Lower secondary education	6	18.75
Upper secondary education	4	12.50
Post-secondary non-tertiary education*	**0**	**0.00**
Short-cycle tertiary education*	**1**	**3.13**
Bachelor's or equivalent level	11	34.38
Master's or equivalent level	0	0.00
Doctoral	0	0.00
Informal Learning	2	6.25
Not mentioned in the study	2	6.25

* These two cycles are part of the VET level of education.

This table is quite revealing in several ways. First, it is worth noticing that AR has been mostly applied in higher education settings ("Bachelor's or equivalent level") and compulsory education ("Primary education", "Lower secondary education" and "Upper secondary education"). Most of the studies reviewed in these target groups applied AR for motivating the students, explaining topics, adding information and other purposes that are discussed later.

It seems to be possible that AR has been applied in settings with this target group in order to improve the educational experience of the students and motivate and engage them by taking advantage of the features of this technology. In the studies reviewed there were no evidence of AR applications in the field "Early childhood education" (0%). A possible explanation of this result is that the technology could be not ready for being used by children since many aspects of interaction, such as the tracking and use of markers, need to be solved. We encourage researchers to explore the use of AR in this field.

On the other hand, "Post-secondary non-tertiary education" (0%) and "Short-cycle tertiary education" (3.1%) are target groups that need further research on the impact of AR in these educational settings. These target groups are part of the VET level of education in which AR could provide benefits in the learning process for facilitating the access to the labor market. So far, not many studies have been reported in this area. The need of more studies that explore the benefits of AR in VET education was indeed one of the open issues found as a result of this literature review.

Finally, there were no evidence of using AR in "Master's or equivalent level" (0%) and "Doctoral" (0%) educational settings. This result may be explained by the fact that Master's and PhD students typically are involved in creating new AR applications for the other levels of education.

d. Results obtained from conference papers in the category "Target Group"

Table 2-9 shows the results of the "Target Group" category in the conference papers.

Table 2-9. "Target group" in which AR studies were carried out in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Early childhood education	0	0,0
Primary education	7	38,8
Lower secondary education	2	11,1
Upper secondary education	1	5,5
Post-secondary non-tertiary education	0	0,0
Short-cycle tertiary education	1	5,5
Bachelor's or equivalent level	4	22,2
Master's or equivalent level	0	0,0
Doctoral	0	0,0
Informal Learning	3	16,6
Not mentioned in the study	0	0,0

As for the "Target Group", in conference papers the most common "Target Group" was "Primary education" (38,8%). This means that research on AR is being conducted in the first levels of education to explore its benefits for the learning process in children. This may be due to the affordances of this technology for engaging children and capturing their attention. "Bachelor's or equivalent level" (22,2%) also rated high but not as high as in the journal papers. As for "Informal Learning" (16,6%), this target group is also being explored. In this target group AR is being used in museums and for historical learning and heritage as part of informal learning processes. Finally, "Lower secondary education" (11,1%), "Upper secondary education" (5,5%) and "Short-cycle tertiary education" (5,5) rated low than the other target groups. This result shows the possibilities for exploring AR in these target groups to uncover its affordances for supporting the learning processes.

e. Results obtained from journal papers in the category "Purposes of using AR"

With respect to category "Purposes of using AR" in education, Table 2-10 summarizes the results. Since one study can report more than one purpose, each study can meet more than one sub-category.

Table 2-10. "Purposes of using AR" in educational settings reported in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Explaining the topic	14	43.75
Evaluation of a topic	0	0.00
Lab experiments	4	12.50
Educational Game	6	18.75
Augment information	13	40.63
Exploration	1	3.13
Other educational purposes	0	0.00

It can be seen from this data that most of the studies used AR with the purpose of "Explaining the topic" (43.7%) and "Augment information" (40.6%). On the one hand "Explaining the topic" refers to the use of an AR application in order to support the learning of a specific topic and to show the learning content with the help of AR. For instance, Wrzesien & Alcañiz Raya, (2010) developed the E-Junior project that is a serious virtual world based on AR for teaching about the Mediterranean Sea. H.-Y. Chang et al., (2013) used mobile AR to teach students on the topics of nuclear energy and radiation pollution.

On the other hand, "Augment information" refers to the use of AR for providing supplemental material by means of markers placed on printed material that students used to access digital resources. For example Huang et al., (2012) used QR codes printed on a physical book so that students can access to supplemental material by using handheld devices. Chen et al., (2011) used QR codes with handheld devices to deliver supplementary materials and scaffolded questions.

Table 2-10 also shows that "Educational Game" (18.7%) and "Lab experiments" (12.5%) are two other "Purposes of AR" that are being explored. In this sense, we encourage researchers to explore in detail the uses of AR in educational games in order to identify its features, advantages and drawbacks. There are few mobile learning games that use AR (Furió et al., 2013). Further research regarding to the role of AR for supporting experiments in laboratories needs to be done, for example, the analysis of the impact of AR for reducing the cost of lab experiments or its strengths for offering a most inclusive experience for people with disabilities.

Furthermore, according to the results, very little was found in the literature on using AR for activities of "Exploration" (3.1%) and discovering the world through AR and no studies were found with focus on using AR for "Evaluation of a topic" (0%) and the use of AR for "Other educational purposes" (0%) different from the ones mentioned before.

f. Results obtained from conference papers in the category "Purposes of using AR"

Table 2-11 shows the results of the "Purposes for using AR" in educational settings reported in conference papers.

Table 2-11. "Purposes of using AR" in educational settings reported in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Explaining the topic	8	44,4
Evaluation of a topic	0	0,0
Lab experiments	4	22,2
Educational Game	3	16,6
Augment information	3	16,6
Exploration	2	11,1
Other educational purposes	1	5,5

As in the results for journals, the studies reported in conference papers have, as the main purpose, the use of AR for "Explaining the topic" (44,4%). This means that on-going and emerging research is being conducted on the use of AR for explaining a topic. This might be due to the advantages of AR for providing an alternative form of presentation of information that differs from the traditional means used in education so far.

"Lab experiments" (22,2%) also rated high, which means that researchers are exploring the uses of AR as a support for the learning processes in laboratories. This result can be explained from the perspective of previous studies that have reported that AR is useful for showing phenomena that cannot be seen without the use of specialized equipment (Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014; Lin, Duh, Li, Wang, & Tsai, 2013; Enyedy, Danish, Delacruz, & Kumar, 2012).

With regard to the purposes "Educational Game" (16,6%) and "Augment information" (16,6%) the results show that AR is being used to create educational games due to the possibilities in terms of graphics and interaction provided by AR and other researchers are also using AR to augment information during the learning process.

However, no studies that used AR for "Evaluation of a topic" (0%) were reported. This means that, so far in the papers reviewed there were no studies conducted on the use of AR for evaluating a topic.

Finally, for "Other educational purposes" (5,5%), only one paper did not fit any of the other purposes reported. This study was conducted by (Radu & MacIntyre, 2012) and is about using AR for exploring how the design of AR is related to some children's skills like motor abilities, spatial cognition, attention, logic and memory. The researchers present the implications of the design of AR with respect to these skills.

g. Results obtained from journal papers in the category "Reported advantages of AR"

Another category analyzed in this systematic literature review deals with the "Reported Advantages of AR" in educational settings. Table 2-12 shows the results of the reported advantages identified in the studies analyzed. Since one study can report more than one advantage, each study can meet more than one sub-category.

Table 2-12. "Reported advantages of AR" in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Learning gains	14	43.75
Motivation	10	31.25
Facilitate Interaction	5	15.63
Collaboration	6	18.75
Low cost	4	12.50
Increase the experience	4	12.50
Just-In-time Information	4	12.50
Situated Learning	3	9.38
Student-centred	3	9.38
Students' attention	3	9.38
Enjoyment	3	9.38
Exploration	4	12.50
Increase capacity of innovation	2	6.25
Create positive attitudes	2	6.25
Awareness	1	3.13
Anticipation	1	3.13
Authenticity	1	3.13

From the results, it can be seen that the major advantages reported in the studies are: "Learning gains" (43.7%) and "Motivation" (31.2%). These results corroborate the benefits of AR for improving the learning performance and motivating students reported in other studies (Liu & Chu, 2010; Di Serio et al., 2013; Jara et al., 2011; Chang et al., 2014). This result is indeed one of the major findings of this literature review and this finding opened up the possibilities for conducting the research presented in this thesis. In particular, we focused on the topic of student motivation and this thesis deepened the analysis of how AR can support student motivation.

Moreover, Tobar-Muñoz, Baldiris, & Fabregat (2017) found a positive impact of AR and Game-based learning (or AR Game-based learning - ARGBL) on student motivation during reading comprenhension activities.

Some studies have reported other advantages of AR such as: "Facilitate Interaction" (15.6%), "Collaboration" (18.7%), "Low cost" (12.5%), "Increase the experience" (12.5%), "Just-in-time Information" (12,5%), "Situated Learning" (9.3%), "Student-centred" (9.3%), "Students' attention" (9.3%), "Enjoyment" (9.3%) and "Exploration (12.5%). This study confirms that there are a wide variety of advantages reported of using AR in education. However, these advantages need to be further explored in order to understand the real benefits of AR-based learning experiences at every educational level or target group.

On the other hand, very little was found in the literature on advantages of AR in educational settings such as: "Increase the capacity of innovation" (6.2%), "Create positive attitudes" (6.2%), "Awareness" (3.1%), "Anticipation" (3.1%) and "Authenticity" (3.1%). In this sense, there is a need of more research in order to validate if those factors are advantages of AR in education.

h. Results obtained from conference papers in the category "Reported advantages of AR"

As for the "Reported advantages of AR" in conference papers, Table 2-13 shows the list of the advantages identified in this literature review.

Table 2-13. "Reported advantages of AR" in conference papers

Sub-Category	Number of Studies	Percentage (%)
Learning gains	8	44,4
Motivation	2	11,1
Facilitate Interaction	3	16,6
Collaboration	2	11,1
Low cost	0	0,0
Increase the experience	0	0,0
Just In-time Information	2	11,1
Situated Learning	3	16,6
Student-centred	2	11,1
Students' attention	0	0,0
Enjoyment	6	33,3
Exploration	0	0,0
Increase capacity of innovation	0	0,0
Create positive attitudes	6	33,3
Awareness	0	0,0
Anticipation	1	5,5
Authenticity	0	0,0

"Learning gains" (as in journal papers) was the most reported advantage of AR in education followed by "Enjoyment" (33,3%) and "Create positive attitudes". The results show that researchers are exploring the uses of AR for increasing learning outcomes and for identifying the aspects of AR that may increase enjoyment and increase the perception of students in educational settings. In these results motivation did not rated high as in journal papers but it is still an advantage reported in conference papers. Other advantages reported in conference papers were: "Facilitate Interaction" (16,6%), "Situated Learning" (16,6%), "Collaboration" (11,1%), "Just in-time information" (11,1%), "Student-centred" (11,1%) and "Anticipation" (5,5%). Further research is needed to identify if the sub-categories that rated 0% are also advantages of AR.

i. Results obtained from journal papers in the category "Limitations of AR"

Turning now to the category "Limitations of AR", this category aims to identify the drawbacks of AR that are reported in educational settings. Results are shown in Table 2-14. In this category each paper might be assigned to more than one sub-category, so the total number of studies does not corresponds to the total number of studies analysed.

Table 2-14. "Limitations of AR" reported in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Designed for a specific knowledge field	1	3.13
Teachers cannot create new learning content	1	3.13
Difficulties maintaining superimposed information	3	9.38
Paying too much attention to virtual information	2	6.25
Short periods of validation	1	3.13
Intrusive Technology	2	6.25
Not specified in the study	22	68.75

From this data it can be seen that the most reported limitation in the studies reviewed are "Difficulties maintaining superimposed information" (9.3%). Students may feel frustrated if the application does not work properly or if it is difficult for them to use the markers or the device in order to see the augmented information. In order to overcome this limitation there is a need of improving the algorithms for tracking and image processing. In addition to this, it is recommended that further research be undertaken in usability studies for AR applications in education as well as guidelines for designing AR-based educational settings.

Another limitation reported was "Paying too much attention to virtual information" (6.2%). This limitation is related to the novelty of the technology effect also known as the Hawthorne effect (Looi et al., 2009) when it is used for the first time in the classroom. So, students may be distracted by the virtual information showed or the technology itself. Although the novelty of the technology was not reported as a limitation of AR in the papers reviewed, other studies have reported this effect as a limitation of AR (Westerfield, Mitrovic, & Billinghurst, 2015; Kyungwon Gil, Jimin Rhim, Ha, Young Yim Doh, & Woo, 2014; Bai, Blackwell, & Coulouris, 2013; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014; Li, Chen, Whittinghill, & Vorvoreanu, 2014; Bressler & Bodzin, 2013; Westerfield, Mitrovic, & Billinghurst, 2013). The novelty effect is a limitation of AR because the initial interest of students in the learning activity may decrease as the time goes when students get used to using the technology.

"Intrusive Technology" (6.2%) was also a limitation reported which is connected with the use of HDM (Head-mounted displays) (Zarraonandia, Aedo, Díaz, & Montero, 2013) because the device can interrupt the natural interaction with others.

Other limitations reported in the studies are: "Designed for a specific knowledge field" (3.3%) and "Teachers cannot create new learning content" (3.1%). In this sense, it is recommended that further research be undertaken in authoring tools for creating AR activities so that teachers can create their own content with AR support.

j. Results obtained from conference papers in the category "Limitations of AR"

Table 2-15 shows the list of limitations reported in the conference papers analyzed. In this category each paper might be assigned to more than one sub-category, so the total number of studies does not corresponds to the total number of studies analyzed.

Table 2-15. "Limitations of AR" reported in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Designed for a specific knowledge field	0	0
Teachers cannot create new learning content	0	0
Difficulties maintaining superimposed information	1	5,5
Paying too much attention to virtual information	0	0
Short periods of validation	0	0
Intrusive Technology	0	0
Not specified in the study	17	95.5

Compared to journal papers, for conference papers there was only one study that reported the limitation in terms of the "Difficulties maintaining superimposed information" (5,5%). The rest of the studies did not reported specific limitations identified in the interventions conducted. This result might be explained because some conference papers report works in progress and preliminary results so researchers may have not identified the limitations of the technology in each study conducted.

k. Results obtained from journal papers in the category "Effectiveness of AR"

With respect to the category "Effectiveness of AR", Table 2-16 shows the results. Although this category seems to be similar to the category "Reported advantages of AR", the category of "Effectiveness of AR" is more related to the result or the effect that AR produce in the educational setting and all the actors involved in the learning process (students, teachers, etc.) as a result of an intervention with an AR application. In other words this category deals with the positive results of using AR in the educational setting. Since one study can report more than one sub-category of effectiveness, each study can meet more than one sub-category.

Table 2-16. "Effectiveness of AR" as reported in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Better learning performance	17	53.13
Learning motivation	9	28.13
Improve perceived enjoyment	4	12.50
Decrease the education cost	0	0.00
Positive attitudes	4	12.50
Student engagement	5	15.63
Not reported	0	0.0

Most of the studies reported that AR applications lead to "Better learning performance" (53.3%) (also reported as better learning outcomes) in educational settings. "Learning motivation" (28.1%) and "Student engagement" (15.6%) were also reported. The results show that AR is a promising technology for improving the student's learning performance and motivate students to learn thanks to the interaction and graphical content used. "Improved perceived enjoyment" (12.5%) and "Positive attitudes" (12.5%) were less reported but are also important in educational settings. However, the effectiveness related to "Decrease the educational cost" (0%) was not reported in the papers.

l. Results obtained from conference papers in the category "Effectiveness of AR"

Table 2-17 shows the list of sub-categories for the category "Effectiveness of AR".

Table 2-17. "Effectiveness of AR" as reported in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Better learning performance	4	22.2
Learning motivation	2	11.1
Improve perceived enjoyment	5	27.7
Decrease the education cost	0	0.0
Positive attitudes	3	16.6
Student engagement	1	5.5
Not reported	3	16.6

The sub-categories "Improve perceived enjoyment" (27.7%), "Better learning performance" (22.2%) and "Positive attitudes"(16.6%) rated better than the others. However, the difference is not remarkable with the categories "Learning motivation" (11.1%) and "Student engagement" (5.5%). In conference papers the category "Improve perceived enjoyment" rated better than the category "Better learning performance" (22.2%) and "Learning motivation" (11.1%). This result may be explained by the fact that some of the conference papers reviewed are about games with AR. However, in general it seems that motivation, attitudes and learning performance are two aspects of the educational process that seem to be positively affected by AR.

As for the category "Decrease the education cost" (0%), conference papers did not report it as part of the effectiveness of AR but further research is needed to identify if AR is useful for decreasing the educational cost.

m. Conclusions of LRQ1 in a nutshell.

Overall, the results obtained as part of the research question **LRQ1** provided an overview of the research conducted from 2003 to 2013 in the field of AR in education. In summary, the results showed that AR has been mostly used in educational settings for teaching Science. However, more research needs to be conducted to determine the benefits of AR for engineering education, social sciences and other fields such as agriculture, forestry, veterinaty and other learning domains that have not been explored yet. Moreover, AR has been mostly applied in higher education settings that it has not been widely applied for early childhood or VET education.

We also identified that more research needs to be conducted in terms of using AR in educational games and the support that AR may provide for lab experiments and reducing consts of procedures in the laboratory. In terms of the advantages of AR we found that most of the studies report that AR supports student motivation and learning gains but further research is needed to identify how and why AR supports motivation and learning gains. Finally, we identified that AR still have some drawbacks and more research is needed in terms of usability issues.

LRQ2 - How did augmented reality evolve with the technological advances between 2003 and 2013?

To analyze the evolution of AR for the period of this literature review (2003-2013) we took into account the type of AR, the devices used and the software used to create the AR learning experiences. The results of this research question are organized as follows: Section *a* shows the results of the evolution of AR by type of AR according to the studies published in journal papers while section *b* shows the results of the evolution of AR by type of AR according to the studies published in conference papers. Section *c* shows the results of the evolution of AR according to the device used.

a. Results of the evolution of AR by "Type of AR" according to the studies published in journal papers

Regarding the "Type of AR" considered in the studies reviewed, Table 2-18 summarizes the results. We considered three types of AR according to the classification of Wojciechowski & Cellary (2013). The first type of AR is "Marker-based AR" which is based on the registration of markers. Markers are labels that contain a colored or black and white pattern that is recognized or registered by the AR application through the camera of the device in order to fire an event that can be, for instance, to show a 3D image in the screen of the device located in the same position where the marker is. The second type of AR is "Marker-less AR" in which no markers are needed since the AR application is able to recognize and register forms and patterns of the objects in the real world through the camera in order to superimpose virtual information. The third type of AR is "Location-based AR" in which data about the position and orientation of the device using the Global Positioning System (GPS) and other sensors are used to superimpose information.

Table 2-18. "Type of AR" applied in the studies published in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Marker-based AR	19	59,38%
Marker-less AR	4	12,50%
Location-based AR	7	21,88%
Not specified in the study	2	6,25%

The results in Table 2-18 reveal that most of the studies used "Marker-based AR" (59.3%) which means that most of the applications developed for educational settings use markers. A possible explanation for this result is that currently the tracking process of markers is better and more stable compared to the marker-less tracking techniques. The use of static markers decrease the tracking work needed and reduce the number of objects to be detected (El Sayed, Zayed, &

Sharawy, 2011). Therefore for educational settings the use of markers could be recommended so that students can have a better experience with the technology until better techniques for tracking can be developed for marker-less AR.

"Marker-less AR" has not been widely used in educational settings (12.5%). However, there is a trend of using Microsoft Kinect sensors and similar technologies in order to create AR applications for educational settings (Fallavollita et al., 2013) (Pillat, Nagendran, & Lindgren, 2012). Kinect provides some advantages in tracking and registering objects in marker-less AR.

Interestingly, based on the studies reviewed the development of "Location-based AR" (21.8%) applications is major compared to marker-less AR applications. This can be due to the availability of sensors in mobile devices like the accelerometer, gyroscope, digital compass and the possibility of using GPS. These technological advancements open possibilities for developing applications of AR that can be aware of the user's location in order to show information according to the geographical position and/or orientation. Table 2-19 shows the types of AR applied in the studies reviewed by year. This table shows that during the last five years of the systematic literature review there was an increasing use of marker-based AR and location-based AR. Marker-less AR has not been widely used.

Table 2-19. Types of AR applied in the studies published in journal papers by year.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Marker-based AR	-	-	-	-	-	-	-	3	7	3	6
Marker-less AR	-	-	-	-	-	-	1	-	-	-	3
Location-based AR	-	-	-	-	-	-	-	-	-	1	6

b. *Results of the evolution of AR by "Type of AR" according to the studies published in conference papers*

Table 2-20 shows the types of AR applied in the studies published in conference papers. In this case, the dominance of "Marker-based AR" is very clear. As in the results obtained for the journal papers (see Table 2-18) "Marker-based AR" is the most common type of AR used. However, in this case, the number of studies that use "Marker-less AR" is higher than the number of studies that use Location-based AR. This may indicate that researchers are conducting more research on marker-less AR to uncover the possibilities of this type of AR. This situation may be also the result of the advances in Head-mounted displays that are promising to achieve better results with smaller devices. This landscape can be clear by analyzing research in this topic in the next years.

Table 2-20. "Type of AR" applied in the studies published in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Marker-based AR	13	72.22
Marker-less AR	4	22.22
Location-based AR	1	5.56
Not specified in the study	0	0.0

Table 2-21 shows the types of AR applied in the studies published in conference papers by year. The table shows that "Marker-based AR" as presented in the table has a tendency to remain stable as one of the most used types of AR as well as "Marker-less AR". However, research on "Location-based AR" is very little. By comparing data for the Table 2-19 and Table 2-21, the research on Location-based AR seems to be more common in journal publications. This may suggest that researchers that are working in on-going projects are moving from the research on location-based AR to the research on "Marker-less AR" or "Marker-based AR".

Table 2-21. Types of AR applied in the studies published in conference papers by year.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Marker-based AR	-	-	-	-	-	3	1	3	2	2	2
Marker-less AR	-	-	-	-	-	-	2	-	1	1	-
Location-based AR	-	-	-	-	-	-	-	-	-	1	-

c. *Results of the evolution of AR by "Device used" according to the studies published in journal papers*

The results about types of AR applied in education are related to the results of the category "Device used". In this category we analyzed the devices used in the AR-based educational settings. Table 2-22 shows the results of our review in the category "Device used".

Table 2-22. "Device used" in studies published in the journals reviewed.

Sub-Category	Number of Studies	Percentage (%)
PC & Web Cam	10	31,2
Handheld devices	16	50,0
Head Mounted Displays	0	0,0
Large Screen projectors	2	6,2
Other device	3	9,3
Not mentioned in the study	1	3,1

From this data, we can see that most of the studies have used "Hand-held devices" (50.0%) and "PC & Web Cam" (31.2%). These results show an increasing interest in using handheld devices (smartphones, tablets, PDA's, etc.) for educational AR applications. This result can be explained due to the fact that handheld devices are now more popular among people especially for young people. "Large Screen projectors" (6.25%) and "Other device" (3.1%) are less used in AR-based educational settings. Sub-Category "Large Screen projectors" corresponds to hardware like stereoscopic projection screens combined with tracking cameras such as the one described in the study by Wrzesien & Alcañiz Raya, (2010). Sub-Category "Other device" (9.3%) refers to hardware designed for specific AR experiences that is applied in educational settings like the four versions of the camera-projector system TinkerLamp (Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013). In this review we did not find studies that used head-mounted displays for creating educational AR-based applications.

Table 2-23 shows the devices used in the studies published in journal papers classified by year. The most striking result to emerge from the data is that most of the studies published in journal papers used "Handheld devices" (50%) (smartphones, tablets, etc.). This means that there is a trend to use handheld devices for creating AR learning experiences. This may be explained by the rapid evolution of handheld devices and the ease access to cheaper devices with good capabilities in terms of computation that allow to create AR learning experiences with an acceptable quality. Thanks to this context many students go to the school and to the university with these devices.

Table 2-23. Devices used in studies published in journal papers by year.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PC & Web Cam	-	-	-	-	-	-	1	2	4	1	2
Handheld devices	-	-	-	-	-	-	-	1	2	1	12
Head Mounted Displays	-	-	-	-	-	-	-	-	-	-	-
Large Screen projectors	-	-	-	-	-	-	-	1	-	1	-
Other device	-	1	-	-	-	-	-	-	1	-	1
Not mentioned in the study	-	-	-	-	-	-	-	1	-	-	-

The use of "PC & Web Cam" (31,2%) showed an increasing tendency until 2011 and then its use decreased. This may be explained by the fact that in terms of logistics it would be easier to deploy an AR learning experience with handheld devices rather than moving students to a room with computers and cameras for the AR learning experience. Regarding the use of Head-mounted displays, the papers analyzed did not use them. However, thanks to the recent advances on these devices, more studies need to be revised to identify the perspectives of this technology for creating AR learning experiences.

A couple of studies used "Large screen projectors" (6,2%) and "Other device" (9,3%). As for "Large screen projectors", only a couple of papers reported to use this type of AR. In this case the AR learning experience in general is centralized in one projector and students interact at the same time or by turns. With "Other device" we refer to the use of a tailor-made devices for particular learning experiences such as the TinkerLamp software reported in the study of Cuendet et al., (2013). Finally, only one study did not mention the device used for creating the AR experience.

d. Results of the evolution of AR by "Device used" according to the studies published in conference papers

Table 2-24 shows the devices used to create the AR learning experiences as reported in the conference papers. Unlike the results obtained from the studies published in journal papers as described in section c, the results of studies published in conference papers show that the most common device was "PC & Web Cam" (50.0%) followed by "Handheld devices"(33,3%).

Table 2-24. "Device used" in studies published in the conference papers.

Sub-Category	Number of Studies	Percentage (%)
PC & Web Cam	9	50,0
Handheld devices	6	33,3
Head Mounted Displays	4	22,2
Large Screen projectors	2	11,1
Other device	3	16,6
Not mentioned in the study	1	5,5

Although the results show that the number of studies that used "PC & Web Cam" is higher than the number of studies that used "Handheld devices", we actually do not know if this is a trend for the last years of the time window selected for this systematic review (2003-2013). **Table 2-25** shows the devices used in the studies published in the conference papers by year. As it can be seen the use of the "PC & Web Cam" seems to be decreasing in the last years but the use of "Handheld devices" seems to be increasing. This result shows that it seems that there is an increasing interest in using "Handheld devices" for creating the AR learning experiences. However, the analysis of the trend for the last years will be useful to identify if there is any change in the tendency.

Table 2-25. "Device used" in studies published in conference papers by year.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PC & Web Cam	-	-	-	-	-	3	1	2	1	1	1
Handheld devices	-	-	-	-	-	-	-	1	2	2	1
Head Mounted Displays	-	-	-	-	-	3	-	1	-	-	-
Large Screen projectors	-	-	-	-	-	-	-	-	1	1	-
Other device	-	-	-	-	-	-	2	-	-	1	-
Not mentioned in the study	-	-	-	-	-	-	-	-	-	1	-

As for the Sub-Category "Head Mounted Displays" (22,2%), the results show that there were some studies that used this type of device between 2007 and 2011 but from 2011 and 2013 there were no studies that used this type of device. So, it is not clear if there is any tendency for using this type of device for creating AR learning experiences.

Moreover, the use of "Large screen projectors" (11,1%) seems to appear as a constant from 2011. This result may be explained by the fact that some AR learning experiences tend to create a better sense of immersion and whole body interaction with the system at a human scale as reported in the study by Pillat et al. (2012), which is indeed one of the studies that use large screen projectors.

e. Conclusions of LRQ2 in a nutshell.

The evolution of AR has shown that the most common type of AR used is marker-based AR followed by location-based AR and marker-less AR. Some of the studies reviewed recognize the limitations of current algorithms and libraries for Marker-less AR. However, emerging research is showing promising advances in terms of marker-less AR and some applications in education are using the Microsoft Kinect device. Moreover, a tendency to use handheld devices for creating AR experiences was identified thanks to the advances in mobile devices in terms of processing and the resolution of cameras and at the same time the use of PC and Web cameras for creating AR applications is decreasing.

We also identified that more studies need to be revised to identify if there is any trend in terms of the use of head mounted displays and large screen projectors.

LRQ3 - Have the inclusion of combined adaptive or personalized processes been considered in augmented reality applications?

In the studies reviewed only 2 out of 32 studies report some kind of personalized process and 1 out of 32 considered a user modeling process. Barak & Ziv (2013) created "Wandering" which is an application for creating location-based interactive learning objects (LILOs) and considers personalization as an "important requirement of the 21st century skills" (Barak & Ziv, 2013). Personalization is considered for meeting the needs and interests of the individual learners. However, in the study where the authors describe the Wandering application is not clear if they have a user model and if the applied any specif process of personalization.

Blake & Butcher-Green (2009) propose an application for customized training based on a scaffolding instructional approach and an agent architecture in order to training individuals from diverse backgrounds. The type of adaptation process considered by the application is personalization based on historical training profiles. However, in the paper is not clear if the information for the user model comes from the learner's profile. In addition to this, the authors states that the system was being integrated with the AR environment when the paper was written. The results of the paper are based on a simulated AR environment (Blake & Butcher-Green, 2009).

In the conference papers analyzed, we did not found studies that applied personalization or adaptive processes in AR learning experiences.

Consequently, in this systematic literature review we found that very little has been done in terms of personalization in AR learning experiences. Thus, further research is needed to explore how personalization may help to improve the learning experiences supported by AR.

LRQ4 - How has augmented reality addressed the special needs of access and people preferences in educational settings?

In the studies reviewed from journals there was no evidence of AR applications in educational settings that address the special needs of students. This finding corroborates the idea of H. Wu, Wen-Yu, Chang, & Liang (2013) who state that few systems have been designed for students with special needs. According to Lindsay (2007) the opportunities for children with special needs and disabilities can be improved by a major policy initiative called "inclusion". Inclusive education is more than integration because integration refers to the learner adapting to the educational setting while inclusion means that the educational setting adapts to the learner in order to meet their needs (Lindsay, 2007). Within this sense AR may offer unique advantages and benefits in order to create inclusive AR-based educational settings. Further research is needed in order to identify the effectiveness and advantages of AR applications for addressing the special needs of students.

In the conference papers, we found that only one study used AR to address special educational needs of students. The study by Bai et al. (2013) describes an AR system created to encourage pretend play for children with Autism. They found that the system encourages children to play for a longer period of time compared to a non-AR experience. The study provides some recommendations on the design of AR systems for children with Autism. Moreover, Bai et al. (2013, p. 50) claims that “there is an emerging focus to design AR systems for children with special needs”.

Overall, the results show that only few studies have considered the use of AR for addressing special educational needs and therefore further research is needed to identify the possibilities that AR may offer for addressing special educational needs. Moreover, it is worth thinking of expanding this review to other sources of information in order to have a better comprehension on how special educational needs have been addressed in AR learning experiences.

LRQ5 - What are the evaluation methods considered for augmented reality applications in educational scenarios?

As for the evaluation methods, we analyzed three categories: “Research sample”, “Research method” and “Time dimension”. The following sub-sections present the results obtained for each one of these categories according to the findings in the journal and conference papers.

a. Results obtained from journal papers with respect to the “Research sample”

With respect to the evaluation methods for AR applications in educational settings we considered four sub-categories for the analysis. The results show that, regarding to research samples (see Table 2-26), most of the studies were conducted with medium research samples “Between 30 and 200 participants” (78.1%) and some studies considered small research samples “30 or less than 30 participants” (18.7%). In our review we did not find studies conducted with research samples greater than 200 participants (Sub-caterogy “More than 200 participants”). A possible explanation of this result is that greater research samples would need more devices (handheld devices, PC, web cam, tablets, etc.) so that each participant can have one device.

Table 2-26. “Research sample” in the studies published in journal papers.

Sub-Category	Number of Studies	Percentage (%)
30 or less than 30 participants	6	18,75
Between 30 and 200 participants	25	78,13
More than 200 participants	0	0,00
Not Specified in the study	1	3,13

It is worth noticing that the number of studies conducted with research samples of “30 or less than 30 participants” (18,7%) is very small compared to the number of studies conducted with research samples “Between 30 and 200 participants”. This result may be explained by the common rule of thumb that recommends the use of research samples of more than 30 participants to have accurate results in terms of effect size and power with some statistical methods (Wilson Van Voorhis & Morgan, 2007).

b. Results obtained from conference papers with respect to the "Research sample"

Table 2-27 shows the proportion of research samples in the studies published in conference papers. As it can be seen, most of the studies were conducted with research samples "Between 30 and 200 participants" (38,8%) followed by the use of research samples of "30 or less than 30 participants". These results are similar to the results obtained for journal papers. In general, it seems that most of the studies are being conducted with research samples with around 30 or more participants which allows having good results in terms of the effect size and power of the statistical methods applied.

Only the study by Pillat et al. (2012) was conducted with a research sample of "More than 200 participants". This study was conducted with a research sample of 233 middle-school children that used a mixed reality system to teach some principles of physics.

Table 2-27. "Research sample" in the studies published in conference papers.

Sub-Category	Number of Studies	Percentage (%)
30 or less than 30 participants	5	27,7
Between 30 and 200 participants	7	38,8
More than 200 participants	1	5,5
Not Specified in the study	5	27,7

c. Results obtained from journal papers with respect to the "Research method"

On the other hand, Table 2-28 shows the results with respect to the "Research Method" of studies published in journal papers.

Table 2-28. "Research method" applied in the studies published in the journal papers.

Sub-Category	Number of Studies	Percentage (%)
Qualitative-Exploratory-Case Study	7	21,88
Qualitative-Exploratory-Pilot Study	4	12,50
Qualitative-Exploratory-Experience Survey	0	0,00
Quantitative-Descriptive Research	5	15,63
Quantitative-Explanatory and Causal Research	1	3,13
Mixed Methods	15	46,88
Other	0	0,00

In this table, most of the studies applied "Mixed Methods" (46.8%) to conduct the research. This result may be explained by the fact that the quantitative methods can be complemented with the information collected from qualitative methods to have a better understanding of the phenomena. In this regard, it seems that most of the researchers are applying this type of research method to gather as much data as possible to identify the effects of AR in the learning processes.

Regarding the qualitative research methods, some studies have applied the "Qualitative-Exploratory-Case study" (21.8%) and "Qualitative-Exploratory-Pilot Study" (12.5%) but none of the studies has applied the "Qualitative-Exploratory-Experience Survey" (0%). On the other hand, with respect to the quantitative methods, the "Quantitative-Explanatory and Causal research" (3.1%) was applied in only one study.

d. Results obtained from conference papers with respect to the "Research method"

Table 2-29 shows the research methods applied in the studies published in the conference papers reviewed.

Table 2-29. "Research method" applied in the studies published in the conference papers.

Sub-Category	Number of Studies	Percentage (%)
Qualitative-Exploratory-Case Study	1	5,56
Qualitative-Exploratory-Pilot Study	2	11,11
Qualitative-Exploratory-Experience Survey	0	0,00
Quantitative-Descriptive Research	2	11,11
Quantitative-Explanatory and Causal Research	7	38,89
Mixed Methods	1	5,56
Other	1	5,56
Not reported	4	22,22

The results show that in the conference papers, the "Quantitative-Explanatory and Causal Research" (38,8%) is the most common method applied to research in AR. This result shows that emerging research on AR is being conducted with this type of quantitative methods that allows identifying and providing an explanation on how a phenomenon occurs and why it occurs. "Quantitative-Descriptive Research" (11,1%) was also used in a couple of studies with the aim of providing a description on how the learning scenario was affected by the use of AR.

As for qualitative methods, the results show that this type of research methods were not common in conference papers. This result may be explained by the fact that conference papers tend to be shorter than journal papers and the space available for reporting the results of applying qualitative methods is reduced.

Another interesting result was that "Mixed Methods" (5,5%) was used by only one paper. One explanation of this result might be that in conference papers researchers usually publish preliminary results and work-in-progress research, so it is not common to publish all the results and therefore it is not very common to apply a combination of methods (mixed methods).

e. *Results obtained from journal papers with respect to the "Time dimension"*

Turning now to the time dimension of the studies reviewed, Table 2-30 shows that most of the studies were identified as "Short intervention" (93.7%) and only 6.2% of the studies were identified as "Long intervention".

Table 2-30. "Time dimension" of the studies published in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Short intervention	30	93,75
Long intervention	2	6,25
Other	0	0.0

An implication of this result could be that the novelty of the technology in studies with a short intervention may affect the results since students can be engaged with the AR application because it is new for them. Future studies conducted as long intervention studies need to be undertaken in order to follow the students in the long term and identify the advantages, benefits, limitations when students are exposed to this technology for a long period of time and also when students are used to using AR in the classroom as well as analyze the student's behavior in different learning scenarios.

f. *Results obtained from conference papers with respect to the "Time dimension"*

Table 2-31 shows the time dimension of the studies published in conference papers. These results show that most of the papers followed a short intervention study which means that the amount of time that the intervention lasted was very short. This result is similar to the result obtained for the journal papers. The implication of this result is that emerging research on AR published in the conference papers is using methods in which the interventions last for short periods and then the results may be affected by the novelty of technology effect.

The conclusion is that more research is needed with studies that last for a longer period of time to determine the real effects of AR in educational settings when the novelty effect wears off.

Table 2-31. "Time dimension" of the studies published in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Short intervention	16	88,9
Long intervention	0	0,0
Other	2	11,1

g. Results obtained from journal papers with respect to the "Data collection method"

Finally, as Table 2-32 shows, most of the studies applied "Questionnaires" (75%), "interviews" (28.3%) and "Cases observation" (9.3%) as data collection methods. "Focus-groups" (0%) and "Writing Essay" (3.1%) have either not been used or used very little. Since one study can apply more than one data collection method, this study counts for more than one category.

Table 2-32. "Data collection method" applied in studies published in journal papers.

Sub-Category	Number of Studies	Percentage (%)
Questionnaires	24	75,00
Interviews	9	28,13
Focus-groups	0	0,00
Cases observation	3	9,38
Writing Essay	1	3,13
Other	1	3,13

h. Results obtained from conference papers with respect to the "Data collection method"

Table 2-33 shows the list of data collection methods published in conference papers. The results shows that "Questionnaires" (61,1%) was the most common data collection method followed by "Interviews" (16,7%), "Focus-groups" (11,1%) and "Cases observation" (11,1%). It is important to note that for conference papers the "Focus-groups" is being used for gathering data but this method is not being used in journal papers.

Table 2-33. "Data collection method" applied in studies published in conference papers.

Sub-Category	Number of Studies	Percentage (%)
Questionnaires	11	61,1
Interviews	3	16,7
Focus-groups	2	11,1
Cases observation	2	11,1
Writing Essay	0	0,0
Other	0	0,0

i. Conclusions of LRQ5 in a nutshell.

We identified that the studies reviewed used small (30 or less participants) and medium (between 30 and 200 participants) research samples and therefore further research may be conducted with larger research samples to be able to generalize and identify the real impact of AR in education. Moreover, in terms of the research methods, the results showed that in journal papers most of the studies applied mixed methods which means a combination of quantitative and qualitative methods. This can be important because quantitative methods can be complemented with qualitative methods to have a better understanding of the phenomena. In conference papers we identified that researchers are using quantitative methods for explaining how AR impact on the educational setting.

Regarding the time dimension of the studies, we identified that most of the studies have been conducted with short interventions and therefore the novelty effect might be affecting the results. Thus, we might recommend conducting more studies with longer interventions to identify the effect of AR after the novelty effect disappears.

LRQ6 - Which frameworks or architectures for augmented reality applications have been developed and tested in educational settings?

In the studies reviewed from the journal papers, very little was found on the definition of frameworks or architectures for AR applications in educational settings. Only 3 out of 32 studies described a framework for AR. For instance, Bujak et al., (2013) created an abstract framework for understanding AR learning from three perspectives: physical, cognitive and contextual. On the other hand, Chen et al., (2011) introduced a conceptual framework as well as the implementation of the system in order to integrate digital materials by means of QR codes into paper-based reading activities. Finally, Price & Rogers, (2004) introduced a framework for designing digitally augmented physical spaces. Based on the three proposed frameworks, it can thus be suggested that frameworks should consider pedagogical and didactical factors as well as recommendations for creating AR-based educational settings.

In the studies reviewed from the conference papers, we did not found any framework definition. Most of the studies are focused in the design, development or evaluation of an AR tool in education but none of them focused on the definition of a framework.

In that regard, it would be important to expand the review to other sources of information and analyze other frameworks for AR in education to have a better understanding on how these frameworks were defined, how they were evaluated and the purposes of these frameworks.

2.2.4 Conclusions of the systematic literature review

In this systematic literature review 32 journal papers and 18 conference papers were reviewed. The main findings of this review are:

1. The number of published studies about AR in education has progressively increased year by year specially during the last 4 years (2010 - 2013) of the timeframe selected.
2. Science and Humanities & Arts are the fields of education where AR has been applied the most. Health & welfare, Educational (teacher training) and Agriculture are the research fields that were the least explored fields.
3. AR has been mostly applied in higher education settings and compulsory levels of education (primary and secondary) for motivating students. Target groups like early childhood education and Vocational educational Training (VET) are potential groups for exploring the uses of AR in the future.
4. The main advantages for AR are: learning gains, motivation, interaction and collaboration.
5. Limitations of AR are mainly: difficulties maintaining superimposed information, paying too much attention to virtual information (related to the novelty of the technology) and the consideration of AR as an intrusive technology.
6. AR has been effective for: a better learning performance, learning motivation, student engagement and positive attitudes.
7. Marker-based AR is the most used type of AR. In addition location-based AR is being widely applied. This can be due to the availability of sensors in mobile devices like the accelerometer, gyroscope, digital compass and the possibility of using GPS. Marker-less AR needs some improvement in algorithms for tracking objects but the use of Microsoft Kinect is becoming more and more popular.
8. The main purpose of using AR has been for explaining a topic of interest as well as providing additional information. AR educational games and AR for lab experiments are also growing fields.

9. Very few systems have considered students' special educational needs in AR learning experiences. Here there is a potential field for further research.
10. Most of the studies have considered medium research samples (between 30 and 200 participants), and most of the studies have used mixed evaluation methods. The most popular data collection methods were questionnaires, interviews and surveys and most of the studies used short interventions.

This systematic literature review provided a landscape of the current state of AR in education from 2003 to 2013 (Until February of 2014). From the findings of this literature review we identified the following Open Issues (OI):

- **OI1:** One of the main advantages of AR in education is that AR increases student motivation. However, most of the studies do not clearly define which are the features or aspects of AR applications that increase student motivation. In other words, we still do not know how and why AR increases student motivation.
- **OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences and therefore the possibilities that AR can offer for creating inclusive AR learning experiences seem to remain unexplored.
- **OI3:** There is a lack of studies that define and evaluate AR frameworks in educational settings. In this regard, some of the frameworks have been defined as architectures that are evaluated for specific contexts or learning domains and those frameworks do not define specific recommendations on how to create AR learning experiences. So, the review of literature need to be extended to identify frameworks in the literature that define guidelines to inform the design and development of motivational AR learning experiences.
- **OI4:** According to the literature review, only 2 out of the 50 studies reviewed were conducted in the VET level of education. Thus, there is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education.

Therefore, we decided to focus on these four open issues and we decided to deepen the analysis of these aspects as follows:

1. As for **OI1**, we decided to review the literature on the topic of **predictors of student motivation** in AR and the topic of acceptance of AR. This review of literature provided a better understanding on which are the features or aspects of AR that support student motivation in AR learning experiences and how these features or aspects (predictors) were identified. This review of literature is described in section 2.3.
2. As for **OI2,** we decided to review the literature on **how special educational needs have been addressed in AR learning experiences**. This review of literature is described in section 2.4.
3. As for **OI3,** we decided to review the literature on **AR frameworks in education**. This means that we searched the literature for finding how the frameworks have been defined, how they were evaluated and which were the purposed of these frameworks. This review of literature is described in section 2.5.
4. As for **OI4**, we decided to review the literature on **the use of AR for supporting learning process in the VET level of education**. This review of literature is described in section 2.6.

It is worth noting that these specific literature reviews are updated to 2016 in order to have a clear ladscape on these open issues while the research in this thesis was conducted. These specific literature reviews correspond to the second activity of the Exploratory Phase (**AEP2**) in the research methodology followed in this thesis. Moreover, these specific literature reviews addressed the specific objective of this thesis: **SO1** – To conduct a systematic literature review to identify the current state of AR in education.

2.3 PREDICTORS OF STUDENT MOTIVATION AND ACCEPTANCE OF AR

In this section we describe a review of literature in the topic of predictors of student motivation and acceptance of AR. The aim of this review is to have a better understanding on which are the factors and aspects (predictors) of AR that positively affect student motivation and how these predictors were identified. This review addresses the open issue **OI1.**

Most of the studies that seek to identify the predictors of students' motivation and the intention to use AR in education used the TAM (Technology Acceptance Model) (Davis, 1989) as the main research model. The aim of the TAM model is to explain the determinants of computer technology acceptance and can be useful for identifying why some technologies may be not accepted (Davis, Bagozzi, & Warshaw, 1989). TAM is depicted in Figure 2-1. The TAM model considers that there are some external variables that influence the Perceived Usefulness (U) and the Perceived Ease of Use (E). Moreover, the Perceived Usefulness (U) and Perceived Ease of Use (E) influence the Attitude Toward Using (A) and at the same time this variable influences the Behavioral Intention to Use (BI) which finally determines the use of the system (Actual System Use).

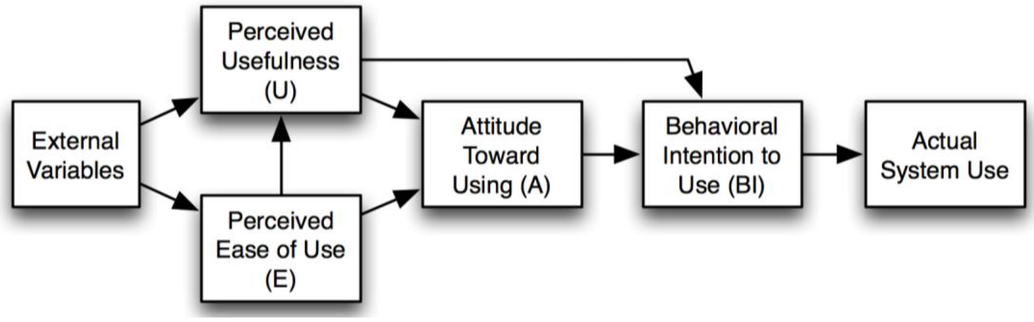

Figure 2-1. Technology Acceptance Model (Davis et al., 1989).

Some researchers have added or replaced some variables in the original TAM model to validate the acceptance and intention to use AR in education.

In their study, Balog & Pribeanu, (2010) hypothesized that perceived enjoyment and perceived ease of use are affected by the ergonomics of the AR teaching platform. As a result of the study, they found that ergonomics has a positive effect on perceived ease of use and perceived enjoyment. They also found that perceived enjoyment is a stronger predictor of perceived usefulness which means that an enjoyable AR experience increases the perceived usefulness towards the system. Moreover, they found that perceived enjoyment is stronger than perceived usefulness in predicting the intention to use an AR system. The researchers identified some variables that are related to the user experience in AR applications: interesting learning, captivating exercises, enjoyable learning, and exciting system (Balog & Pribeanu, 2010). In the same vein, (H.-F. Lin & Chen, 2015) combined the TAM model with the media richness theory and factors of self-efficacy to explore the behavioral intention to use AR for information navigation in museums. From the media richness theory four variables were considered: timely feedback, multiple cues, language variety and personal focus. The results of a case study conducted showed that higher media richness imply higher levels of perceived usefulness which at the same time foster positive attitudes toward the system and an increased behavioral intention to use the technology. The researchers also recommended that designers should consider the variables of media richness theory to improve user attitudes toward the system.

Similarly, Arvanitis et al., (2011) introduced an extension of the TAM model to explore users' perceptions, beliefs and attitudes toward mobile AR in science education. The authors argue that the use of a HMD (Head Mounted Display) provides a complete new experience in which the existing factors of acceptance may not fit properly so new factors of acceptance need to be identified. Satisfaction, exertion and comfort were considered in the research model jointly with some moderating factors such as gender, duration of use, anxiety among others. The researchers found that students' emotion influences most of the TAM constructs. In terms of satisfaction they found that if the students perceive that the information conveyed and its context as useful, the satisfaction will increase. However researchers pointed out that no effects were found between the time the system is used and the acceptance of the system.

Another study that used the TAM as a research model was conducted by Kim & Hyun, (2016) to identify the predictors of the use of mobile AR. In this study, the researchers used the extended TAM model and changed the usefulness variable with a new variable: telepresence. Besides that the ease of use variable was excluded but the system quality, information quality and service quality was maintained in the model. This model is called the telepresence mediation hypothesis (TMH). The model was validated and the researchers found that usefulness can be substituted for telepresence. Besides that they found that system quality and information quality can influence the intention to use AR and these factors influence telepresence. Thus, developers should improve the quality of AR systems to increase the intention to use the AR system (H. Kim & Hyun, 2016). Similarly, the study by Miranda Bojórquez, Vergara Villegas, Cruz Sánchez, García-Alcaraz, & Favela Vara (2016) evaluated a mobile AR system for learning the Mexican Mayo language. The system was tested with 85 students and the TAM model was applied with two additional variables introduced by the researchers to evaluate cultural differences: Individualism and Uncertainty avoidance. The researchers found that individualism is a predictor of the perceived ease of use and therefore to the intention to use the mobile AR system. However, the Unvertainty avoidance variable has no impact on perceived ease of use.

Moreover, in terms of satisfaction and effectiveness, Yuan-Jen, Chin-Hsing, Wen-Tzeng, & Wei-Shiun, (2011) explored the learners' satisfaction, learning effectiveness and behavioral intention of a marker-based AR learning system for learning English vocabulary. By exploring the correlation between the constructs of the TAM model, the researchers found that perceived self-efficacy and e-learning system quality are predictors of students' perceived satisfaction and perceived satisfaction was found to be a predictor of the behavioral intention to use the system. The researchers also found that multimedia instruction and e-learning system quality are predictors of e-learning effectiveness. The researchers highlight that system quality and perceived self-efficacy have an important implication in learners' satisfaction (Yuan-Jen et al., 2011).

Hsieh (2016a) conducted a study in which the Mobile AR Assisted English Learning System (MARAELS) was evaluated in terms of perceived usefulness and perceived ease of use. By using a questionnaire and anecdotal analysis (an observational method) with a sample of 106 seventh grade participants, the researcher concluded that students perceived the system as being useful and easy to use. This study provides insights into the acceptance of AR as a technology and a method for presenting the learning contents in English learning.

Together these studies provide insights into the predictors that affect the intention to use, acceptance, attitudes, beliefs and even motivation in AR systems from the perspective of the TAM, TAM extended and TAM2 models including the modifications introduced by the researchers. Besides, some of the studies have provided recommendations for developers on how to develop a system with features that support specific predictors albeit limited. However to the best of our knowledge none of the studies have considered the TAM3 model (Venkatesh & Bala, 2008) in which new variables have been included such as computer self-efficacy, external control, anxiety, playfulness among others and new relationships have also been introduced (Venkatesh & Bala, 2008). These variables may provide new insights into the acceptance and intention to use AR in educational settings. Notwithstanding the opportunities that may provide the use of the TAM3 model, one of the main disadvantages of this model is the lack of guidance for practitioners (Venkatesh & Bala, 2008). This means that the model does not provide guidelines or recommendations on how to implement a system with features that can be aligned with the predictors. Therefore, further research is needed on recommendations and guidelines on how to develop AR systems and experiences with features that can be aligned with the predictors identified.

Other researchers have identified predictors of students' motivation, attitudes, acceptance and intention to use from other perspectives such as usability, user experience, type of AR, Motivation-Opportunity-Ability model and others. For instance, Ferrer, Perdomo, Rashed-Ali, Fies, & Quarles, (2013) explored the impact of usability on students' motivation in AR serious games. By measuring completion time and interaction errors in an AR system for education in architectural design, the authors concluded that compared to desktop AR, mobile AR increased task completion so the usability was negatively affected. However, they found that despite the usability issues in mobile AR, students' motivation can be improved by using AR games (Ferrer et al., 2013).

In terms of user experience, in their study, Huang & Liaw (2014) developed a prototype of an AR system for health care. The system was evaluated in terms of learning motivation and intention to use AR and the results showed that immersion and interactivity features are predictors of students' motivation but immersion is a stronger predictor. Besides that, students' motivation was predictor of the intention to use AR. The authors highlight that the combination of 3D graphics and different types of interaction in AR provides immersion.

A recent study by Chen & Liao, (2015) identified the effects of the type of AR that can be static and dynamic (without and with animations respectively) and the type of guiding strategy (procedure-guided or question-guided) with respect to the students' motivation and performance in the topic of electrochemistry. In terms of motivation the learners in the static-AR and the procedure-guided strategy outperformed the learners in the dynamic-AR and the question-guided strategy in the dimension of intrinsic goal orientation. The researchers concluded that taking into account that the AR environment was new for the students the procedure-guided strategy was better for helping them to understand the concepts. The researchers point out that the learners perceived a lack of challenge in the question-guided strategy in comparison to the procedure-guided strategy.

In terms of the student's learning styles, C.-P. Chen & Wang (2015) found that students' learning style does not affect their learning motivation in mobile AR instruction.

In terms of the aesthetic experience in AR applications, Lee, Chung, & Koo (2015) applied the Motivation-Oportunity-Ability (MOA) model to explore the predictors of aesthetic experience in AR in the context of tourism. Although the domain of application was tourism, the results can provide insights into the predictors of the aesthetic experience for educational AR applications. The researchers considered two moderating variables: the distrust of technology and social influence. The results obtained through the hypothesis validation showed that enjoyment is the most powerful predictor of aesthetic experience. They also found that distrust on IT moderates the relationship between self-efficacy and aesthetic experience.

A broader perspective was adopted by Rasimah, Nurazean, Salwani, Norziha, & Roslina (2015) who conducted a systematic literature review of papers published from 2005 to 2015 to identify the factors that influence the acceptance of MR (Mixed Reality) technologies. The researchers found that the dominant factors in the evaluation of users' acceptance of MR are the perceived usefulness and perceived ease of use. These factors come from the TAM model as discussed before. Other factors were identified by the authors such as intention to use, enjoyment, information quality, system quality, personal innovativeness, engagement, self-efficacy, playfulness, aesthetics and service excellent. The researchers also identified 4 types of constructs in which the acceptance of MR can be examined: productivity-oriented, entertainment dimension, users' personal background and overall system evaluation. The productivity-oriented factor refers to the perceived usefulness and perceived ease of use from the TAM model. The entertainment dimension refers to factors such as enjoyment, engagement, playfulness, curiosity among others. Finally, the users' personal background and overall system evaluation refers to factors such as visual appeal, media richness and perceived value.

Overall, these studies provide insights into the predictors of students' motivation, attitudes and acceptance of AR in education. However, there is still a lack of research identifying how these predictors are related to the design and development of mobile AR applications and why and how these predictors positively affect student motivation.

2.4 SPECIAL EDUCATIONAL NEEDS AND AR

In this section, we describe a review of literature on how AR has been considered for addressing special educational needs. This review provided a better understanding of the open issue **IO2**.

AR has also been used for addressing some special educational needs of students in different educational levels. In their study, Aziz, Aziz, Paul, & Yusof (2012) conclude that AR could help to capture the attention and encourage active participation of students with attention deficit and hyperactivity disorder (ADHD). C. Y. Lin, Hung, Lin, & Lun (2010) studied the use of AR to make the learning process more interesting and interactive for students with cognitive impairments. The authors conclude that AR and VR technologies could be used to reduce some barriers in the learning process. Likewise, Tobar-Muñoz, Baldiris, & Fabregat (2014); Tobar-Muñoz, Fabregat, & Baldiris (2014) developed an AR-enriched inclusive videogame to support the development of basic mathematics skills in kids and proposed a set of design principles for designing inclusive AR games. In terms of user interaction, Boletsis & Mccallum (2014) developed an AR game for cognitive training and introduced an AR cube as the interaction technique in the "magnifying glass" metaphor. The results show that novice AR users were able to quickly adapt to the system using the interaction technique.

Regarding AR authoring tools for creating educational activities in contexts of special education, Lucrecia, Cecilia, Patricia, & Sandra (2013) developed an authoring tool called AuthorAR for creating educational activities with AR. AuthorAR allows teachers to create exploratory and structuring phrases activities with augmented content. These activities can be used for addressing special educational needs in vocabulary and language acquisition as well as communication needs.

Together these studies provide insights into the use of AR for addressing special educational needs but none of them were focused on VET institutions. In recent years though, some authors have begun to study the impact of AR in vocational education considering special educational needs. Y.-J. Chang, Kang, & Huang (2013) developed ARCoach, a marker-based AR system for vocational skill-training for people with cognitive impairments. The results show that participants increased their success rate in the tasks and maintained their skills after the intervention. Similarly, Y.-J. Chang, Kang, & Liu (2014) developed a marker-based AR game for vocational skill-training for people with cognitive impairments in the context of recycling. The results show that the gaming system has potential for facilitating training in vocational jobs.

In conclusion, the studies found in the literature focused on particular special educational needs and the tools were developed for addressing those particular needs. However, none of the studies adopted a more generic approach such as the Universal Design for Learning (UDL) or other approaches to Universal Design (UD) in order to take advantage of AR features for creating inclusive learning experiences. In that regard, in their systematic literature review on AR in education, Akçayır & Akçayır (2017) conclude that further research on AR systems for people with special educational needs and people in contexts of diversity may help to expand the potential of AR in education.

2.5 AR FRAMEWORKS IN EDUCATION

A review of frameworks for AR and mobile AR in education was conducted. The purpose of this review was to have a better understanding of the open issue **OI3**. In total 35 frameworks of AR and mobile AR were identified in this review. After reading the papers of each framework, we identified that all the frameworks are very different one from another in terms of the learning domain, its purpose, its components or modules, etc.So it is difficult to compare the frameworks according to its characteristics or purposes.

However, we identified some aspects that all of the frameworks have in common such as: **Type of AR** used (marker-based AR, marker-less AR, location-based AR), **learning domain** (Science, Arts, Humanities, multiple learning domains, etc.), **pedagogical and didactical approach** (situated learning, experiential learning, collaborative learning, etc.) and **educational level**

addressed (primary education, secondary education, higher education, etc.). Besides that we analyzed if the framework addresses **special educational needs** and if the framework considers **motivational aspects**. A comparative table with all the frameworks and the categories used to compare them is shown in APPENDIX A.

Some of the frameworks rely on more than one **type of AR** (some frameworks were assigned to more than one category). Table 2-34 shows the results of the analysis. The most common type of AR considered in the frameworks was the marker-based AR (19 frameworks), followed by location-based AR (nine frameworks) and marker-less AR (eight frameworks) and finally five frameworks did not reported the type of AR.

Table 2-34. Type of AR considered in the frameworks analyzed.

Type of AR	Number of frameworks
Marker-based AR	19
Location-based AR	9
Marker-less AR	8
Not reported	5

In terms of the **learning domain**, **Table 2-35** shows the results of the analysis. The tendency has been to define frameworks that can be applied for multiple learning domains (12 out of 35 frameworks). This means that these frameworks are general and the AR applications that instantiate the framework can be designed for teaching in a wide variety of learning domains. Moreover, some of the frameworks have been defined for teaching in a particular learning domain. For instance, for teaching Science (five frameworks have been defined), History and visual communication and arts (three frameworks were identified for each of these learning domains). In the learning domains of Computer Science, Education in Construction and Language Learning two frameworks were identified for each one of these learning domains.

Finally, the rest of the frameworks reviewed cover the following learning domains: Business education, Cyber Physical Systems, Mathematics, Health care, Heritage Education and Everyday tasks / daily routines (one framework was identified for each one of these learning domains).

Table 2-35. Learning domain considered in the frameworks analyzed.

Learning Domain	Number of frameworks
Multiple domains	12
Science	5
History	3
Visual communication and visual arts	3
Computer Science	2
Education in Construction	2
Language Learning	2
Business education	1
Cyber Physical Systems	1
Mathematics	1
Health care	1
Heritage Education	1
Everyday tasks / daily routines	1

Regarding the **pedagogical and didactical approach**, Table 2-36 shows the results of the analysis. It was found that 16 out of 35 frameworks do not report to be based on a pedagogical or didactical approach. This is surprising because it seems that the pedagogical and didactical perspective is not being taking into account in the framework. However, it may be possible that the pedagogical and didactical perspectives were considered to be part of the class in which the framework was instantiated instead of being part of the AR tool. The rest of the frameworks adopted different pedagogical or didactical approaches as follows: Five frameworks were based on collaborative learning, three on experiential learning, three on situated learning, two on student-centred learning and the rest were based on learn by doing, learn with manipulatives place-based education, expository learning, smart environments and flow theory (one framework for each of these approaches). These results provide an overview of the pedagogical and didactical approaches that can be supported by AR.

Table 2-36. Pedagogical and didactical approach in the frameworks analyzed.

Pedagogical / Didactical Approach	Number of Frameworks
Not reported	16
Collaborative Learning	5
Experiential learning	3
Situated learning	3
Student-centred learning	2
Learn by doing	1
Learn with manipulatives	1
Place-based education	1
Expository learning	1
Smart environments	1
Flow Theory	1

With respect to the **educational level**, 12 out of 35 frameworks were designed for multiple educational levels. The results also reveal that there are many efforts to define frameworks of AR for higher education (8 out of 35 frameworks). For other educational levels the results are: For primary education (four frameworks were identified), Informal learning (three frameworks), College (two frameworks) and finally Secondary education, preschool education, vocational education (one framework identified for each category). Finally one framework did not report the educational level addressed.

Table 2-37. Educational level considered in the frameworks analyzed.

Educational Level	Number of Frameworks
Multiple	12
Higher education	8
Primary education	4
Informal learning	3
College and higher education	2
Secondary education	2
Preschool education	1
Vocational Education and training	1
Not reported	1

Surprisingly, only 3 out of 35 frameworks addressed **special educational needs**. For instance, in the framework by Wang, Vincenti, Braman, & Dudley (2013), the researchers state that the framework aims to provide better learning outcomes for students with different educational needs. The authors also argue that the learning materials in the framework should consider the different learning styles and students' needs. This framework adopted a wider perspective because it did not focus on a particular educational need and it aims to address the educational needs of all students.

On the other hand, the framework by Covaci, Kramer, Augusto, Rus, & Braun (2015) focused on the training on everyday tasks for people with cognitive disabilities. The framework was instantiated on a system with VR and AR and after an experiment with 13 participants with Down syndrome and they found insights on how people with Down syndrome understand the environment. However, this framework focused on a particular disability. Finally, the framework by Colpani & Homem (2015) integrates gamification to assist the learning process of identifying daily life objects in children with intellectual disabilities. The authors assert that the framework addresses the learning of children with intellectual disabilities because it provides a way in which children can interact directly with the objects.

Moreover, only 3 out 35 frameworks partially considered the special educational needs. In their framework, Zimmerman & Land (2014) recommend to provide contextualized expert guidance and strategies to focus the learners' attention to important aspects of an activity in AR. These recommendations are aligned with the UDL guidelines (Meyer et al., 2014) to help students to become expert learners considering the variability of students' needs and preferences. In addition, in their framework, R. Chen & Wang (2008) claims that by knowing students' learning style, the learning can be adjusted according to the preferred style. This means that, up to some extent, students' needs related to their learning style are considered within the framework.

In terms of **motivational aspects**, only 2 out of 35 frameworks considered motivational aspects. For instance, in their framework, Jamali, Shiratuddin, & Wong (2014) extended a virtual learning environments framework (Piccoli, Ahmad, & Ives, 2001) in the dimension of motivation by considering the following variables: context, learning groups, internal representation and process of learning. Other variables associated to the learning outcomes were considered such as: perceived learning effectiveness, self-efficacy and satisfaction. It is worth noting that satisfaction is one of the key dimensions of motivation in the ARCS (*Attention*, *Relevance*, *Confidence* and *Satisfaction*) model (Keller, 2010). Moreover, another framework that considered motivation as an important aspect of AR in the learning experience is the framework introduced by Bujak et al. (2013). In this framework, the researchers claim that motivation can be increased with AR because this technology changes the perceptions of reality and provide experiences that can be linked to manipulatives and personal objects (Bujak et al., 2013). Besides, the framework by Colpani & Homem (2015) partially considered motivational aspects through gamification.

Together these results provide an overview of the current state of AR frameworks in education. One of the conclusions of this review was that very few frameworks have considered the attention to students' special educational needs. This means that some of the frameworks may be still creating barriers in the learning process of some students when they are instantiated. As a result, it would be important to consider an approach to address students' educational needs when the frameworks are defined.

Another conclusion of this review is that very few frameworks have considered motivational aspects in their definition. In addition, despite the fact that one of the advantages of AR in education is that it increases motivation, surprisingly none of the frameworks define how to create AR-based learning experiences that increases motivation. Thus, we considered that this is an open issue that needs to be tackled to contribute to the research on AR in education.

2.6 AR IN VOCATIONAL EDUCATION AND TRAINING (VET)

In this section, we describe the current research on the use of AR in the VET level of education. This review provided a better understanding of the open issue **OI4**.

Recently, there has been an increasing interest in research on the use of AR at VET levels of education. As pointed out by Ricky & Rechell (2015) there is an increasing need of using mobile and flexible technologies to enhance learning experiences and technologies that serve as a complement of teaching and learning strategies in the evolving VET field. This need has boosted the research on AR in VET education. Ricky & Rechell (2015) also state that some advantages of using AR to facilitate learning in VET are: AR is a low cost technology. It is easy to change and customize a virtual environment instead of a physical environment for learning practices; and, AR allows repeated practice for a large number of students before doing the work in a real-world environment. Other advantages reported are as follows: AR applications can be used to deliver different learning contents and AR allows to practice skills in a safe environment (Ricky & Rechell, 2015). This view is supported by Emmanouilidis, Papathanassiou, Pistofidis, & Labib (2010) who state that AR provide problem-based maintenance training at low cost without going to the real-world environment.

However, one of the disadvantages of AR-based training systems is that the content cannot be modified easily in the AR application (Y. Kim & Moon, 2013; Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014).

In terms of learning performance in VET levels using AR, (Westerfield et al., 2015) claim that most of the AR systems have focused on improving the user performance rather than focusing on teaching how to perform the task. The researchers introduced an AR system that combines an ITS (Intelligent Tutoring System) with an AR interface and the results of an experiment showed that the system improved the learning performance by 25% and the task performance by 30% in the process of assembling a computer motherboard. Likewise, (Cubillo, Martin, Castro, & Boticki, 2015) developed an AR authoring tool for teachers to create AR learning experiences. The learning experiences created with the tool were tested with a group of VET students and the results show that students who studied with the AR experience had better results than the students who did not use it.

With the aim of exploring the effectiveness of Virtual Reality (VR) and Mixed Reality (MR) applications used for training operators in procedural skills and maintenance, Borsci, Lawson, & Broome (2015) conducted a survey and concluded that more studies are needed that systematically explore the effectiveness of VR/MR in the training of service operators. Borsci, Lawson and Broome also argue that in the field of training car service operators two challenges will be faced by researchers: the first challenge is to explore the training of sequential operations to reach a service procedure, and the second challenge is the design and assessment of tools for training car service maintenance (Borsci et al., 2015).

In contrast, Anastassova & Burkhardt, (2009) argue that AR is an emerging technology that is in a state of searching potential applications. This state is the cause of a technology-driven research that put aside user's requirements and its effectiveness. Consequently, some empirical results do not clearly report the benefits of AR for training. Besides that, the authors conducted 2 field studies and identified a set of requirements for future AR teaching aids. In short, the requirements are: AR applications for automotive service technicians (AST) training should be easy to use, facilitate the construction of shared representations, cost-effective, compatible with other technologies used in training and should collect and save the field experiences in the form of narratives (Anastassova & Burkhardt, 2009).

Cuendet *et al.* (2013) developed three AR learning environments that rely on the TinkerLamp hardware that was also designed by them. Two of the developed learning environments cover VET domains, one is for teaching logistics and the other one is for training carpenters in the topic of 3D visualization. The authors suggest 5 design principles to make an AR system work well in the classroom: integration, empowerment, awareness, flexibility and minimalism (Cuendet et al., 2013). On the other hand, Delic, Domancic, Vujevic, Drljevic, & Boticki (2014) developed a location-based AR application called AuGeo for geodesy vocational education. The application displays geographical information about surrounding land parcels based on the student's position. In terms of the AR application design, the authors point out that a "co-design iterative approach is preferred", which means that cooperation between teachers and developers is needed in order to specify the amount and sort of information that should be presented.

There are some European projects that have been studying AR in VET institutions. For instance, in the Learning Augmented Reality Global Environment (LARGE) project (LARGE Project, 2014) a platform was developed to create educational AR applications. Findings of the project identified that teachers and students think AR to be beneficial in terms of student motivation. Moreover, in the ARAVET (Augmented Reality in the field of Vocational Education and Training) Project, three AR applications were developed in the field of informatics, electronics and textile (ARAVET Project, 2015).

However, these studies have not considered the issue of addressing the student's special educational needs from an inclusive learning perspective in VET domains. As a result, it would be important that future AR learning experiences can be created to address students' educational needs in VET education. This will remove some barriers in the learning process so that all students can benefit from the AR learning experience.

2.7 THEORETICAL BACKGROUND

In this thesis, we focused on the topic of student motivation in AR learning experiences in VET. So, in this section we describe the theoretical underpinnings that we adopted in this thesis as the theoretical background that frame this thesis. The theoretical underpinnings are: Motivational Design, Motivation and the ARCS model of motivation, Universal Design for Learning and Co-creation and Co-design. These theoretical underpinnings are used as a supportive background in the subsequent chapters of this thesis.

2.7.1 Motivational Design

Motivational design is defined as the systemic process of "arranging resources and procedures to bring about changes in people's motivation" (Keller, 2010, p.22). These resources are, in the context of the ARMotiD framework, the modules of AR learning experiences (Mobile or Desktop) that positively impact students' motivation. According to Keller (2010) the motivational design theory is based on the scientific literature on human motivation and its dimensions. Keller (2010) also argues that the motivational design is not an isolated process, it is affected by other factors from the learning environment and the instruction that adds different dimensions to it. Based on this property of the motivational design process, in this thesis we will consider the motivational design in conjunction with the UDL and the Co-Creation process as the theoretical foundations of the ARMotiD framework.

One of the advantages of motivational design, according to Keller (2010) is that it "strives to make instruction more intrinsically interesting". However, it is worth noting that there should also be a connection between the motivational features of instruction and the instructional goals so that both can promote learning.

The motivational design theory supports the ARCS model. The ARCS model was introduced by Keller (1987) and its dimensions are: *Attention*, *Relevance*, *Confidence* and *Satisfaction*. These dimensions provide an overview of the human motivation in relation to learning. These dimensions are based on an extensive research on human motivation.

2.7.2 Motivation and the ARCS model of 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, one that explains this concept in relation to learning processes is the ARCS (*Attention*, *Relevance*, *Confidence* and *Satisfaction*) model introduced by Keller (2010). The ARCS model is based on extensive research into motivational design and is based on the general theory of motivation in relation to learning. The four dimensions of the model provide an overview of the major categories of learning motivation.

In the ARCS model of motivation, attention dimension refers to the interest of learners and their curiosity in the learning process, while *relevance* dimension refers to the learning process meeting the student's learning needs and is related to the student's perception on how the learning process is aligned with their own interests and goals. The *confidence* dimension relates to the opportunities that learners have to succeed in the learning activities. Students may have fears with respect to a topic or may think that they already know everything about a specific topic, so controlling *confidence* levels is important to ensure students remain motivated. Finally, *satisfaction* dimension is related to the feeling of success being reinforced and a sense of satisfaction with the results obtained in the learning process. The ARCS model has been used in previous studies that explore student motivation in AR learning experiences such as conducted by Chiang, Yang, & Hwang (2014), Chin, Lee, & Chen (2015), Chen, Chou, & Huang (2016).

To evaluate student motivation in the four dimensions of the ARCS model, Keller (2010) defined the Instructional Materials Motivation Survey (IMMS). This is a validated instrument with an internal consistency reliability (Cronbach α) of 0,96. The instrument uses a likert scale for each question and consists of 36 questions in total. The values for each answer range from 1 to 5. A value of 1 express total disagreement and a value of 5 express complete agreement. However, there are some questions that are reverse, so for the purposes of the scoring some questions have the value of 5 for total disagreement and the value of 1 for total agreement.

There are other intruments that evaluate motivation such as the Intrinsic Motivation Inventory (IMI) (selfdeterminationtheory.org, 2014) which is based on another approach to human motivation and personality: the Self-determination theory. On the other hand, the Motivated Strategies for Learning Questionnaire (MSLQ) is based on the general cognitive view of motivation. The questionnaire has two sections: a section dedicated to motivation and a section dedicaded to learning strategies (Pintrich, Smith, Garcia, & McKeachie, 1991). After analyzing these questionnaires and taking into account that the ARCS model of motivation is based on an extensive previous research on learning motivation we considered that the ARCS model is more appropriate for the purposes of this research. Furthermore, the ARCS model and the IMMS have been used in previous research on AR learning experiences as mentioned earlier.

Thus, we also draw on the ARCS model to represent student motivation in AR learning experiences, in an aim to explore exactly which unique features of AR learning experiences positively affect student motivation. Moreover, we adopted the IMMS instrument to evaluate student motivation in the four dimensions of the ARCS model.

From a pedagogical perspective, and connected with learning motivation, one of the three main principles of Universal Design for Learning (UDL) framework is to provide multiple means of engagement. UDL is a validated educational framework for addressing student variability and avoiding barriers in the learning process of any student including those with special educational needs (Meyer et al., 2014). It emphasizes the importance of providing a variety of mechanisms to sustain student motivation and engagement for all students to ensure an effective learning process and to address the diverse needs and preferences of students.

2.7.3 Universal Design for Learning

The UDL is a validated framework that is based on neuroscience research for addressing students' variability. The UDL aims to avoid barriers in the learning process so that students become expert learners and they can reach expert learning. Expert learners are students who identify, organize, use and relate previous knowledge to new experiences and information. Besides that, the expert learners create a plan for learning, organize resources and monitor their progress and are motivated to sustain their effort in the learning activities (Meyer et al., 2014).

According to a systematic review of literature conducted by Rao, Ok, & Bryant (2014), UDL has gained attention due to the fact that it provides access to the curriculum for students with disabilities and students in general. Besides that, most of the studies reviewed in the literature have considered the UDL rather than the other two approaches to Universal Design (UD) (Follette, Mueller, & Mace, 1998): Universal Instructional Design (UID) and Universal Design of Instruction (UDI) (Rao et al., 2014).

From an exhaustive analysis of the UDL guidelines with respect to the AR technology (presented in the APPENDIX B), it was concluded that AR technology can be used to support a wide variety of UDL guidelines. This support includes the guidelines that are directly connected to students' motivation and engagement due to the advantages reported in the literature with respect to the affordances of AR to support students' motivation (Di Serio, Ibáñez, & Kloos, 2013; Radu, 2014; Chiang, Yang, & Hwang, 2014; Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014).

Moreover, we concluded that AR learning experiences can be supported by the UDL to create augmented learning experiences for all. The aim of drawing on the UDL is to inform the design of AR learning experiences that differ from the traditional notion of the one-size-fits-all curricula (Meyer et al., 2014). The one-size-fits-all curricula are inflexible learning activities in which there are barriers that are imposed by some instructional materials or activities that are designed for the average student.

The guidelines provided in the UDL seek to foster the concept of "expert learning" so that students become "expert learners". To do so, the UDL define the following three principles:

- **Provide multiple means of representation:** The group of guidelines under this principle orients the design of learning experiences in which the knowledge is conveyed through different formats of presentation. This is important because not all learners perceive the information in the same way. For example some learners may prefer graphics instead of text or videos instead of audio recordings and so on. In particular, since AR is not only restricted to the sense of sight but it can be applied to other senses such as smell, hearing or touch (Azuma et al., 2001), AR can be used for providing multiple means of presentation.
- **Provide multiple means of action and expression:** Students also differ in the way in which they express what they learnt. The group of guidelines under this principle addresses the design of learning experiences in which students can be able to express their knowledge in different ways. From the perspective of AR technology, AR can support this guideline because there are different interaction mechanisms with the augmented information, such as tangible interaction, haptic interaction and touch interaction.
- **Provide multiple means of engagement:** The group of guidelines under this principle addresses issues that are related to the self-regulation of learning, motivation and engagement. In summary, students differ also in their motivations, goals and the way they engage in different learning activities. In terms of AR, there is a growing body of literature that conclude that one of the most important advantages of AR in education is that it increases motivation (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014; Radu, 2014). As a result AR technology can be an effective tool for addressing the guidelines related to motivation and engagement from the UDL.

In the UDL guidelines, for each principle there are a number of checkpoints that support the principle. Each checkpoint contains more specific guidelines and tasks or activities that support the UDL principle associated. The complete list of checkpoints is published in the work of Meyer et al. (2014).

2.7.4 Co-creation and Co-design

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). The term co-creation is also closely related to the term co-design. Co-design is defined as "the collective creativity as it is applied across the whole span of a design process" (Sanders & Stappers, 2008, p. 2). Sometimes, the terms co-creation and co-design are used to refer to the same process and sometimes they are treated as synonyms. However, co-creation is a broader term that has applications to physical aspects as well as to metaphysical aspects. This means that a co-creation process can be applied to collectively create a physical object or a metaphysical aspect. Thus, the term co-design is a specific instance of a co-creation process (Sanders & Stappers, 2008). Co-design is also defined as "a highly facilitated, team-based process in which teachers, researchers and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need" (Roschelle & Penuel, 2006, p. 606).

A co-design approach has many features in common with other "traditions of design" such as the participatory design, the learner-centred design and the user-centred design (Roschelle & Penuel, 2006). This means that a co-design approach integrates features of important approaches in the design of educational innovations that are relevant in the design process. According to Roschelle & Penuel (2006) a co-design process might help to integrate curriculum and technology because the co-design process involves teachers in the process of designing tools and materials that can be effectively used in the classroom according to the teacher´s needs.

Roschelle & Penuel (2006) defined seven characteristics of co-design that are presented as follows:

1. Co-design takes on a concrete, tangible innovation challenge: The co-design process aims to create a tangible innovation.
2. The process begins by taking a stock of current practice and classroom contexts: The co-design process should begin with an exploration of the field in which the potential innovation will be applied. This process involves the identifications of students' characteristics and other key elements from the context.
3. Co-design has a flexible target: Flexibility is important because the information collected and the opinions of teachers may change researchers' conceptions of the innovation. Thus, the iterative process of creating prototypes is important to gather information about the users.
4. Co-design needs a bootstrapping event or process to catalyze the team's work: This refers to the fact that some strategies are needed to have a shared understanding of the needs and requirements of the innovation.
5. Co-design is timed to fit the school cycle: This refers to the fact that the process needs to be adjusted to teachers' schedules and to the school calendar.
6. Strong facilitation with well-defined roles is a hallmark of co-design: The role of each member needs to be very well-defined and each member should help to maintain the team focused on all the activities of the process.

There is a central accountability for the quality of the products of co-design: In a co-design process there is a central accountability structure for quality. This accountability corresponds to the main researcher of the team.

Some studies in the literature have explored the use of co-creation or co-design processes in the design and development of AR applications. For instance, Delic, Domancic, Vujevic, Drljevic, & Boticki (2014) developed an application for learning in the vocational education programme of geodesy. The authors concluded that the best approach to create the application was an iterative co-design process with teachers in which software developers and teachers worked together to create the application and test it within the iterative process. Similarly, Chen, Fan, & Wu (2016) created an AR application for learning horticultural science in a vocational school and remarked that and important aspect in the development of the application was the co-design process because the work between teachers and developers ensured that the design will meet the learning goals. This view was also supported by Tolentino et al. (2009) who developed a mixed reality environment Situated Multimedia Arts Learning Lab (SMALLab) for learning chemistry, in particular for learning the topic of chemical equilibrium and titration. The authors concluded that a mixed-reality environment is viable in high school for improving learning outcomes and spatial reasoning abilities if it is co-designed with teachers.

In terms of Augmented Reality Game-based Learning (ARGBL), in their studies, Tobar-muñoz, Baldiris, & Fabregat (2016); Tobar-Muñoz, Baldiris, & Fabregat (2016) created a co-design method called Co-CreARGBL for creating ARGBL games for learning. In the method, the following roles are identified: leaders, designers, teachers, developers, researchers and students. Moreover, three stages were defined with its corresponding detailed activities: training, iterative design and classroom evaluation. From a case study, the researchers concluded that the co-creation process with the method was useful and teachers felt satisfied with the tools that were ready to be used in the classroom.

Likewise, in their study, Radu, McCarthy, & Kao (2016), identified together with teachers a group of curriculum topics in mathematics that are often problematic in early childhood education in the USA and developed some prototypes of AR applications in these problematic topics. The authors claim that further research is needed to understand how the collaboration of teachers and developers can help to create new technological tools to support the learning process.

2.8 GENERAL CONCLUSIONS

In this chapter we presented the results of a systematic literature review (reported in section 2.2) in which we identified four open issues (**OI1, OI2, OI3** and **OI4**) that deserved more attention. To have a better understanding of these open issues a more detailed review of literature was conducted on these issues. In general, from this chapter the following conclusions were obtained:

- As for **OI1**, we concluded that two of the most reported advantages of AR in education are that AR increases motivation and increases learning outcomes. However, from the content analysis during the systematic literature review we identified that it is still not clear how and why AR increases student motivation. This means that current research on AR in education does not clearly report which are the components or modules) that increase student motivation in AR learning experiences. For this reason, in this thesis we focused on the topic of student motivation in AR learning experiences in VET with the aim of identifying which are the predictors of student motivation and how these predictors (instantiated in components and modules) should be designed in an effort to inform the design of motivational AR learning experiences. Moreover, most of the current research on predictors and acceptance of student motivation in AR are based on the TAM and TAM2 models but they do not provide guidance for practitioners.
- As for **OI2**, we conclude that there are some AR applications that have been developed to address some particular students' educational needs. This means that the applications have been designed to address a specific students' educational need and therefore the application will not address the needs of other students. This is almost equivalent to the provision of curricular adaptations to address the needs of some specific students. In that regard, the design of AR learning experiences requires the adoption of a more generic inclusive approach such as the Universal Design for Learning (UDL) or other approaches to Universal Design (UD). These approaches may provide the flexibility needed to address students' educational needs and therefore create inclusive AR learning experiences.
- As for **OI3** we concluded that there is a wide variety of AR frameworks in education designed for different learning domains, including generic frameworks that can be instantiated in any learning domain. After analyzing 35 AR frameworks in education, we

identified that only two out of the 35 frameworks have considered motivational factors. This means that few of the existing frameworks provide guidelines for designers and developers on how to create motivational AR learning experiences.

- As for **OI4** we identified that despite the fact that the concept of AR was coined in contexts of maintenance tasks and AR has been extensively applied in this context, very little has been done in terms of applying AR as a support for the learning process in VET. Thus, the possibilities that this technology may offer for the learning process at the VET level of education still remain unexplored.

These conclusions with respect to the OI identified opened up the possibilities for further research in this thesis in the field of AR in the VET level of education. Therefore, we decided to focus on these open issues and this lead us to the next phase of the thesis in which we conducted two exploratory studies in the VET level of education that aimed to explore the impact on student motivation of a mobile AR application. These two exploratory studies are: the first exploratory study (described in CHAPTER 3) and the second exploratory study (described in CHAPTER 4).

The systematic literature review presented in section 2.2 addressed the first activity of the Exploratory Phase (**AEP1**) in the research methodology followed in this thesis. Moreover, sections 2.3, 2.4, 2.5 and 2.6 addressed the second activity in the Exploratory Phase (**AEP2**) of the research methodology followed in this thesis. Together these activities allowed to address the first specific objective in this thesis: "**SO1:** To conduct a systematic literature review to identify the current state of AR in education".

2.9 PUBLICATIONS ASSOCIATED TO THIS CHAPTER

Part of the literature review described in section 2.2 was published in the following journal paper:

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

PART 2
EXPLORATORY STUDIES

CHAPTER 3
FIRST EXPLORATORY STUDY

3.1 INTRODUCTION

Based on the issues and opportunities identified in the literature review (reported in CHAPTER 2), in this exploratory study we focused on the VET level of education. By focusing on this level we may contribute to the knowledge on the impact of AR on educational processes in VET programmes. In particular, we focused on the VET programme of Car's Maintenance - often known in the literature as Automotive Service or Automotive Service Technicians (AST) training - because this is one of the fields in which VET teachers have identified more difficulties in terms of learning performance and students' motivation and this is a programme with a wide diversity of students (Bacca, Baldiris, Fabregat, Kinshuk, & Graf, 2015). Furthermore, taking into account the opportunities identified in the literature review with respect to the need of identifiying why and how AR positively affect student motivation, in this exploratory study we focused on student motivation in mobile AR learning experiences.

Thus, this first exploratory study sought to identify the impact of a mobile AR application that we designed and developed under a co-creation process with teachers and that we call the Paint-cAR application on students' motivation in the VET programme of Car's Maintenance.

This first exploratory study corresponds to the third activity of the Exploratory Phase (**AEP3**) in the research methodology followed in this thesis. As such, this first exploratory study addressed the second specific objective of this thesis: "**SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education". Moreover, this first exploratory study provided insights for answering the first research question of this thesis: "**RQ1 -** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?"

This chapter is organized as follows: Section 3.2 presents the design of the Paint-cAR application for this exploratory study as well as the methodology defined for the co-creation process. Then, section 3.3 introduces the research design for this exploratory study and in section 3.4 the results obtained are described. In section 3.5 a discussion of the results obtained are presented and in section 3.6 the conclusions of this exploratory study are also presented. Finally, section 3.7 presents the publication associated to this study.

3.2 DESIGN OF THE PAINT-CAR APPLICATION

In order to explore the impact of AR on students' motivation in the VET programme of Car's Maintenance, we started a collaborative process with two experienced teachers in VET education of this programme. One of the teachers is Joan Clopés i Gasull who has more than 30 years of experience teaching in VET education and the other teacher is Narcis Vidal who has more than 10 years of experience in the industry and teaching in VET education. This collaborative work with the teachers followed a co-creation methodology that we defined. The purpose of this methodology was to co-create a mobile AR application to address a specific educational need in the VET programme of Car's Maintenance and to explore the impact of the application on students' motivation. The methodology combines a user centred and collaborative design process and drew on the research on the Universal Design for Learning (UDL) as an inclusive educational approach. In this sub-section the methodology that we followed is explained together with the results obtained at each phase.

3.2.1 Phase 1: Identify the educational need

In this phase, an educational need is identified and documented by the teacher. The educational need is analyzed and multiple educational proposals could be evaluated in order to provide a solution for the educational need. It is important to remark that some educational needs could be solved by using other technologies different from AR. In this phase, software developers and teachers should evaluate if AR is the best option in order to provide a solution for the educational need. Student's characteristics are also identified in terms of their strengths, qualities, weaknesses, preferences and interests.

After some meetings with the teachers in which they understood the possibilities of using AR as well as its advantages and limitations, we decided to focus on the topic of repairing paint on a car. This is one of the topics that students learn at the intermediate cycle of the VET programme of Car's Maintenance. Repairing paint on a car is a complex process that involves a sequence of 30 steps and the use of many chemical products and tools. Teachers claimed that this topic is very important in the learning process of this VET programme and students often face many difficulties due to the high complexity of this topic. At this point, we had a first approach to the topic.

3.2.2 Phase 2: Understanding the learning domain

A first meeting between teachers, software developers and educational technology experts is needed in order to identify the main characteristics of the educational need and to identify student's characteristics. It is also important to understand what the learning domain is, what its characteristics are and how it is traditionally learned.

In this phase, teachers recorded videos so that we could understand how the learning domain is and how students learn in this topic. After analysing these videos, we understood many details of this process (such as the tools used and the contexts in which students learn) and we thought about the possibilities of using AR to support the learning process. Teachers made a great effort to show us how students learn this topic and teachers also expressed their perceptions about the difficulties that students have in this topic:

a) Student's lack of motivation: This is one of the most common issues that teachers have to face in everyday classes. Student's lack of motivation means that students are disengaged and their attention is not focused on the learning task. According to Keller, (2010) *attention* is a key factor for both learning and motivation and is a concept that is closely related to sensation seeking, curiosity and boredom. Students' lack of motivationmay have many causes but some of the most common causes in this level are:
    - Some students have dropped out of other educational levels and they are enrolled in the VET level because is the last option for them.
    - Some students face some learning difficulties, so some of them feel disengaged because they do not understand some of the learning contents.
    - Some of the students prefer learning by doing to learn with theoretical clases. So, they felt disengaged in theoretical classes that are also very important at this level.
    - Some students seem to be obligued to study in the VET level to learn some skills that are more practical to go to the labour market.

- Some of the students do not identify a motivating factor in the learning process by themselves.

b) Student's lack of background: Some of the students do not have the basic background and basic skills in some topics or they do not remember things they learnt at primary or secondary education.
c) Students have some attention difficulties: Sometimes students are not completely concentrated on the task or instructions given by teachers. Some of the students have learning difficulties.Students need to follow a process and achieve good results otherwise they will feel frustrated.
d) The process of repairing paint on car is complex and has many details for each step: Sometimes students do not remember the correct order of steps in the process or the tools they need to use, how to use them and why to use them.
e) Sometimes students skip some steps in the process. Since they do not remember the process.
f) There is a need of a strategy to identify the steps of the process in which students experience most difficulties so that teachers can make decisions in order to address these difficulties.

By analyzing the learning domain we made a decision regarding the type of AR application that may be most suitable to address the educational need. At this point, we decided that a mobile AR application was the most suitable approach to address the educational needs because:

1. Students are used to learn in the workshop by interacting with the products and tools, so the learning domain by itself requires that students interact with the real products and tools for an effective learning process. This approach is connected with the situated learning theory (Brown, Collins, & Duguid, 1989) that refers to the fact that the learning should occur in contexts in which the knowledge will be used and by doing authentic activities. Thus, desktop-based AR was not suitable because students need to move around the workshop and interact with the real tools and products. In that regard, the portability of mobile devices may help to facilitate that students move around the workshop.
2. Most of the students own a mobile device which facilitates the use of the application because students can use the application anywhere and anytime. Another important requirement would be to have a Wi-Fi network connection just in case the application needs to send and receive information from and to a server. Apart from that, the application does not require additional infrastructure in the VET institute so it can be a cost-effective solution.

The mobile AR application was called the "Paint-cAR application" and was defined as an application to support the learning process in the topic of repairing paint on a car in the VET programme of Car's Maintenance.

The use of the Paint-cAR application was considered in the curriculum as a tool for practicing the process of repairing paint on a car before going to a completely real scenario. The application was considered to be a complement for the learning process and it was never considered to be a tool that replaces the real practices in the VET institute. The application was considered to be a tool that offers an introduction to the basic concepts but having contact with the real products or tools in the workshop (which is the context in which the learning process usually takes place). By using the application students are expected to learn the basic skills and concepts they need to know before going to a real scenario. The Paint-cAR application will be part of the curriculum as an activity for rehearsing the repairing process in class and also as a support for practicing at home the concepts that students learnt in class.

Regarding the design of learning activities to be supported by using the Paint-cAR application, teachers recommended that the learning activities should not be general but they should be focused on specific topics or specific exercises.We agreed to focus the learning activity on the process of repairing paint on a particular part of a car: the hood of a car. Teachers pointed out that this will be an exercise that will help students to learn the basic concepts about repairing paint on a car.

The result of this phase of the methodology was that we made a decision with respect to the type of AR application that we created. Moreover, we identified how students learn this topic and we identified the main difficulties that teachers face when teaching this topic.

3.2.3 Phase 3: Designing the AR application

In this phase developers and educational technology experts propose a design taking into account the learning domain and student's characteristics, in particular to address special educational needs. The design meets the Universal Design for Learning (UDL) principles to ensure the achievement of an inclusive learning experience. According to Meyer et al. (2014) three principles are recommended in order to support expert learning taking into account the variability of all learners:

a. Provide multiple means of engagement.
b. Provide multiple means of representation.
c. Provide multiple means of action and expression.

It is important to note that these principles are divided into guidelines and the guidelines are divided into checkpoints. For this reason, the number of recommendations provided by the UDL is high. Nevertheless, developers and educational technology experts do not have to apply all the principles in the design of the application. The recommendations can be choosen depending on the teaching and learning context in which the UDL is being applied (Meyer et al., 2014).

In this thesis, we analyzed how AR can support the implementation of the UDL guidelines and checkpoints. The analysis is fully detailed in APPENDIX B and from this analysis we concluded that AR can be used to support a wide variety of UDL guidelines and checkpoints in the three UDL principles.

In terms of the design of the AR application, software for creating wireframes and mock-ups could be used in order to show how the interface would work and how the interaction mechanisms would work. This could be very useful in order to have a more realistic idea of the application. Some meetings may be needed with teachers in order to reach a consensus. After each meeting an improved version of the design is desirable. If possible, students can participate in this phase by providing opinions about the user interface and interaction mechanisms that are being proposed. It would be desirable to have the opinion of students with special educational needs in order to improve the design.

At this point of the methodology, teachers suggest how the application should work and how they expect that students use the application in the learning process. Then, together with the software developers and educational technology experts the design is defined taking into account that the design should address the educational need and should follow an inclusive approach. To reach a good design that satisfy the requirements of teachers and that can be technologically feasible, some meetings may be needed.

For the design of the Paint-cAR application, after some meetings with teachers and in agreement with them we decided that the Paint-cAR application should help students to identify which products or tools they need to use for each one of the 30 steps in the process of repairing paint on a car. Besides, it was decided to help students to remember the order in which the 30 steps of repairing paint on a car need to be performed.

The following design decisions were made:

a) The tools and chemical products that students need to use in the process of repairing paint on a car need to have an AR marker that will be recognized by the Paint-cAR application. However, due to the use of the products and tools the markers can be damaged. In this case, the marker should be stuck to the rack or container where the product or tool is stored. Students' will use the Paint-cAR application to scan the markers and the application will validate if the product or tool is adequate for each one of the 30 steps in the process of repairing.

b) For each product and tool the Paint-cAR application should show augmented information about the characteristics of the product and if applicable, the information about the security measures to be taken when the product is manipulated.
c) For each product or tool, the Paint-cAR application need to show an image or 3D model of the tool or product so that students make sure that the product they are scanning is the product that they need to use for that step in the process.
d) The Paint-cAR application should guide students step by step through the process of repairing paint on a car.
e) The Paint-cAR application should have a scaffolding mechanism to assist students to find the appropriate product or tool they need to use for each step in the process. The Scaffolding is a strategy that is used to assists students by introducing scaffolds (hints and clues) to help students to complete a learning activity. The purpose of the scaffolding mechanism is to assist students that may experience some difficulties in the learning process until they reach mastery. For the Paint-cAR application the scaffolding mechanism should provide assistance to students with respect to the products and tools they need to use for each step in the process of repairing paint on a car.
f) The Paint-cAR application should pose a challenge to students. The purpose of the challenge is to engage students in the use of the application and also to introduce a problem to be solved with the use of the application. Teachers recommended to pose the problem of repairing the paint on the hood of a car.
g) The Paint-cAR application should provide real-time feedback to students depending on their interaction with the application (choosing incorrect tools or products, skipping steps of the process, etc.).
h) The Paint-cAR need to be responsive so that it can be used in mobile devices with any resolution and screen size.
i) The development of the Paint-cAR application needs to take into account the recommendations of the UDL to address students' diversity.
j) For this first exploratory scenario, the first 10 steps out of the 30 steps in the process of repairing were designed. The purpose was to guide students through the first 10 steps in the process of repairing paint in the hood of a car. Students can follow the process and search for the products or tools they need to use for each step in the process by moving around the workshop. The Paint-cAR application recognizes the markers associated to each product or tool and displays augmented information about characteristics of the product or security measures to be taken when that product or tool is manipulated. The application validates if students select the correct tool for each step in the process.
k) The first 10 steps of the process were not classified in any particular way. Teachers decided that the steps in the process need to be shown one after the other. The only indication that students had was the number of each step (that ranged from 1 to 10). For each step in the process the following information is shown:
    I. The products or tools that students need to use for that step.
    II. Some information on how to perform that step in the process using the products or tools.

In this phase of the methodology students did not participated in the design process because the feedback from students was gathered at the end of this study when the first prototype was tested.

Figure 3-1 shows the expected use of the Paint –cAR application. In the figure, the tools and chemical products that students use in the workshop have a marker stuck to them (1), students (5) use a mobile device (4) to scan (2) the markers and they see the augmented information in the screen of the mobile device (3).

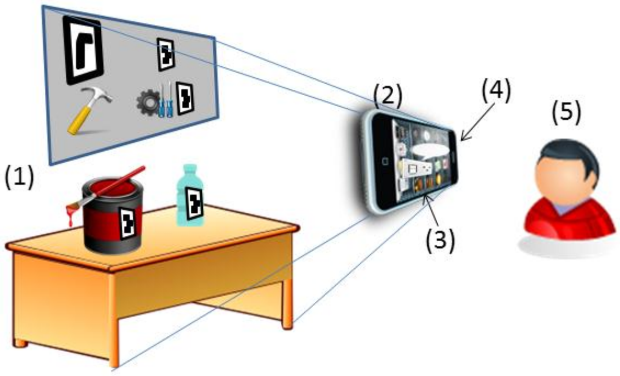

Figure 3-1. Expected use of the Paint-cAR application.

3.2.4 Phase 4: Develop a prototype of the AR application

The original name of this phase was "First prototype of the AR application" and that was the name that we used in the original methodology that we published as explained in section 3.7. However, according to our experience in the development of this study and the second exploratory study, it is better to change the name of this phase to "Develop a prototype of the AR application". Since this methodology is iterative, the name is more appropriate because this phase may correspond to any iteration (not always the first) and therefore this phase may correspond to any prototype of the application (first, second, third, etc.).

After reaching a consensus in the design, a first prototype of the Paint-cAR application is implemented. Teachers provide the contents that should be included in the application such as texts or graphics. Sometimes graphical designers are needed in order to create 3D models of objects that will be augmented or to address user interface issues. Developers should evaluate available technologies in order to choose the best options. After the first prototype is ready, a meeting with the teachers is needed so that they can evaluate the prototype. Educational technology experts should evaluate the prototype on how it addresses special educational needs from the UDL perspective. In particular, for the purposes of this exploratory study we focused on the topic of motivation. Thus, the aim of this evaluation is to identify if the Paint-cAR application positively impact students motivation. If something is missing a redesign process is needed in order to improve the application.

In this phase, we analyzed the technological possibilities for implementing the Paint-cAR application. Thus, we tested the following AR libraries and software for creating AR experiences:

a) NyARToolkit (NyARToolkit Project, 2014) with Unity 3D (Unity Tecnologies, 2016).
b) OpenSpace3D (OpenSpace3D - I-maginer, 2014)
c) AndAR (WISTA MFG programme, 2014)
d) Vuforia (PTC, 2014) and Unity 3D (Unity Tecnologies, 2016)

After testing the tools, we decided to use the Vuforia and Unity 3D tools for creating the mobile AR experience because those tools offer better support, there are more documentation and they are more mature that the others. Moreover, other projects have successfully used these tools for developing AR learning experiences such as: (Weiquan Lu, Linh-Chi Nguyen, Teong Leong Chuah, & Ellen Yi-Luen Do, 2014; Syberfeldt, Danielsson, Holm, & Wang, 2016; Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos, 2015; Colpani & Homem, 2015; Kyungwon Gil, Jimin Rhim, Ha, Young Yim Doh, & Woo, 2014; Tobar-Muñoz, Baldiris, & Fabregat, 2014; Diaz, 2015). These conditions will facilitate the development of the Paint-cAR application.

The development process started taking into account the design defined in phase 3. Figure 3-2 shows the screenshot of the splash screen of the first prototype of the Paint-cAR.

Figure 3-2. Screenshot of the splash screen.

Figure 3-3 shows the screenshot of the interface that explains the challenge to students. As mentioned earlier in the design decisions made, the challenge is to repair the paint on the hood of a car. This user interface is showed to students immediately after the splash screen.

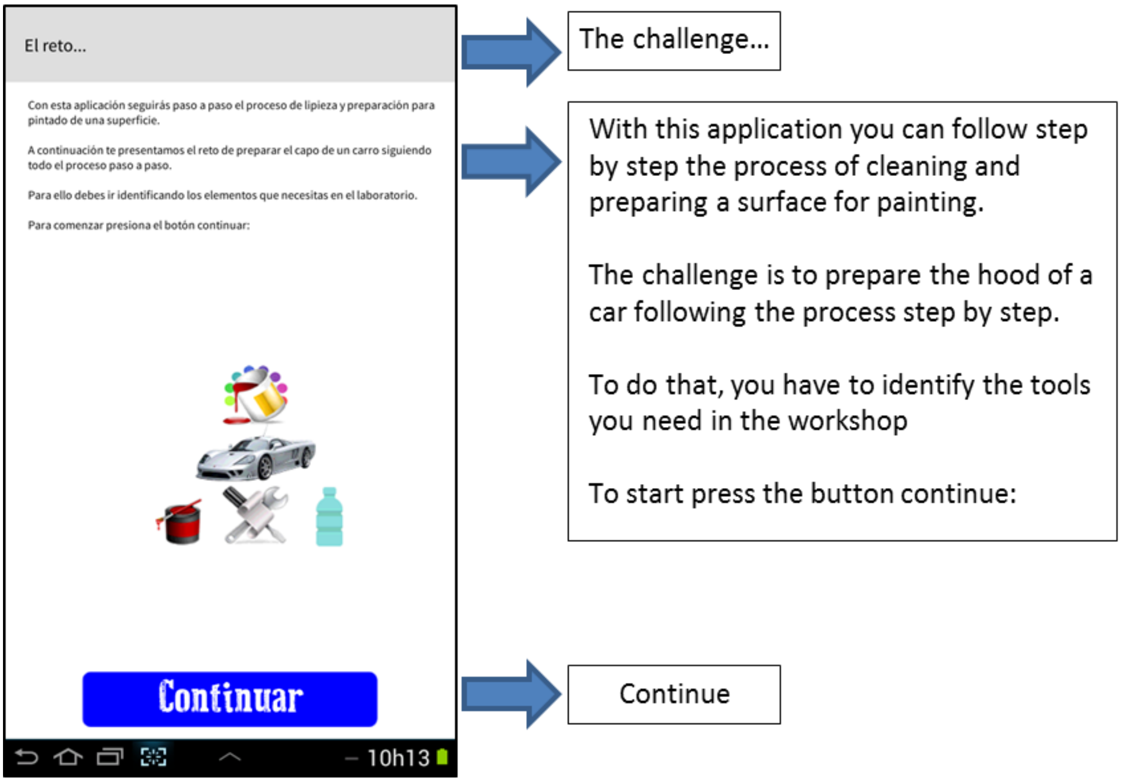

Figure 3-3. Screenshot of the interface that explains the challenge to students.

Figure 3-4 shows a screenshot of the user interface that explains the first step in the process (To clean the surface with water and soap). The user interfaces for the first 10 steps in the process were similar to the one showed in this image. In this interface, students can see the number of the step in which they are working and the products and tools they need to use for that specific step as well as some information on how students should perform that step. When students press the button "Continue" (at the bottom of the interface) the AR experience starts.

Figure 3-4. Screenshot of the interface that describes the first step in the process.

Figure 3-5 shows a screenshot of the augmented information that is shown when students scan a marker associated to a chemical product or tool.

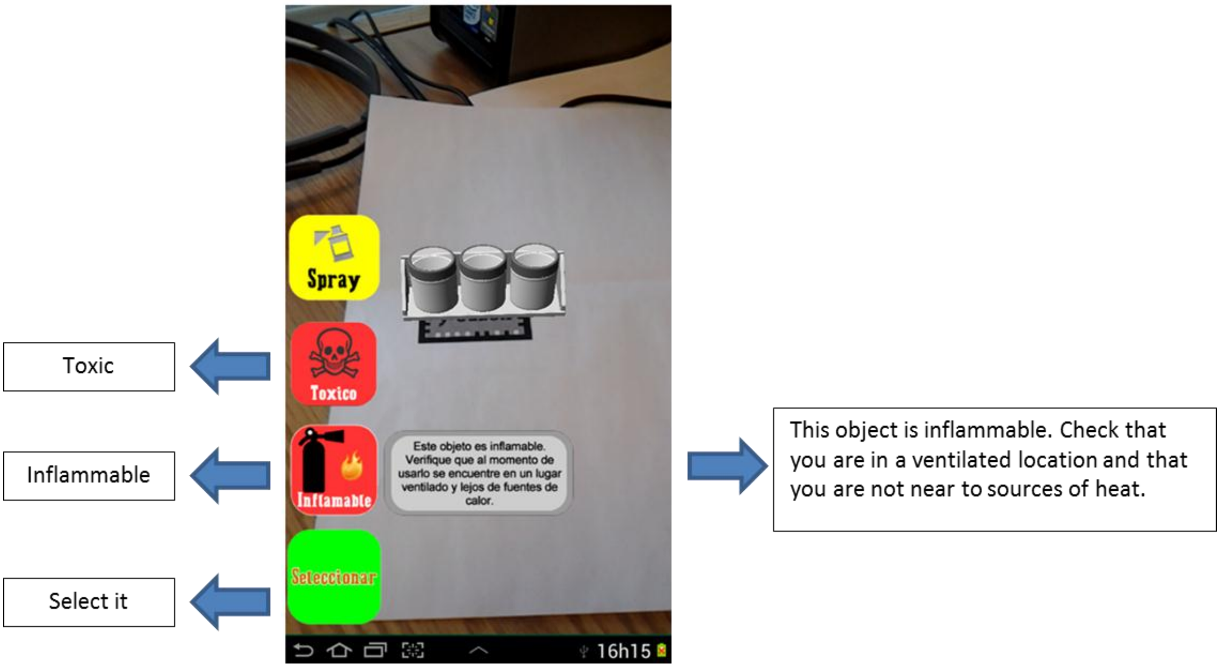

Figure 3-5. Screenshot of the augmented information showed from the marker of a chemical product.

For the purposes of this pilot study the first 10 steps of the process of repairing paint on a car were completely developed. The development lasted for 3 months (August 2014 to November 2014).

3.2.5 Phase 5: Testing with students

The original name of this phase in the original methodology that we published (as described in section 3.7) was “First testing with students”. However, due to the iterative nature of this methodology a better name for this phase would be “Testing with students” because it is not always the first testing, it can be the second or third depending on the iteration.

After the first prototype is approved by teachers and educational technology experts, a first testing could be carried out with students in a real scenario. It is important to gather as much information as possible in terms of user interaction, engagement (a test for measuring motivation would be useful), attention to the educational need and how the application address student’s special educational needs. The real scenario should be prepared for the testing: markers, light conditions, time for the testing, etc.

For the purposes of this exploratory study, we focused on evaluating students’ motivation so the testing with students was prepared to gather information about students’ motivation. The testing that we did with students is reported in sections 3.3 and 3.4.

3.2.6 Phase 6: Evaluation

After the first testing with students, the information gathered is evaluated in order to identify issues in the design. When we use the term “evaluation” in this phase, we refer to the analysis of the information gathered to obtain conclusions on the effectiveness of this tool and their alignment with the educational objectives. The results of the evaluation will allow teachers, experts in educational technology and developers to redesign the application and make the appropriate changes in order to overcome the educational need. If the redesign is needed, start again from phase 3.

Complete details on the evaluation (analysis of information gathered) are presented in section 3.5.

3.3 RESEARCH DESIGN

The purpose of this testing was to evaluate the impact of the co-created Paint-cAR application on students’ motivation in a real scenario. In short, the testing involved the use of the Paint-cAR application for learning the topic of repairing paint on a car. To accomplish that goal a pre-experimental research design was chosen. The following subsections describe the participants in this study as well as the instruments and procedure.

3.3.1 Participants

The participants of this study were 13 students from a VET institution in Spain. These students were enrolled in the intermediate training cycle of Car’s Maintenance. Students did not have previous knowledge of the topic of repairing paint on a car. More details on students’ demographic data are provided in section 3.4.

3.3.2 Instruments

Since the purpose of this study was to identify if the Paint-cAR application positively impact on students’ motivation, the IMMS instrument (Keller, 2010) was applied to gather information of the students’ levels of motivation in the four dimensions of the ARCS model. More details on the IMMS instrument are provided in section 2.7.

We decided to adopt the ARCS model and the IMMS instrument to explore the impact of AR on students’ motivation because the ARCS model is based on an extensive research on learning motivation and also because this model and instrument has been successfully applied in other studies that analyze the impact of AR on students' motivation such as the studies conducted by Chiang, Yang, & Hwang (2014), Chin, Lee, & Chen (2015), Chen, Chou, & Huang (2016) as described in section 2.7.

The IMMS instrument was adapted for the purposes of this study to gather data about student motivation when using the Paint-cAR application for learning. The adapation of the IMMS instrument is presented in APPENDIX D. It is important to note that that all the 36 questions of the instrument were maintained (to avoid affecting reliability of the instrument) but the questions were slightly adapted to ask about the experience using the Paint-cAR application.

3.3.3 Procedure

The procedure of this first exploratory study was: First, an initial questionnaire was applied to gather information about users' characteristics and the use of mobile devices in daily activities as well as information about the smartphone's model and brand in order to test the Paint-cAR application responsive design. This questionnaire was completed in 15 minutes. Then, an introduction to the concept of AR was given to students and they installed the Paint-cAR application with the support of the researcher. Then, the intervention took place, it lasted 1 hour. Students used the Paint-cAR application as part of learning activity for the topic of repairing paint on a car. The learning activity took place in the workshop. The AR markers were stuck to the real chemical products and tools in different places of the workshop (this was done before the leaning activity starts). Students used the Paint-cAR application to follow the first part of the process. Students were guided step-by-step by the instructions of the application. During the intervention, the learning activity was recorded and two researchers gathered data from direct observation.

After finishing the exercise with the application, the IMMS instrument was administered in order to evaluate the *attention, relevance, confidence* and *satisfaction* dimensions. The questionnaire was completed in 40 minutes.

3.4 RESULTS

Regarding the initial questionnaire, 100% of the students were male (age 16 - 25) and owned a mobile device (tablet or smartphone) with internet connection (3G, 4G or Wi-Fi). Moreover, 71,4% of the students frequently uses laptop or PC. Another category analysed was the "uses of mobile devices". In this category students were able to choose multiple options, so each option may appear more than once. Students used the mobile devices for: Chatting (100%), making calls (92,8%), Social networking (85,7%), Searching on the internet (71,4%), playing games (57,1%), using maps - GPS (57,1%) and sending emails (50%).

Most of the students used mobile devices with Android operative system (78,6%) and 14,3% used Windows Phone and 7,1% used IPhone. It is important to remark that 85,7% of the students stated that they would like to use the mobile device for learning some topics related to their studies in the VET institution. In addition, 71,4% stated that they had ever used educational applications in their smartphone. But 50% of the students reported that they hardly ever install new applications. Overall, the results provided an overview of some conditions that may affect the study such as the user acceptance, diversity of devices and common uses of mobile devices.

Regarding the IMMS motivation measurement instrument, the results are summarised in **Table 3-1** according to each dimension of the ARCS model.

Table 3-1. Results of students' motivation for each dimension of the ARCS model.

Dimension	Mean	Standard Deviation
Attention	3.97	0.95
Relevance	3.90	0.92
Confidence	4.02	1.09
Satisfaction	4.19	0.86

After analysing the videos recorded and the information gathered by the two researchers that observed the testing, the main conclusion was that students focused too much on the basic task of finding the products and tools. This is positive up to some extent, but students did not pay attention to the augmented information that was displayed for each product and tool so they missed important information that was also essential for their learning process. Besides that, some students just followed their classmates on the actions they did instead of trying to do the activity by themselves. For example, the first student that found a product or tool was followed by the rest of their classmates. We observed though that for students this was an experience that differs from the traditional experiences in the classroom and some of the students seemed engaged in the learning activity.

Regarding to the scaffolding mechanism included in the application to support the learning task of students, we observed that the information conveyed through this mechanism was not adequate because this mechanism provided too much information to students with respect to the product and tool they needed to use for each step in the process. The result of this situation was that the level of challenge perceived by students was low and therefore students completed the activity with little effort. As for the feedback it was observed that it needed to be more informative.

Another issue identified was that poor light conditions in the workshop may negatively impact the performance of the Paint-cAR application, because the camera is not able to detect the AR markers. Therefore, this affected students' perception because they felt frustrated when the application did not recognize the marker.

3.5 DISCUSSION

Overall, the results are promising since they indicate positive impact in the 4 dimensions of the ARCS model. In this sub-section the results are discussed from the dimension that obtained the highest score to the dimension that obtained the lowest score.

Satisfaction dimension (rated 4.19) is about reinforcing accomplishments. And one of the best ways to do that is to use meaningful opportunities to use the acquired knowledge such as experiential learning activities (Keller, 2010). Paint-cAR application provide this opportunity by using AR since students are guided through the process of repairing paint in a real workshop scenario having the opportunity of interacting with real tools, products and augmented information. The score obtained in the *satisfaction* dimension shows a positive perception of students with respect to the learning experience and as pointed out by Keller (2010) high levels of satisfaction are the result of a positive perception of students with respect to having obtained a desired level of success in topics that were personally relevant and meaningful for them. Thus, the results of the score in this dimension are indicators of a positive feeling of *satisfaction* created by the application during the learning experience.

According to Keller (2010), *confidence* dimension is about helping students feel they can succeed and control their success. Besides that, providing the possibility of succeeding at challenging tasks is important to foster motivation. The result of the *confidence* dimension (rated 4.02) can be explained due to the design of the Paint-cAR application because students are not only challenged to repair the paint of car's hood but they are also guided to accomplish that challenge by increasing the opportunities for succeeding in the task. This reinforces *confidence* in students since they can succeed in the process. In relation to *confidence* dimension of motivation, Keller, (2010) also asserts that one of the main characteristics of *confidence* is the perception of control. In this regard, the Paint-cAR application provide opportunities so that students can use the application at their own peace to complete the challenge and they have complete control over their actions in the application that does not affect real products and tools so students feel free to do any action in the application. Digital feedback helps them to identify and correct errors. This situation seems to build and strength students' *confidence*.

Attention dimension (rated 3.97) is about engaging the learners and capturing their interest. Keller (2010) claims that activating curiosity and creating problem-based situations could help to increase attention factor. By analysing the recorded videos of the test, the Paint-cAR application seemed to capture the interest of the learners. Nevertheless, since the process is sequential and all students work almost at the same pace, students tend to move to the same place in the workshop at the same time to search for the AR marker. This caused distraction in some of the students while they waited for their classmates to scan the AR marker. Even, some of the students tried to search strategies for scanning the markers from the mobile devices of their classmates to speed up and avoid waiting for their turn. This needs to be revised for future testing.

Finally, *relevance* dimension (rated 3.90) is about meeting personal needs and goals and discovering the meaningfulness of the learning activity (Keller, 2010). The results show that the perception of students is positive with respect to the use of the application for the learning activity. It seems that the Paint-cAR application addresses in a positive way the personal needs and interests of students. (Keller, 2010) states that for supporting *relevance* students need to make a clear connection between the things they are learning and their own goals in the learning process. The result in this dimension may suggest that the Paint-cAR application helps students to make those connections and therefore the *relevance* dimension increases.

Although the result in the *relevance* dimension was positive, the time that students spent on using the Paint-cAR application was not enough so that they can establish a clear relationship between the concepts they are learning and rehearsing and its applicability in the real environment. This is a clear evidence of the need for longitudinal studies using the application. Moreover, a longitudinal study may help to discard the consequences of the novelty effect on students' motivation.

The results obtained in our study are in line with the findings in the study by Y. Chen (2013) regarding to the impact of AR applications for learning on the *attention* and *satisfaction* dimensions of the ARCS model. Moreover, the results of our study are also in line with the results obtained by C.-H. Chen et al. (2016) in their study in which they found that there is a significant difference in the ARCS dimensions of motivation between students that used an AR application for learning and students who did not used it. It is important to note that higher levels of motivation were reported by students who used an AR application for learning. Besides that, C.-H. Chen et al. (2016) found that the use of an AR application increases students' self-confidence because AR positively affects the *confidence* dimension of motivation. According to the findings in the comparative study by Chiang et al. (2014). There is a significant difference between students who use an AR application for learning and students who do not use it. In particular, the researchers found that the *attention, relevance, confidence* and *satisfaction* dimensions rated high and are significantly different from the students who did not use the AR application. This result is also in line with the results of the study by Chin et al. (2015) who reached to similar conclusions that at the same time are aligned with our findings.

With respect to the results of the analysis of the video recordings and the observations made, it can be concluded that the Paint-cAR application needs a mechanism to help students to stay focused on their task and avoid the behaviors observed in the testing. It was found that the scaffolding mechanism needs to be modified to provide better support and create a better perception of the challenge and the feedback needs to provide more information on why the product or tool selected was not appropriate for the learning process.

3.6 CONCLUSIONS

This study sought to explore the impact of a mobile AR on students' motivation in the VET programme of Car´s Maintenance. The results obtained in this study were promising in terms of motivation because the 4 dimensions of the ARCS model rated high. In general we may conclude that there is a positive impact of the mobile AR Paint-cAR application on students' motivation. This result is in line with other findings in the literature regarding to the positive impact of AR on students' motivation but in our study these assumptions were confirmed in the VET programme of Car's Maintenance. Besides that, this study allowed us to identify some issues in the Paint-cAR application for supporting the learning process at the VET programme of Car's Maintenance. These issues may inform the design of future mobile AR applications in this field. Therefore, this study is a contribution to the knowledge in the field of AR in the training at the VET level of education. This is in line with the need expressed by Borsci et al. (2015) who claims that more studies that systematically explore the effectiveness of Virtual Reality (VR) and Mixed Reality (MR) in the training of service operators are needed.

Another contribution of this study is that we introduced an iterative methodology based on a collaborative creation (Co-creation) process integrating the Universal Design for Learning (UDL) as the inclusive learning approach for creating mobile AR applications for education. A practical implication of this study is that the introduction of AR in VET institutions for supporting the learning process could help students to become familiar with this technology that they could use in the future when they go to the industry. This is mainly because the use of AR in the industry for maintenance tasks is increasing.

This study has resulted in identification of the need for a longitudinal approach as further research direction in order to explore the impact of AR in VET institutions to avoid the novelty of technology factor. Besides that, as a result of this study we identified the following issues that need to be redesigned in the Paint-cAR application so that it can be effective for the learning process and for increasing students' motivation:

- The scaffolding mechanism need to be adjusted to the level of challenge in the application. The current mechanism was not making students reflect on their actions.
- The feedback mechanism needs to be more informative rather than simply inform of a success and error.
- The application need to offer different levels of challenge to students.
- Students need to have more information on how each step in the process is conducted because they are focusing only in selecting the appropriate products or tools for each step in the process.
- For each step in the process students need to be assessed to check if they are paying attention to the augmented information.

Apart from these design issues, we identified that students needed to be exposed to the use of the application for longer period of time. This means that the intervention should last for more than one day so that students can use the application at their own pace for learning. An increment in the time that students are exposed to the application will provide us with a better overview of the effect that the Paint-cAR application may have on students' motivation.

Finally, this study demonstrated the execution of the third activity of the Exploratory Phase (**AEP3**) in the research methodology defined for this thesis and addressed the second specific objective of this thesis: "**SO2**: To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education.". Some insights for answering the first research question **RQ1** of this thesis were also gathered. The results presented in this chapter give insights to tackle the second and fourth open issues identified in the literature respectively: "**OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences" and "**OI4:** There is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education".

The limitations of this study are described as follows:

a) The research sample in this study is small (N=13) because this was the first exploratory study and we wanted to gain some insights into the effect of the AR application on students motivation. However a bigger research sample may help to generalize the results.

b) The research design was a pre-experiment because it was not possible to divide students into a control and experimental groups due to the restrictions in the VET institute and also because there was only one group of students in the VET programme of Car's Maintenance in the VET institute. So, it was not possible to compare students' levels of motivation with other instructional materials.

c) The direct observation of the experiment and the recording of videos make some students to feel ashamed or afraid of doing the activities naturally. So this may have affected the normal behavior of students when using the application.

3.7 PUBLICATIONS ASSOCIATED TO THIS STUDY

The results of this study and the methodology for the co-creation of mobile AR applications were published in the conference proceedings of the 2015 International Conference on Virtual and Augmented Reality in Education (VARE'15) and the proceedings were published in the Procedia Computer Science Journal:

Bacca, J., Baldiris, S., Fabregat, R., Kinshuk, & Graf, S. (2015). **Mobile Augmented Reality in Vocational Education and Training**. Procedia Computer Science, 75(0), 49–58. http://doi.org/10.1016/j.procs.2015.12.203

CHAPTER 4
SECOND EXPLORATORY STUDY

4.1 INTRODUCTION

In the first exploratory study presented in CHAPTER 3, we confirmed that the first prototype of the Paint-cAR application had a positive impact on student motivation. We also identified some issues in the application that needed to be addressed. Thus, a second exploratory study was conducted. The purpose of this second exploratory study (hereinafter called "this study") was twofold: First, this study aims to confirm the impact of an improved version of the Paint-cAR application on student motivation for a longer period of time and second, this study aims to explore the impact that the improved version of the mobile AR application may have on students' learning outcomes in the VET programme of Car's Maintenance. It is worth noting that other researchers such as Di Serio, Ibáñez and Kloos (2013), Chin, Lee and Chen (2015) and (Akçayır & Akçayır, 2017) have pointed out that more studies are needed to explore the impact of AR in extended periods of time to overcome the issues associated to the "novelty effect" (Looi et al., 2009) of AR.

This second exploratory study corresponds to the third activity in the Exploratory Phase (**AEP3**) in the research methodology followed in this thesis. Moreover, this study addressed the second specific objective of this thesis: "**SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education.". Besides, this second exploratory study provided insights for answering the firs research question of this thesis "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?". The results presented in this chapter give insights to tackle the second and fourth open issues identified in the literature respectively: "**OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences" and "**OI4:** There is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education".

This chapter is organized as follows: Section 4.2 describes the second iteration in the design of the Paint-cAR application. Section 4.3 describes the research design followed for this study and section 4.4 describes the results of our study. Finally, sections 4.5 and 4.6 presents the discussion and conclusions respectively.

4.2 DESIGN OF THE PAINT-CAR APPLICATION

The results from the first exploratory study (CHAPTER 3) were analyzed in some meetings with the teachers in order to identify strategies that allowed us to improve the application and address the issues identified in the first exploratory study. We worked with the same teachers (Joan Clopés and Narcis Vidal) and another iteration of the co-creation methodology was carried out to improve the design of the Paint-cAR application. Since the methodology specifies that if the redesign is needed the process should start from phase three, a description of the results for each phase of the co-creation methodology is presented as follows starting from phase three:

4.2.1 Phase 3: Designing the AR application

By analyzing the issues identified in the first exploratory study a number of design decisions were made in agreement with teachers. It is worth noting that the design decisions were also based on the UDL to address students' needs. For the purposes of this study the following design decisions were made:

a) Regarding the process of repairing paint on a car: In the first prototype of the Paint-cAR application, the steps of the process were not classified in any particular way, so students followed one step after the other. By examining this aspect of the application in the results of the first exploratory study, teachers suggested that students would understand and remember the process better if the process were divided into single units. Thus, it was decided to divide the process into phases and steps. These concepts are defined as:

Phase: A phase is a major unit in which the process of repairing paint on a car is divided into. Each phase contains a set of steps. There are six phases that in the corresponding order are: Cleaning, Sand down, Applying putties, Applying sealers, Painting and Applying Clear Coats.

Step: A step is a unit in which a phase is divided into. The step represents a particular single procedure or task that need to be performed to achieve the actions needed for completing the phase. The number of steps varies for each phase but they all have to be performed in a fixed order. All the steps in a phase are required to be successfully completed for the corresponding phase. In total, the process consists of 30 steps.

Based on these concepts, the Paint-cAR application was organized in a way that students identify the phases of the process, as well as the steps and the procedure that each step involves during the repairing process. The phases and steps of the process were defined by the teachers and the software developers designed the user interfaces that reflect the organization of the process in phases and steps. Moreover, teachers suggested that students have to understand the correct order of the phases and steps in the process. This is an important skill that students need to master for this topic. For this reason, an activity was designed for this purpose. This activity consists of a puzzle where students have to organize the phases of the process into slots in the correct order. Besides that, for each phase, students have to organize the steps that correspond to that phase in the process.

b) As a result of the first exploratory scenario (described in chapter 3) we identified the need of providing different levels of challenge to students. This means that the Paint–cAR application needs to offer different modes depending on the level of knowledge that students have in the topic. This is particularly important because in the first exploratory study we identified that the level of challenge perceived by students needs to be adjusted to their level of knowledge. For example, for a student who is just starting to learn the topic the Paint-cAR application should provide support for learning the basic concepts but for a student with a more consolidated knowledge the Paint-cAR application needs to offer a higher level of challenge. This recommendation is also supported by the motivational design theory in the dimension of *confidence* (Keller, 2010). After some meetings with teachers we decided that the application needs to offer the following modes so that students can use each mode according to their needs and preferences:

i. **Guided Mode:** In this mode, students are guided step by step through the process of repairing paint on a car. In this mode, a scaffolding mechanism was developed. This mechanism was developed as a module in the AR application and we call this module as the **Scaffolding module**. By using the scaffolding students can ask for help in the Paint-cAR application at any time and the application will provide hints and information to help them to find the appropriate tools and products that they need for each step in the process. In short, in this mode students have as much information as possible so that they can learn about the products and tools for each step in the process.
The introduction of the scaffolding mechanism was inspired by the recommendations of the UDL in terms of providing graduated scaffolds to help students in the learning activities and this recommendation supports the principle of providing multiple means of action and expression (Meyer et al., 2014). Moreover, this design decision supports the recommendations of the motivational design (Keller, 2010) for supporting the *confidence* dimension of motivation by providing a mechanism to help students to achieve in challenging tasks.

ii. **Evaluation Mode:** In this mode students need to go through the process of repairing paint step by step (as in the Guided Mode) but in this mode, they have less help and assistance (i.e. the scaffolding mechanism show less information). Students are challenged to complete the process using the knowledge they acquired in the Guided Mode. Students need to successfully complete each step before starting the next step.

iii. **Informative Mode:** In this mode, students have all the steps available and they can see the information of any step at any time. This is intended for students who want to focus on a specific step without completing the other steps of the process.

c) We also identified the need of providing more information on how each step of the process is performed. This issue was identified in the first exploratory study because students did not reflect on their actions and they did not read all the information presented in the Paint-cAR application. Therefore, a strategy was needed so that students can learn even more about how the process of repairing is performed. Thus, in agreement with teachers it was decided to design some activities that students have to complete for each step of the process. This design decision was also inspired by the recommendations of the UDL regarding to the provision of multiple means of representation, action, expression and engagement (Meyer et al., 2014). Students should complete all the activities before they can continue with the next step in the process. For each one of the 30 steps students have to complete the following activities: tools and products, watch a video about the process and pass a self-assessment questionnaire. These activities are described as follows:

i. Tools and Products: This activity uses marker-based AR. For the implementation of this activity and all its functionalities we designed an **AR module** for the application. The AR markers are stuck to the real products or tools if possible or in the place where the products or tools are stored in the workshop. Markers were not stuck to the real product or tool in some cases because the markers could be damaged due to the use of the product or tool. For example a marker stuck to the paint gun will be damaged when the paint gun is cleaned with solvent. In this activity, students have to search for the tools or products they need to use in each step of the process. To do that, students use the mobile device's camera in order to scan the AR marker. When the AR marker is detected, augmented information appear in the device's screen.

This activity is different for the Guided Mode and for the Evaluation Mode. For the Guided Mode, a user interface was designed in which it is explained to students which products they need to use and why. After students read this information the AR experience starts. This means that the camera is activated and students can search for the markers in the workshop. At the same time the scaffolding mechanism is activated to provide support to students. For the Evaluation Mode, some hints are provided in the user interface and then the AR experience starts. The scaffolding mechanism is activated but it shows less information since the challenge is higher in this mode. The AR experience also includes a mechanism for real-time feedback that provides feedback to students when they scan the markers of the chemical products and tools so that students can reflect on their choices, success and mistakes. The real-time feedback is more informative and helps students to reflect on why a particular product would not be appropriate for a step in the process. The real-time feedback mechanism was designed in a module that we call the **Real-time feedback module**. In the AR experience, the following augmented information about each product or tool is shown:

- **Information about the product or tool:** The main characteristics and relevant information about the product or tool are shown. An iconic representation of the characteristic is shown and additional information is displayed if the student taps over the iconic representation.
- **Safety measures:** Iconic representations as well as written information about the safety measures that students must take when they manipulate the products. For example the use of gloves or dust / gas mask, etc. The written information is shown if the student tap over the iconic representation.
- **Image of the product or tool:** An image of the product or tool is shown superimposed in the marker if the 3D model is not available. The purpose of this image is that students make sure the marker that is being scanned is the product that they need to use. In addition to this, if the marker is stuck to the place where the product is stored the image allows students to confirm if the product corresponds to the one that is located in that position.

ii. **Videos about the process:** In this activity, students have to a video that shows how the step of the process is performed by an expert. The purpose of this video is that students can see how to perform that step of the process correctly. This will help students to have a clear understanding about the way each step should be carried out. For this activity, teachers recorded one video for each step of the process with very specific details that students need to learn. As mentioned earlier, this design decision was inspired by the UDL with the purpose of providing an alternative mechanism of presentation of information to students. For the implementation of this activity we designed a module called **Module for watching videos**.

iii. **Self-Assessment:** In this activity, students are required to answer multiple choice questions. These questions are problem-based and are defined by the teacher using a web application that works as a repository of questions. By using this activity, students can evaluate if they understood the information provided in that step of the process and help them to reflect on their understanding of the process. For each step in the process a number of questions (that are defined by the teacher using a web application designed for that purpose and described later in this chapter) are randomly selected from the database and shown to students in the mobile device. Teachers can also configure the number of questions needed to pass the test.

The Paint-cAR application corrects the questions automatically and highlights the questions in which students made a mistake with a red "X" mark and the questions that are correct with a green tick. Students can correct the questions with mistakes in two opportunities for choosing another answer. After students correct the questions, the test is automatically revised again. If the number of correct questions is less than the threshold defined by the teacher for passing this test, then students will have to answer a new test. This activity aims to address the need of providing a mechanism so that students can reflect on their learning process and apply the knowledge they acquired in the solution of real situations. If students did not pass the test they can revise the learning content again and try to answer the questionnaire again. For each attempt to answer the questionnaire the system selects different random questions for each student. In the Paint-cAR application the module that manages the assessment is called the **Assessment module**.

iv. **Take a picture of the safety sheet data and technical data sheet:** This activity will be available in the steps where there are chemical products that have a safety sheet data and/or technical data sheet. Students have to take a picture of the safety sheet data and the technical data sheet using the Paint-cAR application and it will send the picture to the server. Teachers are able to see the picture taken by the students to identify if students know how to find the data sheets. The purpose of this activity is to be sure that students know how to find the appropriate data sheet for each chemical product.

d) Teachers also pointed out that it is important to trace the use of the Paint-cAR application to know if students are using it or not and to know if they are facing difficulties in the learning process at any phase or step in the process. This information will help teachers to make decisions in the teaching process in class. For this reason, a monitoring mechanism was designed for the Paint-cAR application and this mechanism is called the **Monitoring module**. With the Monitoring module, the interaction of students with the Paint-cAR application is registered (clickstream) in the student's mobile device and sent to a server to be stored. If no internet connection is available at that moment, the application stores the clickstream data in the mobile device and synchronizes this information the next time that the Paint-cAR application detects and internet connection.

As a result of this design decision, a mechanism to identify each instance of the application associated to each student was needed. So a code was given to each student and the application asks for that code the first time the application is installed. By using this code the application sends information to the server and the information is stored for each student.

e) In the application students are able to follow the process of repairing paint step-by-step. But students need to complete the activities of each step before going to the next step. However, if students want to practice even more, teachers suggested that students should have the possibility of restarting the Evaluation Mode or the Guided Mode to start the process again from the first step. Therefore, a mechanism for restarting the guided and Evaluation Mode from the beginning was designed.

f) Together with teachers we identified the need of providing a web application for teachers to manage users, manage the questions for the self-assessment activity and to get information about the use of the application. So we made the decision of designing a web application for teachers.

4.2.2 Phase 4: Develop a prototype of the AR application

Based on the design phase of the application described in phase 3 of this methodology, a new prototype of the Paint-cAR application was developed. This prototype was developed from January to August 2015. The Paint-cAR application can be downloaded from a web site that we designed for this application in the following link: https://goo.gl/wQRsQm In summary, apart from the module that manages the user interface and user interaction, the Paint-cAR application was developed with the following main modules:

- Scaffolding module.
- Real-time feedback module.
- Assessment module.
- AR module.
- Module for watching videos.

In this sub-section some of the user interfaces of the second prototype of the Paint-cAR application are presented and explained. Since the language of the user interfaces is Spanish, the translation into English of the user interfaces is provided in small boxes next to each text.

The interfaces for the splash screen and the challenge interface designed as part of the first prototype (described in CHAPTER 3) had only small changes. For instance, the text of the splash screen was changed to "Process of Repairing paint" and some changes in the writing style and some words that describe the challenge proposed to students were made in the interface that explains the challenge to students. Following the challenge interface, students navigate to the selection of mode interface, where they can select if they want to use the application in Guided Mode, Evaluation Mode or Informative Mode. Figure 4-1 shows the selection of mode interface.

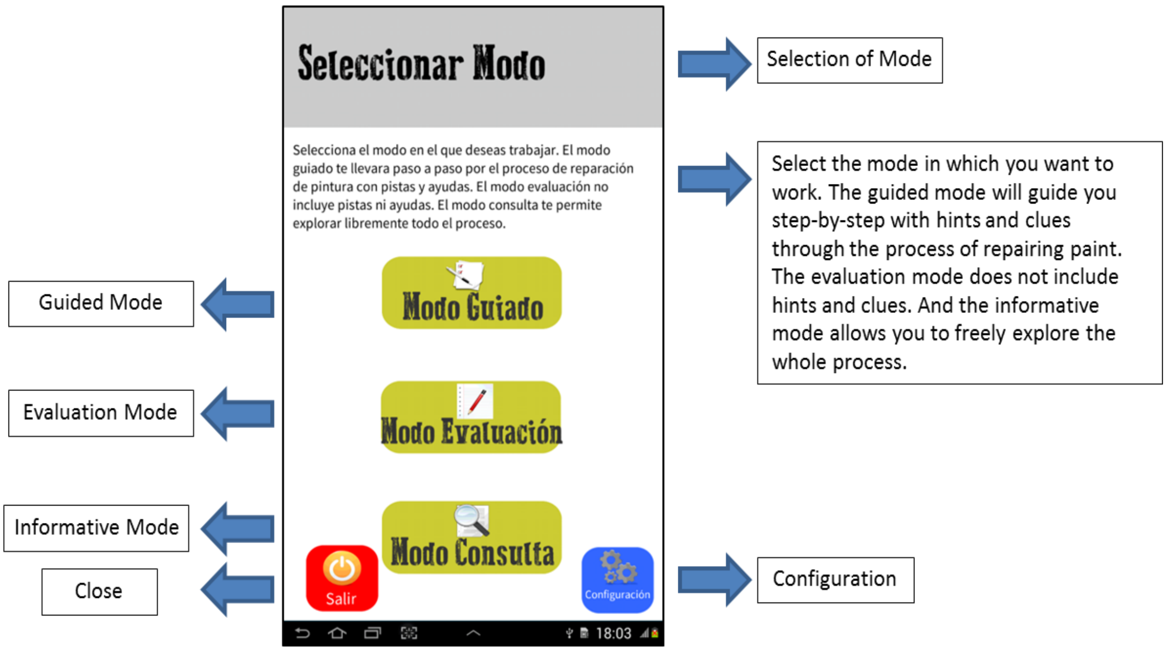

Figure 4-1. Selection of mode interface.

If students select the Guided Mode, a user interface with the phases of the process is displayed. The phases in which students have completed all the activities and all the steps of that phase, are shown in color but the phases that have not been completed yet are shown with gray scale icons. Figure 4-2 shows, the user interface that presents the phases of the process in which the cleaning phase is active (in color) which means that the student is currently working in that phase and it also means that the other phases (in gray scale) have not been completed yet.

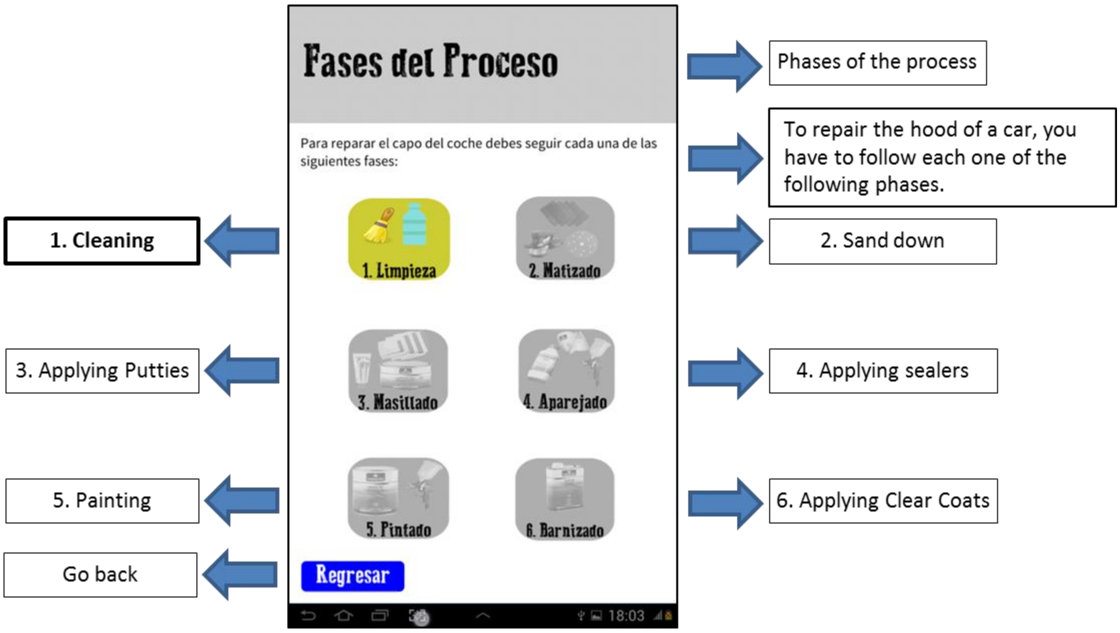

Figure 4-2. User interface that presents the six phases of the repairing process.

Figure 4-3 shows the steps for the first phase (Cleaning) in the process. In this figure, the first three steps are enabled (highlighted in color rather than in gray scale). This means that those are the steps were already completed by the student.

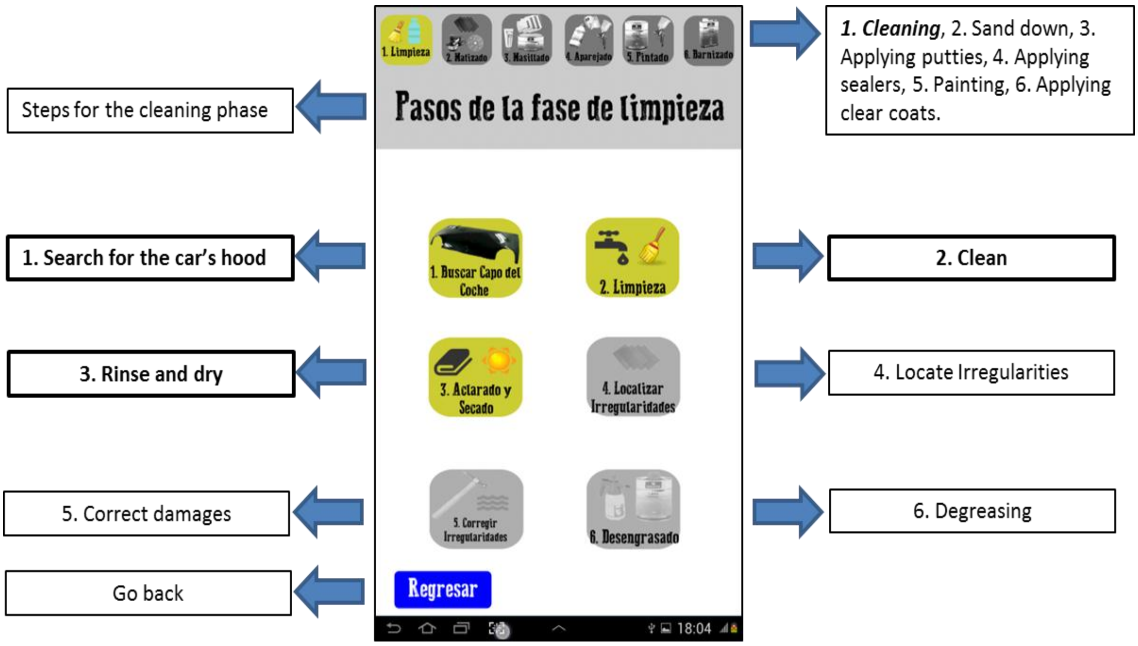

Figure 4-3. User interface that presents the steps of the first phase of the process (cleaning).

For the user interface showed in Figure 4-3, teachers recommended that students should have a guide to know in which phase of the process they are working. For this reason in Figure 4-3, the upper side of the figure has a list of the phases of the process. The phase that is enabled (the one highlighted in color rather than in gray scale: cleaning) is the current phase and this means that the steps shown in this interface are the steps that belong to that phase (cleaning). In the English translation the phases that are in bold and with remarked boxes are the phases that are active.

When students go into each step in the process, the list of activities available for that step are presented in the user interface shown in Figure 4-4. This figure shows an example of the list of activities for the step “2. Cleaning”. The upper side of the figure shows the list of phases in which the current phase (1. Cleaning) of this step is highlighted in color. Besides, the list of steps that belong to the cleaning phase is shown and the current step (2. Clean) of the process is highlighted in color. The user interfaces that show the activities for the rest of the steps in the process are similar to the user interface shown in Figure 4-4.

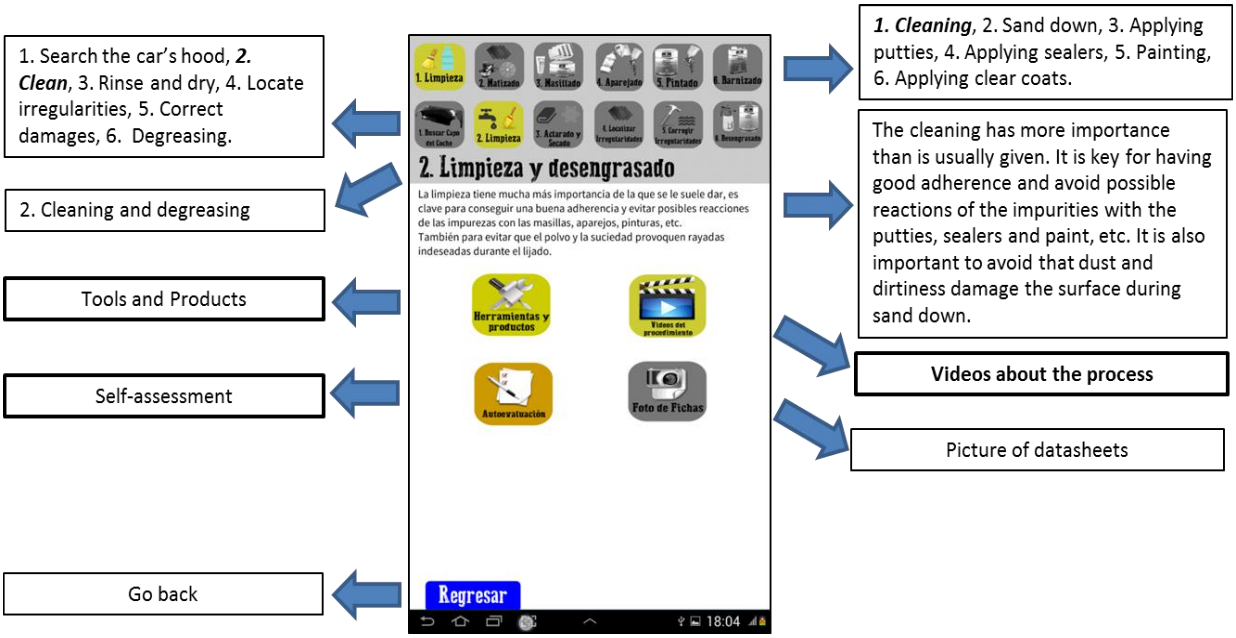

Figure 4-4. Activities available for the step “2. Cleaning” in the process of repairing.

Figure 4-5 shows the AR experience. In the image it can be seen that the student is scanning an AR marker of one of the tools used in the repairing process and the image of the tool is superimposed in the AR marker. Besides that, the augmented information about the safety measures is being displayed in the screen and the icons can be used to display or hide the additional information. The green button can be used to select this tool for this step in the process. The interaction with the augmented information was designed in a way in which students can be able to easily read the information and it includes the icons to facilitate the connection of the information with an iconic representation of it. These design considerations were defined by following the UDL guidelines (Meyer et al., 2014).

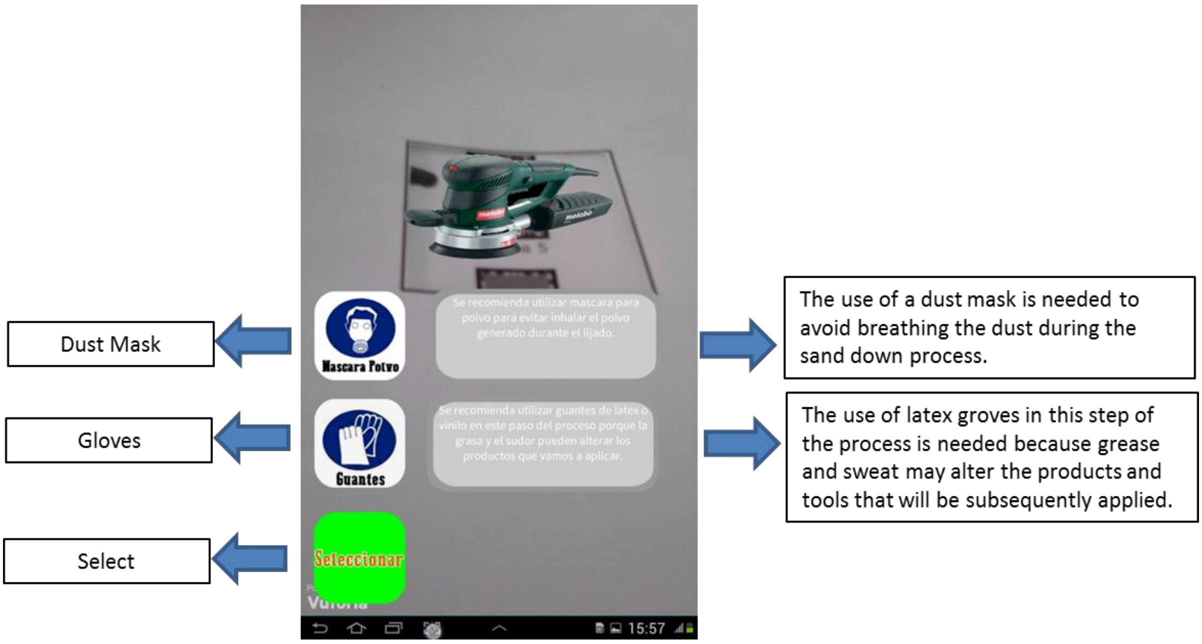

Figure 4-5. User interface of the AR experience showing the augmented information about safety measures.

Another activity in the Paint-cAR application was the self-assessment activity. Figure 4-6 shows an example of the list questions for the step "2. Clean" in the self-assessment activity. The image shows a list of five questions numbered 1 to 5 and at the bottom of the user interface a button "submit questionnaire" which is used for sending the answers to the questions for validation.

Figure 4-6. Example of a list of questions for the step "2. clean" in the self-assessment.

After students submit the questionnaire for validation, the icon with the question mark that can be seen in Figure 4-6 changes to a red "x" mark or a to a green tick to show that the question was correct or not.

Figure 4-7 shows an example of the interface in which some of the questions have the red "x" mark and some of the questions have the green tick. The questions that are wrong can be revised by students and at the bottom of the user interface the button "Finish questionnaire" can be used to send the revised questionnaire for validation. If the questionnaire is correct, then this activity will be approved but if not, a new questionnaire is generated for the student and a recommendation is provided for revising the learning contents again.

Figure 4-7. Example of the user interface that shows the correct and incorrect questions.

As for the Evaluation Mode, the first activity that students have to complete is to solve the puzzle designed for evaluating if students remember the order of the phases and steps in the process. Figure 4-8 shows the user interface of this puzzle. The rest of the interfaces in the Evaluation Mode are similar to the interfaces shown in this section. The difference is the level of challenge and the amount of information provided by the scaffolding mechanism.

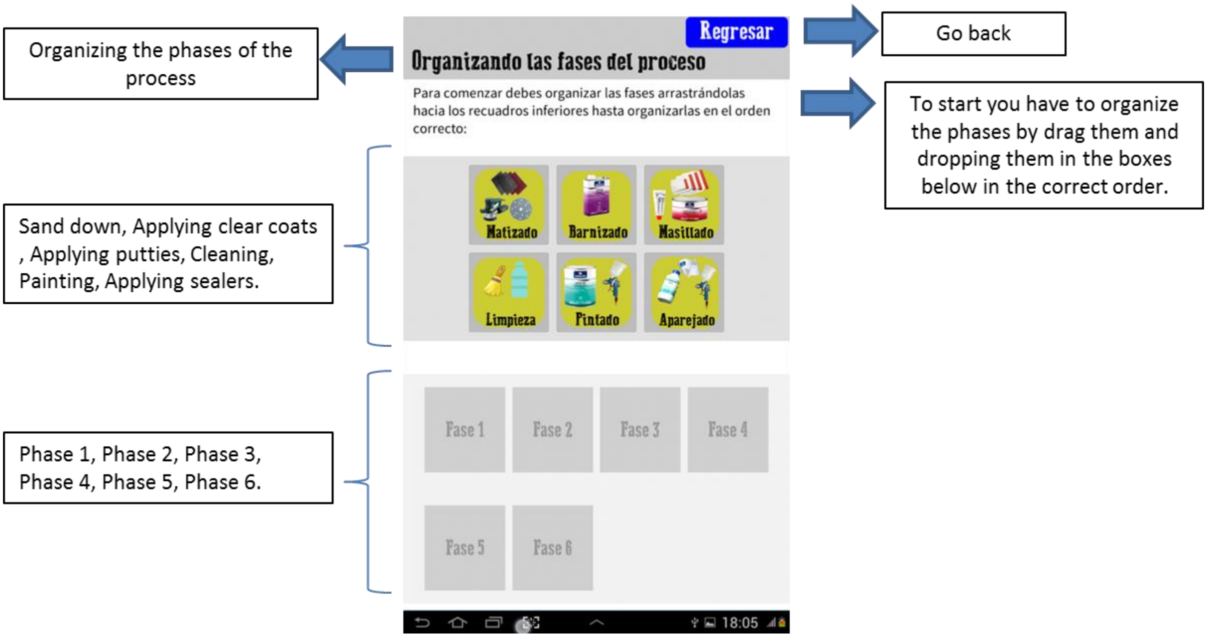

Figure 4-8. User interface of the puzzle for organizing the phases of the process.

Figure 4-9 shows the user interface for restarting the Guided Mode and Evaluation mode. With this option students can start the process from the beginning (this means from the step 1 of phase 1).

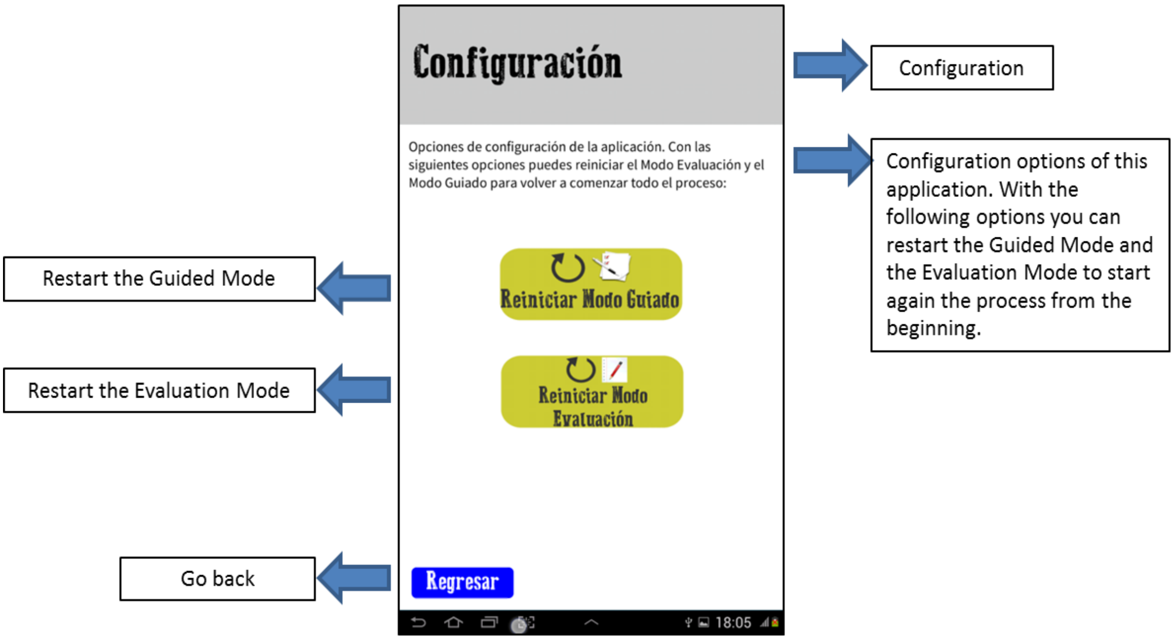

Figure 4-9. User interface for restarting the Guided Mode and the Evaluation Modes.

As for the web application designed for teachers, the application has the following features:

- It has a login module for authentication with username and password.
- Creation of new users.
- Restrict the access to the mobile application for any user.
- The last date and time when the application was used by any user.
- Create, update and delete multiple-choice questions (see Figure 4-11).
- For each multiple-choice question, teachers can include an image as part of the question.
- Define a threshold for the number of questions needed for passing a test.
- See the results of the activity of the puzzle. Each attempt of the students is registered by the application.

The web application for teachers is available at https://goo.gl/wQRsQm but it needs a previous registration to access to the administrative functions. The web application was developed in Spanish language.

Figure 4-10 shows a screenshot of the menu of the administrative options that teachers have in the web application.

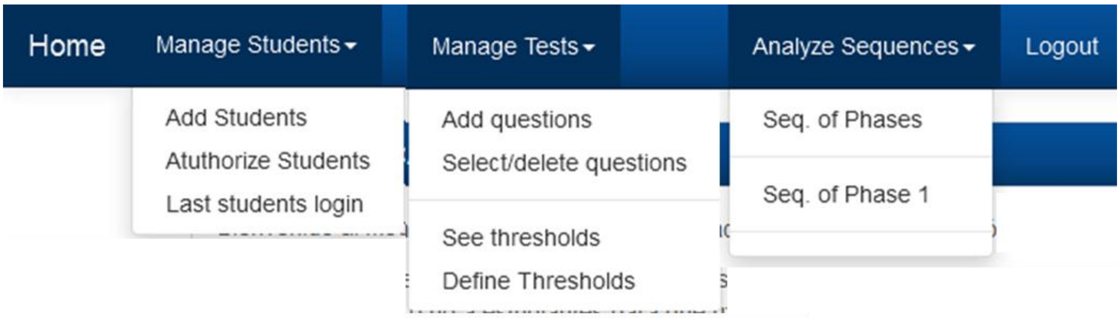

Figure 4-10. Screenshot of the menu of administrative functions in the teachers' web application.

Figure 4-11 shows a screenshot of the user interface of the web application in which teachers can create, edit and delete the multiple-choice questions that students answer in the Paint-cAR application.

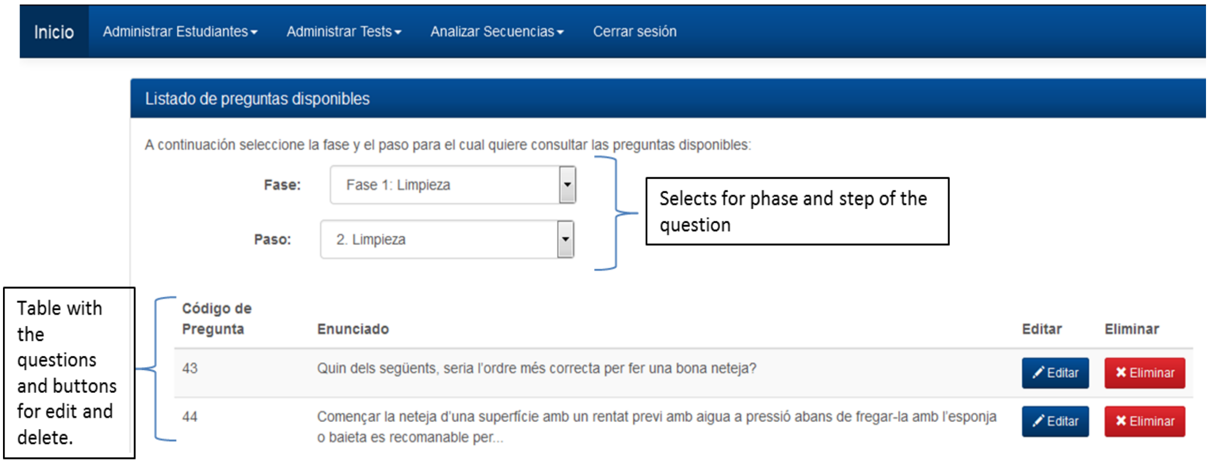

Figure 4-11. User interface of the option for creating, updating and deleting multiple-choice questions.

4.2.3 Phase 5: Testing with students

After this second prototype of the application was finished and approved by the teachers. The next step in the methodology that we defined was to conduct a testing in a real scenario with students. Further details on this testing are described in section 4.3 in this chapter.

4.2.4 Phase 6: Evaluation

This phase of the methodology correspond to the analysis of the results obtained from the first testing with students. This analysis is detailed in section 4.4 and 4.5 in this chapter.

4.3 RESEARCH DESIGN

The purpose of this study was to evaluate the impact of an improved version of the Paint-cAR application on students' motivation and students' learning outcomes when the Paint-cAR application is used for a longer period of time. We hypothesize that a longer exposure of students to the Paint-cAR application may reduce the novelty effect and may provide insights into the real impact of the application on students' motivation and students' learning outcomes. Although in this thesis we focused on student motivation, we thought that it was important to ensure that the application does not negatively affect students' learning outcomes. For this reason in this study we also considered students' learning outcomes. With that aim, the research design of this study is as follows:

To evaluate students' learning outcomes a quasi-experiment with a comparative study was chosen. This research design was chosen because we needed to determine that the application did not affect in a negative way the students' learning outcomes. So, we needed to compare with a control group to determine if the learning effectiveness when using the Paint-cAR application is equal or greater than the lerning effectiveness using tradicional instruccional materials.

To evaluate student motivation a pre-experimental research design was chosen. In this case, the purpose was to determine the students' levels of motivation after using the improved version of the Paint-cAR application for a longer period of time to identify if students are still motivated after the novelty effect wears off. With this research design we gathered information about students' levels of motivation that was subsequently used in the next phase of this thesis as described in CHAPTER 5.

4.3.1 Participants

Participants in this study were 73 students enrolled in the intermediate training cycle in "Car Bodywork" in the context of the Vocational Education and training programme of Car's Maintenance. These students came from four different VET institutes in Catalonia (Spain), identified as Institute 1, Institute 2, Institute 3 and Institute 4. The four VET institutes had exactly the same VET programme on Car's Maintenance. Since the research design for measuring students' learning outcomes was a quasi-experiment, 35 out of the 73 students were assigned to the experimental group and 38 were assigned to the control group. The assignation of students to the control and experimental groups was random except in the Institute 1 in which the sample was a convenience sample (Coolican, 2014) because there were two groups of students: one that took classes in the morning and one that took classes in the afternoon. So, students that took classes in the morning were assigned to the control group and students that took classes in the afternoon were assigned to the experimental group. As mentioned before, in the Institute 2, Institute 3 and Institute 4 the assignation of students to the control and experimental groups was random. Table 4-1 shows the distribution of participants in the experimental and control group for each VET institute.

Table 4-1. Distribution of participants in the experimental and control groups for each VET institute.

Institute	Students in the Experimental Group	Students in the Control group	Total of students	Teachers of the VET programme
Institute 1	17	26	43	2
Institute 2	7	6	13	1
Institute 3	7	6	13	1
Institute 4	4	0	4	2
Total	**35**	**38**	**73**	**6**

Moreover, six teachers participated in this study. These teachers included the Paint-cAR application as a support for the learning process. Teachers reminded students to use the application at home and they were present all the time during the tests conducted in the workshop to solve any doubt that students might have. Feedback from the teachers was valuable to understand the results obtained in this study. Furthermore, the teachers designed the instrument applied to measure students' learning outcomes.

4.3.2 Instruments

To evaluate motivation, the Instructional Materials Motivation Survey (IMMS) (Keller, 2010) instrument was also used in this study as in the first exploratory study (detailed in CHAPTER 3). The adapation of the IMMS instrument is presented in APPENDIX D. It is important to note that that all the 36 questions of the instrument were maintained (to avoid affecting reliability of the instrument) but the questions were slightly adapted to ask about the experience using the Paint-cAR application.

To evaluate learning outcomes in the control and experimental groups, a test for knowledge assessment was created by the five teachers that participated in the study. The test consisted of 38 multiple-choice questions with four options but only one correct answer. The reliability of the questionnaire was analysed with the KR-20 (Kuder-Richardson) in two phases. In the first phase of analysis the questionnaire had 40 items and the analysis of reliability was conducted by administering the questionnaire to nine students of the advanced cycle in Car's Maintenance from the Institute 4 in Spain. It is important to note that these nine students did not participate as part of the control or experimental group for this study. This group of students only answered the questionnaire so that we could gather data to validate the reliability of the questionnaire. The Cronbach's alfa was 0,57 and the questions that affect the reliability were identified. These questions were analysed with one of the expert teachers in this field. The questions were then adjusted in terms of clarity, wordiness and general style to make them more understandable.

Besides that, two questions were removed from the questionnaire because they caused confusion to students.

In the second phase of the reliability analysis, the adjusted questionnaire (with 38 questions) was administered to 11 students enrolled in the advance cycle in Car's Maintenance from the Institute 3. In this case this group of students did not participated in the experiment described in this study. These students only answered the questionnaire in order to validate its reliability. The KR-20 method was used again to evaluate reliability. The Cronbach's alfa was 0,77 and 2 questions were identified as problematic questions. These questions were adjusted. Please refer to APPENDIX E to see the complete questionnaire.

In addition, a second test of knowledge was designed by teachers to evaluate learning outcomes in an extended validation that was carried out in the Institute 3. The test consists of 22 questions that evaluate students' learning outcomes.

4.3.3 Procedure

The standard procedure followed in this study for the experimental group is described as follows:

1. **Paint-cAR application installation:** In this phase, students were guided in the process of downloading and installing the application. Students were introduced on how to use the application and basic concepts about AR were explained as well as the main objectives of the activity. A booklet that contains the markers that the application recognizes was given to each student so that they can use the application at home.
2. **Use of the Paint-cAR application for learning (I):** In this phase students used the Paint-cAR application at home or at the workshop (in the vocational education institute) in order to learn about the process of repairing paint on a car. Since the application can be used in Guided Mode or in Evaluation Mode, students were advised to use the application in Guided Mode at home so that they can practice for a testing in the workshop in Evaluation Mode. Teachers had access to a web application and were able to see if students were using the application at home or not.
3. **First testing in the workshop in Evaluation Mode:** One week after students had been using the application at home for learning or practicing about the topic, a testing in the workshop was carried out in Evaluation Mode. The markers that the application recognizes were placed in the corresponding locations in the workshop and students need to find the appropriate tools or chemical products around the workshop in order to complete the process of repairing paint on the hood of a car. The testing lasted 2 hours on average for each vocational education institute. The teachers and the researchers were present in this phase to identify problems and solve any doubt.
4. **Use of Paint-cAR application for learning (II):** In this phase, another period for using the application at home or at the workshop was given to students. This phase lasted from 1 to 2 weeks. Students were able to use the booklet or to use the application in the workshop. Students were advised to use the application in Guided Mode and to practice in the Evaluation Mode. The learning process was followed by the teachers in class by attending some doubts of students about the topic and checking if students used the application at home or not.
5. **Second testing in the workshop in Evaluation Mode:** After the period of practicing with the application at home a second testing in Evaluation Mode was carried out in the workshop. The testing lasted an average of two hours on average for each VET institute. At the beginning of the testing the application was restarted so that students start again from step 1 in the process. Students used the application in the workshop in order to scan the markers that were stuck to each tool and product in the workshop and the challenge was to complete the process of repairing paint on the hood of a car. Students used the application in Evaluation Mode. The teachers of each VET institute and the researchers were present in the testing to identify problems and solve any doubt.

6. **IMMS Motivation instrument:** After the last testing, the IMMS instrument was applied to gather information about the levels of motivation in the four dimensions of the ARCS model with respect the use of the Paint-cAR application.
7. **Test for evaluating students' learning outcomes:** Although this phase of the research procedure does not evaluate students' motivation, the experimental group followed this phase with the aim of collecting information about students' learning outcomes that was subsequently used for evaluating learning outcomes as is explained later in this section. Two days after the last testing in the workshop, students in both the control and the experimental groups answered the test for knowledge assessment. Students spend 40 minutes on average answering this test.

The standard procedure followed for the control group is simple because the control group followed traditional classes with the support of online material in Moodle and at the end they answered the test for evaluating learning outcomes. The content equivalence was ensured for the control group. Figure 4-12 shows the standard procedure followed by the control group and the experimental group for evaluating student motivation and student learning outcomes.

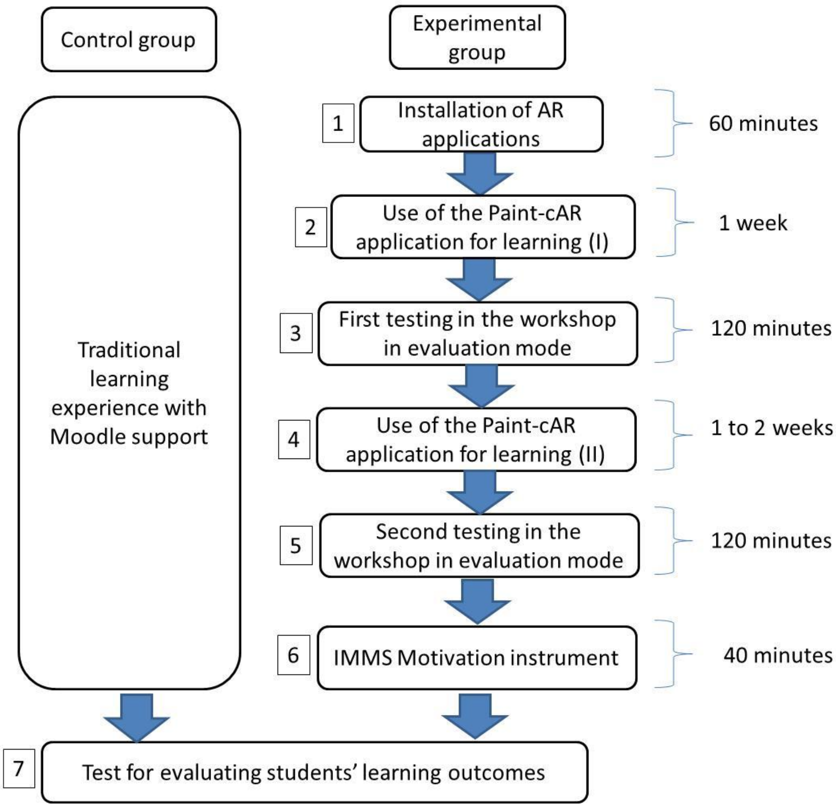

Figure 4-12. Standard procedure followed for evaluating motivation and learning outcomes.

In this study we identified the need of conducting an extended validation in one of the institutes that participated in this study, to evaluate if an extension in the time that students were exposed to the use of the Paint-cAR application may have some effect on students' motivation. A complete description of why this extended validation was needed is presented later in section 4.4.2. Moreover, student motivation was not measured as part of the extended validation, so for that reason the procedure of the extended validation is described apart from the standard procedure. The procedure for the extended validation followed by the experimental group is described as follows:

1. **Using the Paint-cAR application in Guided Mode:** In this phase students used the Paint-cAR application for practicing the process of repairing in Guided Mode. Students were able to use the booklet or to use the application in the workshop. Students were advised to use the application at home. This phase lasted for three weeks.
2. **Using the Paint-cAR application in Evaluation Mode:** Students used the application in Evaluation Mode for practicing the process with a higher level of challenge. Students were able to use the booklet or to use the application in the workshop and students were advised to use the application at home. This phase lasted for 1 week.
3. **Second Test of Knowledge Assessment:** In this phase students from the experimental group answered a second test of knowledge assessment to gather information about students' learning outcomes. This phase lasted for 30 minutes.

The procedure for the control group included traditional classes with self-guided work in Moodle and after these classes the Second Test of Knowledge Assessment was applied. The content equivalence for the control group was ensured. Figure 4-13 depicts the procedure for the extended validation.

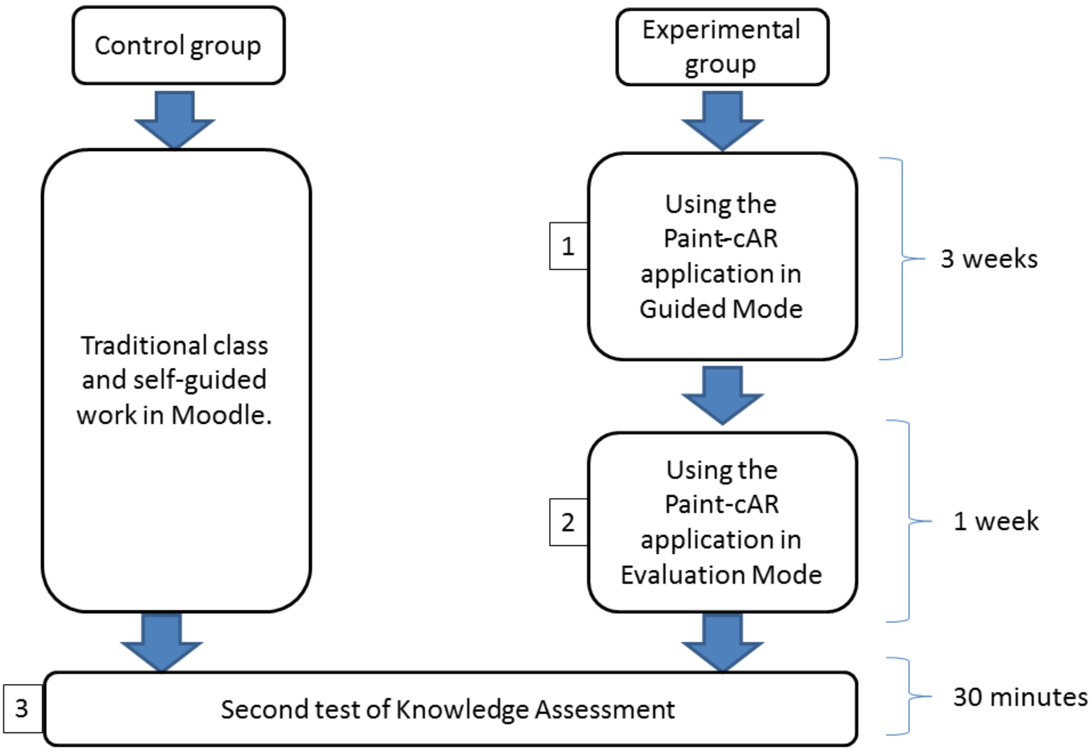

Figure 4-13. Procedure for the extended validation conducted in the Institute 3.

To evaluate student motivation, the 35 students (from the four VET institutes) assigned to the experimental group participated in this part of the study. The distribution of students in the experimental group for each VET institute is shown in Table 4-2 and was as follows: 17 students from the Institute 1, seven students from the Institute 2, seven students from the Institute 3 and four students from the Institute 4. The 35 students followed the standard procedure described earlier (experimental group only).

Table 4-2. Distribution of participats for evaluating student motivation.

Institute	Students in the Experimental Group	Students in the Control group	Total of students	Teachers of the VET programme
Institute 1	17	0	17	2
Institute 2	7	0	7	1
Institute 3	7	0	7	1
Institute 4	4	0	4	2
Total	**35**	**0**	**35**	**6**

To evaluate students' learning outcomes, 69 out of the 73 students participated (which corresponds to students assigned to the control and experimental groups in the institutes 1, 2 and 3). Institute 4 did not participate in this part of the study because the four students were assigned only to the experimental group. The distribution of participants for this part of the study is shown in Table 4-3 and was as follows: In the Institute 1, 43 students participated (26 students were assigned to the control group and 17 to the experimental group), in the Institute 2, 13 students participated (6 students were assigned to the control group and 7 to the experimental group) and finally in the Institute 3, 13 students participated (6 students were assigned to the control group and 7 were assigned to the experimental group).

Table 4-3. Distribution of participants for evaluating students´ learning outcomes.

Institute	Students in the Experimental Group	Students in the Control group	Total of students	Teachers of the VET programme
Institute 1	17	26	43	2
Institute 2	7	6	13	1
Institute 3	7	6	13	1
Institute 4	0	0	0	0
Total	**31**	**38**	**69**	**4**

A quasi-experiment was conducted to analyze students' learning outcomes when using the Paint-cAR application for learning. Students in the experimental group used the Paint-cAR application as part of their learning process as explained in the research procedure described earlier and students in the control group followed a traditional class with the support of online material in Moodle as depicted in Figure 4-12. The content equivalence was ensured for the control group.

To analyze students' learning outcomes, the independent variable was the group in which each student was assigned (control or experimental) and the dependent variable was the students' learning outcomes. Students' learning outcomes were measured with the test for knowledge assessment as described in section 4.3.2. The null hypothesis H_0 is that the two populations from which scores were sampled are identical and the alternative hypothesis is that the two populations from which scores were sampled are different. This difference may explain that the Paint-cAR application positively affects students' learning outcomes in the experimental group.

4.4 RESULTS

The results of this study are organized in three main sub-sections: section 4.4.1 presents the results of students' motivation obtained from the IMMS instrument. Besides that, section 4.4.2 presents the results of students' learning outcomes and the results of an extended validation conducted in one of the institutes is also described. Finally, section 4.4.3 presents the results of students' learning outcomes in the activity of the puzzle for organizing the phases of the process in Evaluation Mode.

4.4.1 Results of students' motivation

Table 4-4 shows the results of students' motivation for the Institute 1, Institute 2, Institute 3 and Institute 4. These tables summarize the data collected from the IMMS instrument applied after the intervention with the Paint-cAR application. The score obtained for each dimension of the ARCS model is presented in the table. It is important to note that the scores of the IMMS instrument range from 1 to 5 with 5 as the maximum value.

Table 4-4. Results of students' motivation for the Institute 1, Institute 2, Institute 3 and Institute 4.

	Institute 1 (N=17)		Institute 2 (N=7)		Institute 3 (N=7)		Institute 4 (N=4)	
Dimension	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Attention	3,16	1,22	3,55	1,17	3,64	1,04	3,97	1,18
Relevance	3,20	1,08	3,22	1,14	3,46	1,24	3,80	1,03
Confidence	3,09	1,09	3,49	1,24	3,62	1,01	3,75	0,93
Satisfaction	3,15	1,18	3,11	1,22	3,52	1,18	3,95	1,18

4.4.2 Results of students' learning outcomes

Data collected from the tests of knowledge assessment was used to conduct a group difference study. An analysis of each one of the three VET institutes was conducted and the results are described in the following sub-sections. The Kolmogorov-Smirnov and the Shapiro-Wilk test for normality were also conducted to identify if data of each VET institute have been drawn from a normal distribution. This section presents the results of the statistical analysis applied for data analysis and section 4.5 presents a detailed discussion of these results.

Results of the testing scenario in the Institute 1

The results of the normality test confirmed that data followed a normal distribution. Then, a parametric independent samples t-test was conducted on the scores. Participants in the control group obtained slightly better scores (M=45.34, SD=10.89) than those in the experimental group (M=42.56, SD=11.25). The difference between means was not significant, $t(41)=0.806$, $p>0.05$, two-tailed.

This result means that the null hypothesis cannot be rejected, so it seems that there is no difference between the students that use the Paint-cAR application and those who did not use it in terms of learning outcomes in the Institute 1.

Results of the testing scenario in the Institute 2

The results of the normality test confirmed that the data followed a normal distribution. Then, a parametric independent samples t-test was conducted on the scores. Participants in the control group obtained lower scores (M=42.10, SD=8.4) than those in the experimental group (M=47.36, SD=16.7). This means that students who used the Paint-cAR application obtained better scores than those who did not use it. However, the difference between the means was not significant, $t(11)= -0.693$, $p>0.05$, two tailed.

The results show that the students in the experimental group (those who used the Paint-cAR application) got better results than those in the control group in terms of learning outcomes. However, this result is not significant to reject the null hypothesis and this means that the groups do not seem to be different.

Results of the testing scenario in the Institute 3

The results of the normality test confirmed that the data followed a normal distribution. Then, a parametric independent samples t-test was conducted on the scores. Participants in the control group obtained lower scores (M=41.66, SD=30.4) than those in the experimental group (M=59.39, SD=17.1). But, the difference between means was not significant, $t(11)=1.32$, $p>0.05$, two-tailed.

The results show that the students in the experimental group (those who used the Paint-cAR application) got better scores than those who did not use it as it can be seen by comparing the mean of each group. However, the test was not significant and the null hypothesis cannot be rejected showing that the difference between the means is not enough to assert that the two groups are different in terms of learning outcomes.

Figure 4-14 shows the comparison in terms of students' learning outcomes for the three VET institutes that participated in this part of the study. Institute 4 did not participate in this part of the study because the four students were assigned to the experimental group and there was no control group in this institute to compare the learning outcomes. As it can be seen in **Figure 4-14**, the results of student learning outcomes range from 0 to 100.

However, the results obtained in the Institute 1, Institute 2 and the control group of the Institute 3 did not reach 50 out of 100. This means that students' learning outcomes are not good either in the control or the experimental groups. At first sight, this was a concern for us, but when we analysed the results with the teachers they told us that these are normal results at this level. This means that students do not usually obtain high grades and teachers stated that this a general concern in VET programmes of Car's Maintenance in which we conducted our research because some of the students do not have the background needed and their learning outcomes are not good. Some of the teachers pointed out that some of the students that enroll in VET programmes have dropped out of the school because of low learning performance and this is one of the causes of low grades in VET programmes.

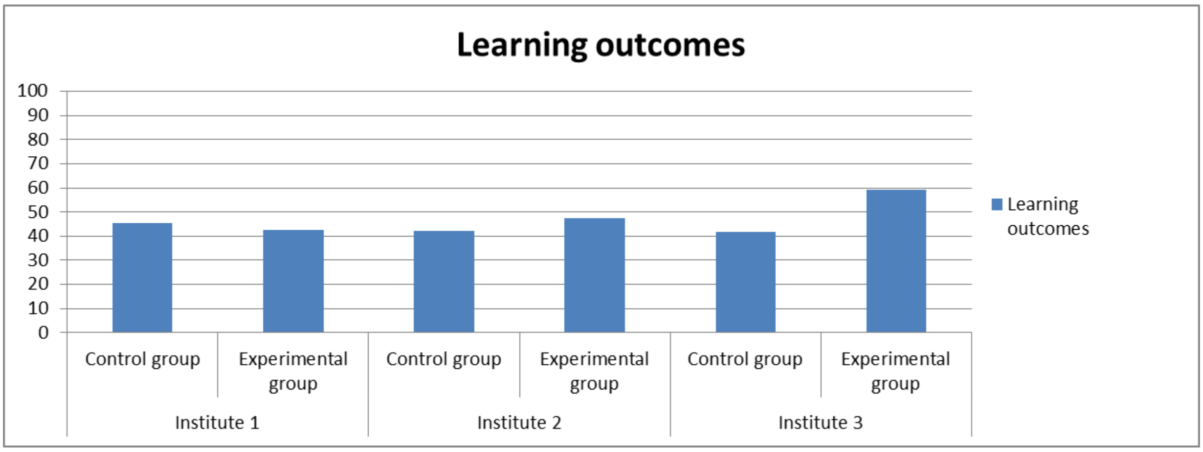

Figure 4-14. Learning outcomes comparison for the institutes 1, 2 and 3.

So far the results of students' learning outcomes show a small difference between the control and experimental groups. However, in Institute 2 and Institute 3 the learning outcomes are higher for the experimental group in both institutes than the learning outcomes in the control group. Thus, we selected one of these two institutes to conduct an extended validation to explore if an extension in the time using the application will benefit students' learning outcomes. Institute 3 was selected for this extended validation due to the following reasons:

- The teacher in this institute participated in the co-creation process of the Paint-cAR application and was eager to participate in the extended validation.
- The institute was located in Girona (near to the University of Girona) and it was easier to follow the extended validation (the other institutes were located in Barcelona and near towns).
- Students from this institute outperformed students from other VET institutes in terms of the number of activities completed in less time and with fewer errors using the Paint-cAR application.

The extended validation lasted for four additional weeks and the procedure was depicted in section 4.3.3.

Results of the extended validation

A comparison between the scores of the first test of knowledge (applied at the beginning of the extended validation) and the second test of knowledge (applied at the end of the extended validation) was made in order to determine if an increase in the time using the Paint-cAR application would change students' learning outcomes. In this regard, first the normality test was applied to identify if data was drawn from a normal distribution. The results of the normality test confirmed that the data followed a normal distribution.

Then, a parametric paired sample t-test was conducted on the scores. As a result, all participants (from the control and experimental groups) obtained better results at the end of the extended validation. With respect to the control group, the mean of scores at the beginning of the extended validation was: M=62.28, SD=25.55 and the mean of scores at the end of the extended validation was: M=75.43, SD=17.12. It is worth noting that the scores at the end of the extended validation is considerably higher than the mean at the beginning of the extended validation. However, the difference between the means was not statistically significant, $t(2)=-1.25, p>0{,}05$, two-tailed. With respect to the experimental group, the mean of scores at the beginning of the extended validation was: M=59.39, SD=17.17 and the mean of scores at the end of the extended validation was: M=62.40, SD=25.7. The difference between the means was not significant, $t(6)=-0.563, p>0.05$, two-tailed.

Together these results show that both groups (control and experimental) obtained better results at the end of the extended validation. Then, a comparison between the results of the control and experimental group at the end of the extended validation (a between-subjects comparison) was carried out to determine differences between the groups at the end of the extended validation. The results show that participants in the control group obtained better results (M=75.43, SD=17.12) than those in the experimental group (M=62.40, SD=25.77). The difference between the means was not significant, $t(8)=0{,}452$, $p>0{,}05$, two-tailed.

For each one of the four sessions of using the Paint-cAR application in Guided Mode, researchers and the teacher were present to observe students' behaviour and progress with the use of the application. The progress made by the students after each session was evident. In the four sessions almost all students completed the 14 steps of the Guided Mode during the time provided in class. In the previous sessions using the application, students had only completed part of the process and it took more time for them to complete it. By analysing the responses to the self-assessment tests in the Paint-cAR application, an improvement was evident after each session because students approved more tests with fewer errors.

As for the session using the Paint-cAR application in Evaluation Mode, there was a remarkable improvement of students in this testing. The reason may be that they had used the application in Guided Mode for 4 sessions before the testing in the Evaluation Mode. The student that completed the whole process (first and second phase of the process) more quickly than the others, completed the process in 40 minutes. The average time for completing the whole process in the extended validation was of 64 minutes. This result shows an improvement if we compare this time with the average time that students from the other institutes usually spend for completing the process which is of 100 minutes.

4.4.3 Results of students' learning outcomes in the puzzle

The puzzle activity was part of the Evaluation Mode in the Paint-cAR application. Since students need to learn to identify the correct order of phases and steps in the process, a further analysis of the work done by students in this activity was conducted by applying sequence analysis. This method was selected because the order of the phases in the process and the order of steps for each phase can be represented by a sequence of numbers. This sequence can be compared to the ideal sequence (the correct order of phases and steps) by applying metrics that have been defined in the field of sequence analysis. For this analysis, we used TraMineR (M. Studer, Ritschard, Gabadinho, & Muller, 2011), a library developed in the University of Geneva for sequence analysis with the statistical software R.

The bubble graphic in Figure 4-15 and Figure 4-16 show (in blue) the quantity of sequences organized by students in terms of the Optimal Matching (OM) metric and the Overlap metric. Figure 4-15, corresponds to data collected during the first testing in workshop in evaluation mode. We call this testing as the First Moment. On the one hand, in this First Moment 24 out of 35 students used the puzzle activity and these data are presented in Figure 4-15. On the other hand, Figure 4-16 corresponds to data collected during the second testing in the workshop in evaluation mode. We call the second testing in the workshop as the Second Moment. In this Second Moment 16 out of 35 students used the puzzle activity and these data are presented in Figure 4-16.

The OM metric is based on the concept of edit distance. This means that this metric measures the minimum cost of transforming a particular sequence into the ideal sequence (Matthias Studer & Ritschard, 2014). In this context this metric measures how different is the sequence organized by the students with respect to the ideal sequence. Besides that, the Overlap metric measures the quantity of sub-sequences that students organized no matter if the sub-sequences are in the correct position or not. We used the Overlap metric because for teachers was important to know if students identify some sub-sequences of the whole sequence because it means that they have some basic ideas about the order of the ideal sequence.

The X axis shows the OM similarity and the Y axis shows the Overlap similarity. Both of them range from 0 to 1 where 1 means that the sequence is equal to the ideal sequence. The bubbles in pink color show the theoretical data. These data correspond to the 720 possible sequences, which are all possible combinations without repetition of the six phases of the process that the students can organize in the puzzle activity in the Paint-cAR application. As it can be seen in Figure 4-15 and Figure 4-16, most of the theoretical data is concentrated between 0 and 0,5 in the OM similarity and between 0 and 0,5 in the Overlap similarity. This means that the probability of getting a sequence by trial and error is higher in this region. We will name it as the Region of High Probability and the rest of the region (between 0,5 and 1 in both axes) we will name it as the Region of Low Probability.

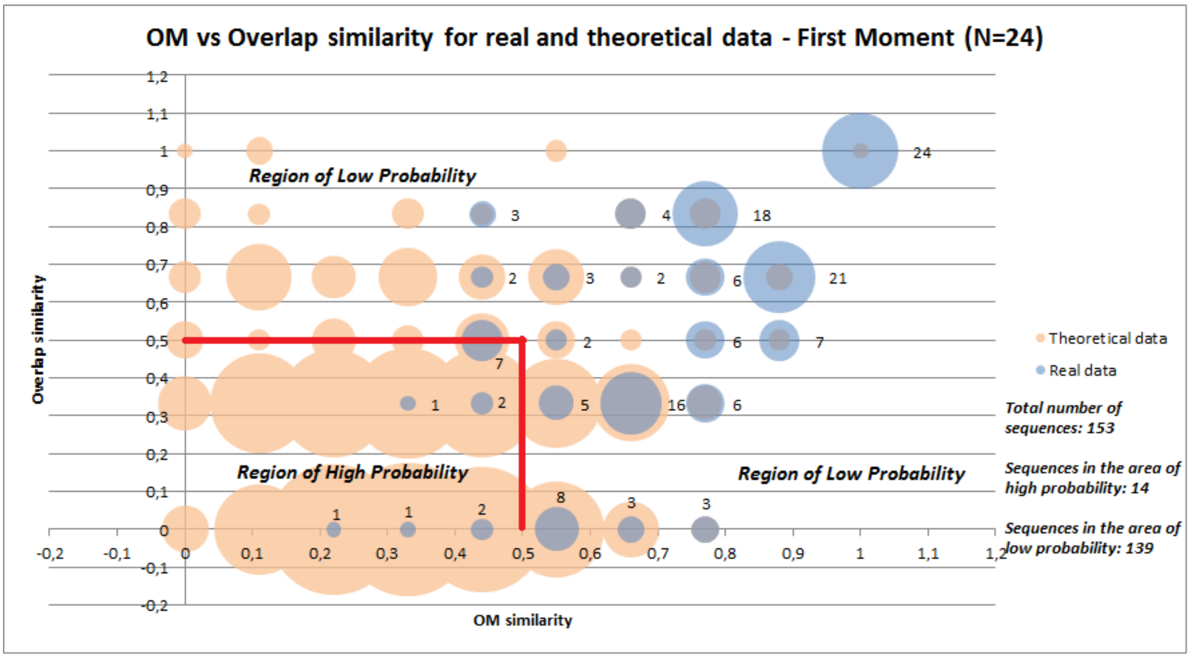

Figure 4-15. Optimal Matching similarity Vs Overlap similarity metrics for theoretical data and real data for moment 1.

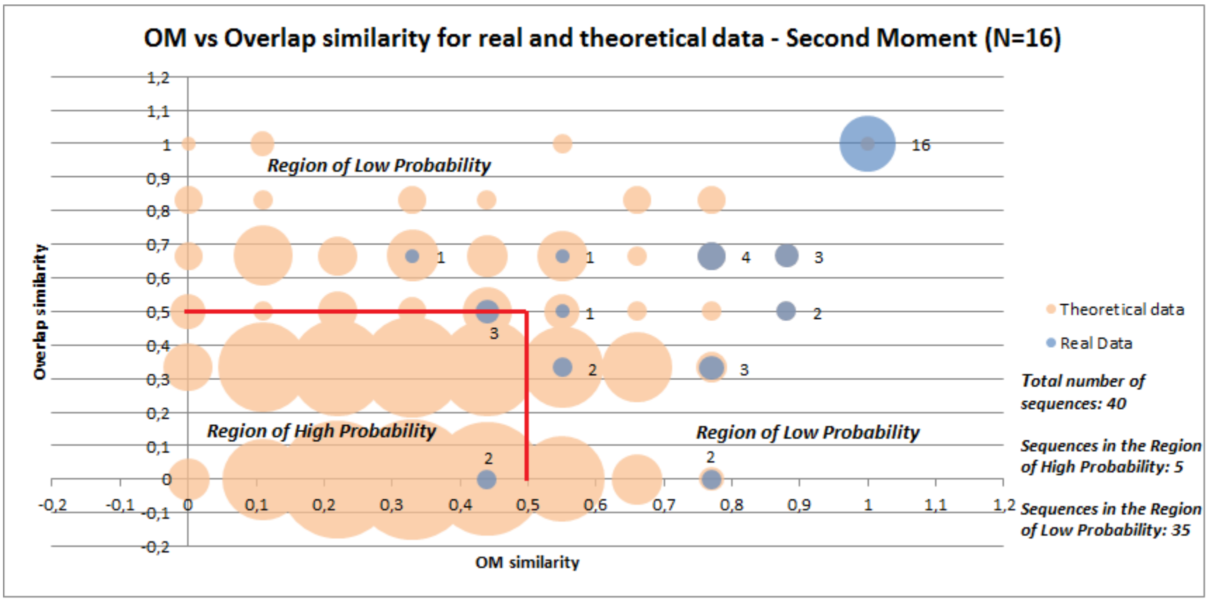

Figure 4-16. Optimal Matching similarity Vs Overlap similarity metrics for theoretical data and real data for moment 2.

By analyzing both figures we can identify some details. On the one hand, in Figure 4-15, 14 out of 153 sequences organized by the students are located in the Region of High Probability and in Figure 4-16 only 5 of the sequences are inside the Region of High Probability. This reflects some sort of effort that students make in order to be as closer as possible to the ideal sequence and it means that students are not doing the exercise only by trial and error. On the other hand, the quantity of sequences in the Second Moment (40 sequences) of the experiment (Figure 4-16) is lower than the number of sequences in the First Moment (153 sequences) because students arrived to the ideal sequence more quickly. It is important to note that the Second Moment of the experiment was carried out one week after the First Moment. Between the First Moment and the Second Moment of the experiment students were able to use the application at any time and the results may suggest that students practiced with the application at home or they were able to remember the correct order of phases in the process even after one week.

In both figures, most of the sequences are located in the region (OM Similarity > 0,5 and Overlap Similarity > 0,5). It means that in terms of the OM similarity, most of the sequences are at least 50% similar to the ideal sequence and in terms of the Overlap similarity the sequences contain at least one sub-sequence with 3 or more elements in the correct order with respect to in the ideal sequence. This is a positive result because it shows that most of the students had some clues about the correct order of the ideal sequence after using the Paint-cAR application in the Guided Mode.

In terms of the improvement in the skill for organizing the sequences, Figure 4-15, which corresponds to the First Moment, shows that only 24 out of 153 (15,6%) of the sequences organized by the students correspond to the ideal sequence (sequences in the coordinate (1,1)). In contrast, Figure 4-16, which corresponds to the Second Moment, shows that 16 out of 40 (40%) of the sequences organized by the students correspond to the ideal sequence. In other words, for the First Moment of the test, the percentage of sequences that did not correspond to the ideal sequence was 84,4% and in the Second Moment of the test, the percentage of sequences that did not correspond to the ideal sequence was 60% which means that the sequences that students created in the Second Moment were closer to the ideal sequences than in the First Moment. Besides that, it is important to note that the number of sequences in the Second Moment (40 in total) is less than the number of sequences in the First Moment (153). This means that despite the number of students, students reached the ideal sequence in fewer trials in the Second Moment than in the First Moment. These results provide insights into the ability developed by students with the use of the Paint-cAR application.

However, if we analyze the Overlap similarity separated from the OM similarity in both figures, the number of sequences with an OM similarity > 0,5 (134 sequences in Figure 4-15 and 34 sequences in Figure 4-16) is greater than the number of sequences with an Overlap similarity > 0,5 respectively (83 in Figure 4-15 and 25 in Figure 4-16). This means that in both moments of the experiment, students tend to organize the sequences considering that the elements of the sequence should be located at the correct position (getting a better result in the OM similarity) rather than forming sub-sequences of the ideal sequence in other positions different from the correct one (getting small values for the Overlap similarity). In terms of the knowledge acquired by the students this means that by using the Guided Mode, they learned the correct order of the elements in the sequence rather than learning only sporadic sub-sequences of the ideal sequence. This confirms the findings reported before regarding the fact that students made an effort to organize the sequences in the correct order.

Another important observation is that the proportion of sequences with an Overlap < 0,5 change from 46% in the First Moment (19 sequences) to 38% (6 sequences) in the Second Moment which is a reduction of 8% in the number of sequences with lower values for the Overlap similarity. This means that students tend to organize more sequences with correct sub-sequences in the Second Moment of the experiment. These results may suggest an improvement in the skill of students for organizing the phases of the process in the correct order.

4.5 DISCUSSION

This section presents a discussion of the results regarding student motivation and student learning outcomes presented in section 4.4. To have a better understanding of the institutes that participated in the first and second exploratory studies and in the extended validation, Table 4-5 shows the institutes that participated in the first and second exploratory studies and in the extended validation.

Table 4-5. Institutes that participated in the first and second exploratory study and extended validation.

Institute	First Exploratory Study	Second Exploratory Study		Extended Validation	
	Student Motivation	Student Motivation	Students' Learning Outcomes	Student Motivation	Students' Learning Outcomes
Institute 1		X	X		
Institute 2		X	X		
Institute 3	X*	X	X		X
Institute 4		X			

* Students that participated in the first exploratory study (Institute 3) were students enrolled in the course 2014-2015 but students that participated in the second exploratory study and extended validation were students enrolled in the course 2015-2016.

4.5.1 Regarding the results of student motivation

Overall, the results of students' motivation are promising in the four VET institutes. The scores for the four dimensions of motivation are above 3 in a scale from 1 to 5. It is important to note that the results of student motivation in this study are lower than the results obtained in the first exploratory study (see CHAPTER 3). This result may be explained by the Hawthorne effect or "novelty effect" (Looi et al., 2009), which is commonly associated to the level of engagement created by AR applications when these applications are used for the first time in class. The "novelty effect" is an increase in the interest and attention as a result of the introduction of AR as a new technology that provides new experiences that are different from other existing technologies. However, the interest and attention decreases as the time increases. This effect has been reported in studies that involve the use of AR applications in education (Westerfield, Mitrovic, & Billinghurst, 2015; Kyungwon Gil, Jimin Rhim, Ha, Young Yim Doh, & Woo, 2014; Bai, Blackwell, & Coulouris, 2013; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014; Li, Chen, Whittinghill, & Vorvoreanu, 2014; Bressler & Bodzin, 2013; Westerfield, Mitrovic, & Billinghurst, 2013). The results of student motivation (by comparing the first study and the second study) show that the novelty effect might have diminished students' levels of motivation in our second study. Similar results have been obtained by other researchers such as Li et al., (2014) and Kyungwon Gil et al., (2014).

Nevertheless, the results show that despite the novelty effect, students' levels of motivation were not severely affected because at the end of this study students' levels of motivation are still high. This means that the content of the Paint-cAR application and its design were able to sustain students' engagement until the end of the learning experience. This is in line with the recommendations of Kourouthanassis, Boletsis, Bardaki, & Chasanidou (2015) to face the consequences of the novelty effect. It is worth noting that the design of the Paint-cAR application is also aligned with the UDL guidelines for addressing students' needs and preferences. Thus, by incorporating mechanisms to address students' needs and preferences in the design of a mobile AR application, it is possible to sustain students' motivation.

For all institutes the *attention* dimension rated higher than the other three dimensions (see section 4.4.1). This suggests that the Paint-cAR application capture students' interest and curiosity and that the Paint-cAR application seems to be engaging after students used it for around 20 days.

The results of students' motivation in the Institute 1 are lower than the other three institutes. This result may be explained by the conditions of this institute in terms of the Wi-Fi network infrastructure. Since the Paint-cAR application relies on the internet connection to send and retrieve information for the multiple-choice questionnaires, the internet connection needs to be good to avoid delays in the self-assessment activity. Due to the problems with the internet connection in this institute, some of the students were disengaged because they could not complete the activities that required internet connection as they expected and this feeling was reflected on their levels of motivation. A solution to the issue in the internet connection was to share internet by using the 3G standard mobile network but the geographical location of the institute did not allow to have good 3G signal so it did not help. However, students tried to complete the activities that did not require internet connection. *Attention* dimension (rated 3,16) and *Relevance* dimension (rated 3,20) rated better than the other two but the difference with the other two dimensions was not high.

In contrast to Institute 1, Institute 2 had a better Wi-Fi network infrastructure and students could complete all the activities without any problem. In this institute (Institute 2), *attention* dimension (rated 3,55) and *confidence* dimension (rated 3,49) rated better than the other two. This means that the Paint-cAR application captured students' attention and students perceived that they could succeed in the activities and control their success. These results may be explained by the design of the Paint-cAR application because the application included a scaffolding mechanism to help students to succeed at challenging tasks and a real-time feedback mechanism to reinforce students' accomplishments. These components seem to support student motivation but further research is needed to confirm this claim. Moreover, *relevance* dimension (rated 3,22) and *satisfaction* dimension (rated 3,11) rated lower than the other two dimensions. This result may be explained by the fact that in this institute students did not have all the products and tools that the application recognizes. Some of the AR markers had to be stuck to the wall to simulate certain products and this created an unreal experience because students were not in contact with the real tools and products. This might have created negative perceptions with respect to the learning experience.

For Institute 3, *attention* dimension (rated 3,64) and *confidence* dimension (rated 3,62) rated better than the other two. Besides, the *relevance* dimension (rated 3,46) had the lower score which might indicate that the content should be revised so that it can be perceived by the students as important. As for the *satisfaction* dimension (rated 3,52), the results show that students were satisfied with the application. According to Keller (2010) *satisfaction* dimension refers to the perceived opportunities for using the knowledge in experiential learning activities. Thus, the Paint-cAR application seems to provide these opportunities even after a longer period of time using the application.

Finally, Institute 4 had the best results in terms of student motivation. Students that participated in this learning experience were really engaged with the Paint-cAR application but the results may be higher than the other institutes because of the small research sample in this institute. *Attention* dimension (rated 3,97) and *satisfaction* dimension (rated 3,95) rated better than the other two although the difference with respect to the other two dimensions is not high. The results show that students perceived that the application helped them to maintain their attention and interest in the learning activity. Besides that, students reported to be satisfied with the Paint-cAR application and the learning activity in general. *Relevance* dimension (rated 3,80) and *confidence* dimension (rated 3,75), although lower than the other two, rated high in general and show that students felt self-confident when completing the learning activity with the Paint-cAR application and perceived the content to be relevant for their learning process and personal interests.

In general, these results show a good perception of students in terms of motivation with respect to the use of the Paint-cAR application for learning. An important observation here is that all dimensions rated more or less at the same level (i.e. there are no extreme variations between the four dimensions of motivation). This means that the Paint-cAR application supported all dimensions of motivation at the same level and did not favoured any specific dimension. Our results are aligned with the findings of other researchers such as Y. Chen (2013), C.-H. Chen, Chou, & Huang (2016), Chiang, Yang, & Hwang (2014), Chin et al. (2015) in terms of the positive effect that AR has on students' motivation in a learning experience.

4.5.2 Regarding the results of students' learning outcomes

A quick overview of the results may suggest that there is no difference between the students that used the Paint-cAR application and those who did not. However, (Anastassova & Burkhardt, 2009) claim that Automotive Service Technicians (AST) training cannot be considered a well-structured, closed and fully working learning system. Therefore, the research on this topic cannot be studied in strictly controlled experiments but instead a description on how this open learning system works and how the formal and informal learning process occur in this context are needed (Anastassova & Burkhardt, 2009).

By drawing on this assumption, we argue that the analysis of the results of students' learning outcomes in the VET institutes must consider the conditions of each VET institute in terms of infrastructure, materials for learning, teachers and the diversity of students to provide insights that drawn on empirical studies with respect to the use of AR technology in VET education.

In terms of the learning outcomes, the results obtained in the Institute 1 seem to show no difference between the students' learning outcomes in the control and experimental groups. In this institute, there were two groups of students, one that took classes in the morning and the other that took classes in the afternoon. For logistic reasons, the teachers decided that the group in the morning would be the control group and the group in the afternoon would be the experimental group. However, it seems that the group in the morning (control group) had students with a better background knowledge than those in the afternoon (experimental group). This was the result of an internal selection of students that the institute made at the beginning of the course and the students with better background knowledge were in the group that took classes in the morning. It is worth noting that the standard deviation in the results of the control group (SD=10,89) and the experimental group (SD=11,25) are high which shows a high variability in the results obtained by students in terms of the learning outcomes. However, teachers of this institute stated that these results are normal.

In terms of the infrastructure, Institute 1 has two workshops with enough space and enough materials for students to practice the real process of repairing paint on a car. However, one of the disadvantages during the testing was that the students who finished the testing with the Paint-cAR application started to work with real materials in the workshop and the students who were still working with the application felt that they missed real practice because they were using the application and they felt discouraged. Another limitation in the Institute 1 was that the students did not have access to the Wi-Fi and they had to use their 3G and 4G connections. However, the 3G and 4G signals are very low and sometimes cannot be used. Since the application uses internet connection to send and retrieve data from the servers, some students felt upset because sometimes they could not use the application.

With respect to the type of students, in Institute 1, for some of the students Catalan is not their first language. Some of them are not proficient enough in this language despite of the fact that most of the training is done in this language because it is the official language of teaching in Catalonia. Although the user interfaces were developed in Spanish, the multiple-choice questions and the learning content for each step in the process was developed in Catalan language as the official language of teaching. For some of these students, it was difficult to understand the contents and answer the multiple-choice questions due to some difficulties with some vocabulary. This suggests that AR applications should be designed in a way that can support multiple languages spoken by the students or at least provide a mechanism for them to understand the contents.

The results of the Institute 2 show that students in the experimental group (M=47.36) obtained better results than those who did not use the application (M=42.10). In this institute, the assignation of the students to the control and experimental groups was random. Despite the fact that the difference between the score means of the control and experimental groups was not significant, it is worth noting that the use of the application seems to somehow help students to get better results. In terms of the standard deviation, the results show that there was a high variability in the results of the students in the experimental group (SD=16.7) compared to the standard deviation of the results of students in the control group (SD=8.4). This result might show that some of the students are having better results than others in the experimental group and for that reason the standard deviation is high.

In Institute 2, the infrastructure is small for learning this topic and the students do not have enough materials. The consequence of these conditions was that some of the markers that are recognized by the Paint-cAR application had to be stuck in places that simulate the products and tools. However, in this kind of environments, AR offers the opportunity to interact with virtual materials without the need of using real materials, which reduces costs as stated by Emmanouilidis, Papathanassiou, Pistofidis, & Labib (2010). Another limitation in this testing was the internet connection because the students did not have access to the Wi-Fi, so they needed to use the 3G and 4G connections.

Notwithstanding the conditions in the Institute 2, once the students started working in the application, they got engaged in the activities and they made an effort to complete the process as required by the teacher. This is in-line with the findings in other studies that recognize the benefits of AR for increasing attention, motivation and engagement (Dunleavy, Dede, & Mitchell, 2009; Di Serio et al. (2013); Furió, González-Gancedo, Juan, Seguí, & Rando (2013); Chang et al. (2014); Kamarainen et al., (2013).

Taking into account that the students almost never used the application at home, they did not have enough background knowledge to complete the process in the Evaluation Mode during the testing in the workshop. Therefore, they felt disengaged because they could not advance in the process. When students had to use the application at home, they did not use it. They claimed that they did not have time or they forgot it. The teachers shared their opinions about this and they claim that it is very difficult to motivate students at this level and it is always needed to tell them what to do and how to do it. Otherwise they are not going to do it by themselves.

We recommend that future learning scenarios that include AR applications should encourage students to use the AR application at home, or more time in class should be provided so that the students can use the application for learning.

Surprisingly, in Institute 2, some of the students who were not using the application (because they were in the control group) showed their interest in the application and they tried to help their classmates to complete the activities. Another relevant observation made during the testing was the fact that although the students were advised to pay special attention to the information in the Guided Mode so that they could complete the Evaluation Mode, some of the students still depended a lot on the help and assistance provided by the application in order to complete the task in the Evaluation Mode. This suggests that an important recommendation in the design of AR applications for supporting learning outcomes is to include a scaffolding mechanism to assist students in completing the tasks. This is in-line with findings in other studies that remark the importance of using a scaffolding strategy in AR applications (Tsai & Huang, 2014; Yoon, Elinich, Wang, Steinmeier, & Tucker (2012); Singh et al., 2014).

On the other hand, the results in the Institute 3 show that the students in the experimental group (M=59.39) outperformed students in the control group (M=41.66). However, the difference between the means was not statistically significant. In this institute, some of the students in the experimental group had used the Paint-cAR application before the first testing in workshop (as recommended by the teacher in the first session of introduction and installation of the application), and during the testing those students showed a better learning outcomes than those who had not used the application before. By analyzing the standar deviation, it can be seen that there is high variability in the results of the control group (SD=30.4) and as such the standard deviation is very high. This is indeed, the higher standard deviation obtained in the results of learning outcomes. In the experimental group the standard deviation is also high (SD=17.1) but is lower than the standard deviation in the control group. By talking with the teacher in this institute, he concluded that two of the students who were in the control group are very good students and always obtain remarkable grades and for that reason the results show this variability.

From the observation of the testing, the teacher concluded that most of the students focused on the virtual information more than on the real objects they were exploring. This confirms one of the disadvantages of AR applications that is about paying too much attention to the virtual information as reported in previous studies (Chang et al., 2014; Chao et al., 2014). This suggests the need of a correct balance between virtual and real information in the AR applications so that students pay attention to real and virtual objects at the same time to achieve the link between virtual and real information.

Another issue identified during the testing is that the workshop in this institute sometimes has light conditions that are not optimal for an AR learning experience. The result was that some students had problems when trying to scan the markers. This led to disengagement in the task because the students felt that they could not use the application properly. This is a disadvantage of AR that has been reported in previous studies (Di Serio et al., 2013) (Ibáñez et al., 2014). We recommend that the use of AR applications in this type of contexts should take into account that light conditions in the workshops need to be optimal to create a successful AR learning experience. Besides that, the students were confused at the beginning because they did not know if the marker was not correct or the camera was not recognizing the AR marker.

Another disadvantage was that sometimes students felt that they were competing with their classmates. The result of this situation was that they just tried to complete the task faster than their classmates and they did not focus on the information provided by the application. This may have led to negative or poor learning outcomes. We recommend that future studies should have more control over student's activity and teachers will need to control future AR learning experiences in this regard.

In contrast to the other VET institutes, the internet connection in this institute was very good. This facilitated the AR learning experience. In terms of using the application at home, most of them used it because the teacher continuously reminded them to use the application at home. Consequently, it was evident in their learning outcomes in the test carried out in the workshop and they outperformed students from other VET institutes in terms of the number of activities completed in less time and with fewer errors. For this reason, the extended validation was conducted in this VET institute in order to determine if an increased exposure to use of the Paint-cAR application may improve the students' learning outcomes. The results of the extended validation are discussed in section 4.5.3.

In terms of the activity of the puzzle for organizing the phases of the process, the results showed an improvement in terms of students' learning outcomes when we compared the first and the second testing in the workshop in Evaluation Mode. In general, the analysis allowed to see that students organized the phases and steps according to their knowledge and not just by trial and error. The results also showed a tendency of students to organize the phases and steps in the correct order or at least to obtain sub-sequences that were very close to the ideal sequence.

4.5.3 Regarding the extended validation

In terms of students' learning outcomes as highlighted in the results (sub-section), the difference between the means of the control and the experimental group was not statistically significant. However, both of the groups improved their learning outcomes after the extended validation. In particular, the students who used the Paint-cAR application showed remarkably better results in the three additional tests in the workshop using the Paint-cAR application carried out during the extended validation. By analyzing the responses to the self-evaluation tests, an improvement was evident after each session because the students completed more tests with fewer errors. This means that the students had improved their knowledge after each session.

As a conclusion of this extended validation, the teacher from the Institute 3 highlighted that the AR learning experience with the Paint-cAR application should be complementary to the traditional class and a tool that the students should use for practicing at home. The teacher recognized the importance of the application as a complementaty material for the class in which sudents can get used to using the tools and products that they will use in the class but using the Paint-cAR application with virtual tools and products before going to a real scenario in which they will need to use the real products and tools. This is indeed a cost-effective solution to save resources because students can practice with the virtual products until they reach mastery to use the real products and tools. With respect to the cost-effectiveness, Anastassova & Burkhardt, (2009) highlight that the cost-effectiveness is a requirement for the development of future applications for teaching to Automotive Service Technicians (AST).

It is important to note that the scores obtained by the students ranged from 40 to 75 out of 100. One may think that these results are very low for a test of knowledge assessment. However, the teachers from the VET institutes claimed that the results are as expected because this is the average score for students at this level and in this particular VET programme. When we analyzed, together with teachers, the results of the test of knowledge assessment, teachers pointed out that poor grades are very common at this level. Students often face many difficulties in the learning process and teachers are challenged by a wide diversity of students in terms of background, needs, preferences and interests.

Overall, these results provide insights into the students' learning outcomes in AR learning experiences in the process of repairing paint on a car.

4.6 CONCLUSIONS

In this chapter, we described a second iteration of the co-creation methodology. The aim of the second iteration was to improve the design of the Paint-cAR application to overcome some issues identified as part of the first exploratory study (described in CHAPTER 3). The Paint-cAR application was designed and developed with the following main modules: a Scaffolding module, a Real-time feedback module, an Assessment Module, the AR module and a Module for watching videos.

We analyzed the impact of the Paint-cAR application on students' motivation and students' learning outcomes when they used the Paint-cAR application for a longer period of time (20 days) to overcome the issue of the "novelty effect" or Hawthorne effect (Looi et al., 2009).

This study allowed us to confirm that the Paint-cAR application creates positive perceptions in terms of motivation when this application is used as a support for the learning process. The results showed that the application positively affected the four dimensions of the ARCS model of motivation. We also confirmed that the levels of motivation continue to be high even after 20 days using the Paint-cAR application which means that the application engage students even after the novelty effect wear off. Thus, we conclude that AR applications should be designed in a way that engages students even after the novelty effect disappears. One of the main contributions of this study is that we conducted an exploratory study for an extended period of time as recommended by other researchers (Di Serio et al., 2013; Chin et al., 2015; Akçayır & Akçayır, 2017) to explore the real effect of AR on students' motivation after the novelty effect disappears.

Although we confirmed that the improved version of the Paint-cAR application supported students' motivation for a longer period of time, we still cannot conclude which are the specificcomponents or modules of the Paint-cAR application that positively impact on students' and how these aspects or features impact on student motivation. For this reason, a further analysis is needed to provide answers to these questions. This open issue lead us to the next phase of this thesis (CHAPTER 5) in which we identified the factors and features of AR (predictors) that positively affect motivation.

This study also allowed us to recognize the complexity of VET education in terms of students' learning outcomes. Not only the results, but the observations of the different tests in the four VET institutes provided an overview of the complexity of the educational processes at this level of education in terms of students' variability. This study also provided insights into the implications of using a mobile AR application (the Paint-cAR application) in terms of students' motivation and students' learning outcomes. In particular we identified that the Paint-cAR application can support the four dimensions of motivation and address, up to some extent, students' variability in terms of motivation at this level thanks to the design based on the UDL and the motivational design. Moreover, we identified that it is important to encourage students to use the AR application and for that purpose a system for providing notifications to students can be an option.

In terms of students' learning outcomes, the results showed that students in the experimental group tend to have better results than those in the control group. However, as mentioned earlier, learning processes in VET education are quite complex due to the wide diversity of students. Therefore, the results are not conclusive and further research is also needed to identify the real affordances of AR in VET education for students' learning outcomes. As a result of this analysis, in this thesis we did not focus on studying the effect of AR on students' learning outcomes but instead we focused on studying the effect of AR on students' motivation.

These results provided insights for addressing the first research question of this thesis: "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?". Besides, this study together with the first exploratory study described in CHAPTER 3 addressed the second specific objective of this thesis: "**SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education". Moreover, these results provide insights to tackle the second and fourth open issues identified in the literature respectively: "**OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences" and "**OI4:** There is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education".

4.7 PUBLICATIONS ASSOCIATED TO THIS STUDY

It is worth noting that we participated in the 2nd e-Learning excellence Awards held as part of the 15th European Conference on e-Learning (ECEL 2016) (Prague – Czech Republic) and we were awarded with the 3rd best e-Learning initiative in the competition among 50 initiatives from 24 countries. In the competition we participated with the Paint-cAR application as an e-Learning initiative in VET education. Our e-Learning initiative was published as a book chapter in the following book:

Bacca, J., Baldiris, S., Fabregat, R., Kinshuk, & Clopés, J. (2016). **Augmented Reality in Vocational Education and Training: The Paint-cAR application**. In D. Remenyi (Ed.), e-Learning Excellence Awards – An Anthology of Case Stories. Reading: Academic Conferences and Publishing International. http://www.academic-bookshop.com/ourshop/prod_5381189-eLearning-Excellence-Awards-2016.html

The results of students' learning outcomes were published in the following conference paper.

Bacca, J., Baldiris, S., Fabregat, R., Clopés, J., & Kinshuk. (2016). **Learning Performance with an Augmented Reality application in the Vocational Education and Training programme of Car's Maintenance**. In Proceedings of the VIII International Conference of Adaptive and Accessible Virtual Learning Environment (pp. 90–102). Cartagena de Indias, Colombia: Sello Editorial Tecnológico Comfenalco. Retrieved from http://cava2016.com/wp-content/uploads/2016/10/REAumentados.pdf

PART 3
DEFINITION AND VALIDATION OF THE FRAMEWORK

CHAPTER 5
PREDICTORS OF STUDENT MOTIVATION

5.1 INTRODUCTION

In CHAPTER 3 and CHAPTER 4 we showed how the Paint-cAR application was co-created with teachers in two iterations. Under this co-creation process the following modules were designed and developed: a Scaffolding module, a Real-time feedback module, an Assessment Module, the AR module and a Module for watching videos. Thus, the design of the application is in line with the teachers recommendations to address the educational need identified in the topic of repairing paint on a car in the VET programme of car's maintenance. Moreover, the Paint-cAR application was designed with a Monitoring module that tracked students' interaction with the other modules in the application.

As a result of the first exploratory study (see CHAPTER 3) and the second exploratory study (see CHAPTER 4) we identified that the Paint-cAR application positively affect student motivation. This means that the modules of the Paint-cAR application that were co-created with the teachers might be positively affecting student motivation. However, in the second exploratory study we also concluded that we still do not know how and why these modules affect student motivation. Thus, in this chapter we present a study that sought to determine why and how these modules positively affect student motivation and therefore we sought to determine the predictors of student motivation when students use the Paint-cAR application for learning in an AR learning experience. A predictor is a variable that is used to predict the values of a criterion variable (or dependent variable)(Coolican, 2014). For instance, according to the study by H. Kim & Hyun (2016), usefulness is a predictor of the behavioural intention to use an Information System (IS). This means that the the values of the variable usefulness (the predictor and independent variable) can be used to explain and predict the values of the behavioural intention to use an IS (the predicted variable or dependent variable). Based on this definition of predictors, we sought to determine the variables that may predict the values of student motivation in AR learning experiences. To do that, we need to first identify a group of variables (independent variables) that are related to the AR learning experience and then determine how these variables affect student motivation (the dependent variable).

With the aim of identifying how the modules of the Paint-cAR application affect student motivation, we created a research model based on hypotheses with the variables that were automatically measured by the Monitoring module during the second exploratory study. These variables are associated to each module in the Paint-cAR application and each variable registers the information about students' interaction with the corresponding module. The six variables are: *Use of scaffolding, Real-time feedback, Learning outcomes, Degree of success, Time on-task and Watching videos*. In this study we call this group of variables as the 6-VARLE (6 Variables of an AR Learning Experience).

Then, based on the literature we theoretically defined the relationships of each one of the 6-VARLE with the others and we suggested four hypotheses that may explain these relationships. Moreover, we suggested six hypotheses between the 6-VARLE and the four dimensions of the ARCS model of motivation to determine how these variables affect student motivation. These ten hypotheses were then empirically validated with data obtained from two sources: the interaction of 35 students that used the Paint-cAR application for learning during the second exploratory study (described in CHAPTER 4) and the IMMS instrument as a self-report measure.

We hypothesize that the identification of predictors of student motivation may help to inform the design and development of authentic motivational AR learning experiences for the VET level of education by identifying the modules that positively affect student motivation in AR learning experiences. Thus, the predictors of student motivation are the basis of the framework for the design of motivational AR learning experiences for the VET level of education that is described in CHAPTER 6. It is also important to note that these predictors might not be unique for AR learning experiences but they might be also predictors of student motivation in other learning environments such as web-based learning and others. So there might be other variables that can be predictors. However, in this thesis we only focused on these predictors to contribute to the understanding on how these predictors affect student motivation in AR learning experiences. Other predictors might be identified by including other modules in an AR application.

This CHAPTER therefore describes the results of the first activity in the Hypothetico-deductive and Explanatory Phase (**AHEP1**) of the research methodology followed in this thesis. Moreover, this study addressed the third specific objective of this thesis: "**SO3:** To identify the predictors of student motivation in AR learning experiences.". Furthermore, the results of this study answered the first research question of this thesis: "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?". The main contribution of the results presented in this chapter is the identification of the predictors of student motivation in AR learning experiences which addressed and contributes to tackle the first open issue identified in the literature: "**OI1:** Research studies on AR in education do not clearly define how and why AR increases student motivation.".

The rest of this CHAPTER is organized as follows: Section 5.2 presents the hypotheses development and section 5.3 presents the method followed in this study. Section 5.4 presents the hypotheses testing and results. Section 5.5 presents the validated research models as a result of the hypotheses validation process and finally section 5.6 presents the implications of this study for the design of motivational AR learning experiences. Finally, sections **¡Error! No se ncuentra el origen de la referencia.** describes the limitations of the study conducted, section 5.7 presents some concluding remarks of this chapter and section 5.8 presents the publications associated to this chapter.

5.2 HYPOTHESIS DEVELOPMENT

To identify the predictors of student motivation by following a hypothetico-deductive and explanatory approach according to the research methodology we adopted in this thesis, we needed to first identify the variables to define a research model based on hypotheses that can be empirically validated.

As mentioned before, we identified two groups of variables. The first one is related to the students' interaction with each module in the Paint-cAR application and the second one is related with the dimensions of student motivation according to the ARCS model.

The first group consist on six variables: *Use of scaffolding*, *Real-time feedback*, *Learning outcomes*, *Degree of success*, *Time on-task* and *Watching videos*. We call this group of variables as the 6-VARLE (6 Variables of an AR Learning Experience). The 6-VARLE were automatically measured by the Monitoring module that was integrated into the Paint-cAR application. The Monitoring module automatically registered all the interaction of students with the modules of the Paint-cAR application during the AR learning experience.

The second group of variables variables are the dimensions of student motivation according to the ARCS model: *Attention*, *Relevance*, *Confidence* and *Satisfaction*. These variables are measured using the IMMS instrument.

As mentioned earlier, these variables are not unique in AR learning experiences but they can appear in other learning experiences such as web-based learning. However, the aim of this study was to confirm if these variables can also be predictors of student motivation in AR learning experiences in VET to contribute to the knowledge in this topic.

It is important to note that the information of the 6-VARLE was collected during the 20 days that the intervention lasted. **Table 5-1** shows the modules of the Paint-cAR application and the corresponding variable that was measured by the Monitoring module and a description of each variable. Moreover, a short explanation of the events measured is provided but further details on how these events were measured are provided later in section 5.3.2. Notice that in **Table 5-1** *Learning Outcomes* and *Degree of success* seem to be quite similar. This is because these two variables measure two different dimensions of student achievement as described in tha table and therefore these variables are considered to be independent because they represent two different things.

Table 5-1. Modules of Paint-cAR application and its associated variables measured.

Module in the Paint-cAR application	Variable measured by the Monitoring module (the 6-VARLE)	Description of the variable	Events measured
Scaffolding module	*Use of Scaffolding*	This variable represents the use of the Scaffolding mechanism in the Paint-cAR application during the AR learning experience.	The number of times that each student uses the scaffolding module in the evaluation mode or guided mode during the AR learning experience.
Real-time feedback module	*Real-time feedback*	This variable represents the use of the real-time feedback mechanism when students interact with objects in the AR learning experience.	The number of times that each student read the feedback provided by the application in the AR experience. This event is registered when students do not ignore the message of feedback (close it).
Assessment Module	*Learning outcomes*	This variable represents the results of students when they answer the tests in the Paint-cAR application.	A ratio of the number of test approved and the number of test answered in the application.
AR Module	*Degree of Success*	This variable represents the number of successful activities completed in the AR learning experience. This means when students succeed in selecting the correct product or tool they need to use for each step in the process of repairing paint on a car.	Number of correct products or tools selected in each one of the steps in the process of repairing paint on a car.
	Time on-task	This variable represents the amount of time that students spend in the AR learning experience using the Paint-cAR application.	The amount of time in seconds that students spend on the AR learning experience.
Module for watching Videos	*Watching videos*	This variable represents the use of the module for watching videos in the Paint-cAR application.	The number of times that students watched videos in the application during the AR learning experience.

Once the 6-VARLE were identified as shown in **Table 5-1**, the next step was to identify how each variable was related to the others and how these variables were related to the four dimensions of the ARCS model of motivation to uncover the relationships between these modules and its effects on student motivation.Subsections 5.2.1 and 5.2.2 presents the findings in the literature that might explain the relationships between each one of the 6-VARLE and the other variables. The relationships between these variables are relevant to have an overview on how these variables interact one with each other and therefore determine the effect that one variable may have on the others. This will also help us to understand why and how the interaction of these variables might subsequently affect student motivation (the dimensions of the ARCS model).

Finally, section 5.2.3 presents the findings in the literature that might explain the relationship between the 6-VARLE and the four dimensions of the ARCS model of motivation.

5.2.1 *Use of Scaffolding* and *Real-time feedback*

In this subsection we present the findings in the literature that might explain the relationship between both the *Use of Scaffolding* and *Real-time feedback* and other variables in the 6-VARLE. These relationships will provide us with a better understanding on how the relationships between these variables might subsequently affect student motivation when we explore the relationship between these variables and the four dimensions of the ARCS model of motivation later in section 5.2.3.

Scaffolding is a strategy which assists students by introducing scaffolds to help them to complete a learning activity and has been successfully applied in AR applications to enhance learning outcomes. For instance, Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos (2016) conducted a group difference study in which a scaffolding strategy was incorporated in an AR-based simulation tool to assist students to focus their attention on the learning tasks. They found that students who used the scaffolding strategy had better learning outcomes. Likewise, C.-H. Chen, Chou, & Huang (2016) combined concept maps and AR in a tool called CMAR and found that the use of the system lead to better learning outcomes and increased motivation in the four dimensions of the ARCS model but in particular in the *satisfaction* dimension and *confidence* dimension of motivation as student self-confidence improved. Tsai & Huang (2014) designed the Historical Time Tunnel, a mobile AR application that combines scaffolding in a location-based AR experience to support field trips in the context of local culture courses. The validation results showed that the scaffolding strategy was useful for providing assistance to novice young teachers in the field trips.

Apart from including a scaffolding strategy to support the AR experience, other researchers have indeed considered that AR is by itself a scaffolding strategy for learning. For example in their work Yoon, Elinich, Wang, & Van Schooneveld (2012) and S. Yoon, Anderson, Lin, & Elinich, (2017) concluded that the augmented information is valuable as a scaffold for conceptual understanding in science museums. This view is also supported by Singh et al. (2014) who considered AR as a scaffolding for learning history and facilitate engagement and inquiry learning. Besides that, Yoon, Elinich, Wang, Steinmeier, & Tucker (2012) found that students who were exposed to digital augmentation and scaffolds had increased cognitive abilities for theorizing about a phenomenon studied. As a result the combination of AR and scaffolding strategies increases student's abilities.

Together these studies suggest that there is a positive relationship between the *Use of scaffolding* towards the *Learning outcomes*. This means that the Use of scaffolding might positively affect students' *Learning outcomes*.

Scaffolding has also supported other pedagogical approaches like experiential learning and discovery based learning. For instance, in their work, Yin, Song, Tabata, Ogata, & Hwang (2013) scaffolding and fading strategies were used to support experiential learning in participatory simulations in mobile learning. Researchers found positive attitudes with respect to the scaffolds provided. Likewise, in their study, Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos (2015) designed the AR-SaBEr application with scaffolding strategies for teaching the basic principles of electricity in secondary education and found evidence that the system supports discovery learning.

Other scaffolding strategies in AR have been considered. For example, Chen, Teng, Lee, & Kinshuk (2011) applied the scaffolded questioning strategy to improve student's reading comprehension. Scaffolded questions and additional learning materials were accessed by scanning a QR code during reading activities. The authors concluded that the scaffolding strategy benefits students reading comprehension. Similarly, Huang, Wu, & Chen (2012) applied procedural scaffolding to support collaborative discussions with access to learning materials by scanning QR codes. Authors concluded that procedural scaffolding benefits group's discourse levels and individual learning outcomes.

Toghether these studies have shown the importance of the scaffolding for helping students to succeed in challenging tasks and to increase students' *Learning outcomes* in AR learning experiences. Consequently, the *Use of Scaffolding* might be increasing achievement in the learning activities and therefore there might be a positive relationship between the *Use of Scaffolding* and the students' *Degree of success*. For the purposes of this study the *Degree of success* is one of the 6-VARLE that represent the level at which students succeed in the learning activities in the context of the AR learning experience.

Moreover, these studies have shown the benefits of scaffolding strategies as a support for AR learning experiences. As pointed out by Ibanez, Di-Serio, Villaran-Molina, & Delgado-Kloos (2015), it is important to consider various scaffolding options in AR-based simulators in order to increase the learning effectiveness in students who have low levels of motivation and self-regulated learning. However, very little has been done to determine if the *Use of scaffolding* strategy can be a predictor of students' motivation in mobile AR learning experiences.

Some studies have also demonstrated the usefulness and importance of *Real-time feedback* to increase the user experience and performance in mobile AR experiences. Real-time feedback is part of the 6-VARLE. For instance, Liu, Huot, Diehl, Mackay, & Beaudouin-Lafon (2012) concluded that real-time feedback in mobile AR improves the user experience and task performance. Moreover, "provide feedback about infrastructure's behavior" is one of the design principles for developing mobile AR applications proposed by Kourouthanassis, Boletsis, & Lekakos (2015, p. 1051). The study by Kotranza, Lind, & Lok (2012) introduces an approach for providing real-time feedback of task performance in Mixed Reality environments. Mixed reality is defined as a subclass of VR technologies that combines the real world with virtual worlds (Milgram & Kishino, 1994). Through a case study the researchers confirmed the potential of this approach to guide novice learners to achieve mastery in the context of training cognitive-psychomotor tasks in clinical breast examination. From the perspective of the cognitive psychology, Chao et al., (2014) claims that in the context of performance assessment with AR showing feedback in real-time situations during assessment activities helps to create better impressions with respect to the feedback and helps to incorporate the recommendations for improving the results of the learning tasks.

According to the UDL framework, it is recommended to provide feedback that encourage learners and help them to maintain the perseverance (Meyer et al., 2014). Moreover, the *Real-time feedback* should be informative and oriented toward mastery rather than being a simple indicator of progress. Feedback should emphasize the effort to achieve the objectives.

Together these studies suggest that the *Real-time feedback* might have a positive effect on *Learning outcomes* and *Degree of success*. Based on these findings from the literature the following hypotheses are suggested in which both *Use of scaffolding* and *Real-time feedback* will be considered as independent variables and both *Learning outcomes* and *Degree of success* will be considered as dependent variables:

H_1: Both the *Use of scaffolding* and the *Real-time feedback* have a positive and significant effect on students' *Learning outcomes* in mobile AR learning experiences.

H_2: Both the *Use of scaffolding* and the *Real-time feedback* have a positive and significant effect on students' *Degree of success* in mobile AR learning experiences.

5.2.2 *Time on-task* and *Watching videos*

In this subsection we present the findings in the literature that might explain the relationship between both the *Time on-task* and *Watching videos* with respect to the other variables in the 6-VARLE. These relationships will help us to understand how these variables are related to the others and these relationships will help us to understand how the variables of the 6-VARLE might subsequently affect student motivation.

In the motivational design theory, Keller (2010) argues that one of the challenges in motivational design is the measurement of the factors that have a direct effect on motivation. The author points out that researchers usually use changes in learning outcomes as a dependent variable of motivation effect rather than other direct measures of motivation such as effort, Time on-task or latency of response (Keller, 2010). Thus, for the purposes of this study, we considered *Time on-task* as a direct measure of motivation, exploring its effect on student's motivation in mobile AR experiences and therefore the *Time on-task* variable is also part of the 6-VARLE.

Time on-task is a variable considered in many studies that explore, for example, the relationship between the time spend in e-learning contexts and the grades obtained by students (Margarida Romero & Barberà, 2011), student's achievement (Cerezo, Sánchez-Santillán, Paule-Ruiz, & Núñez, 2016) or to identify student's profiles in MOOC (Massive Open Online Courses) (Romero & Usart, 2014). In their research, Zydney & Grincewicz (2011) found that there is a positive correlation between the time that students spend on a learning activity and their ability to identify multiple perspectives of a problem. According to Kovanović et al. (2015) *Time-on-task* measures have been used as an accurate estimation of student's learning. These findings in the literature suggest that there is a positive effect of *Time on-task* on students' *Learning outcomes*.

Kim & Frick (2011) points out that the learning activities should be in the zone of proximal development so that the activities can be done with the support and guidance of the teacher and other educational resources and should not be repetitive and boring. This emphasizes a connection between *Time on-task* and the Use of Scaffolding because the scaffolding is the support and the mechanism for guidance and support that helps students so that they can achieve in the learning activities. This claim is supported with the findings by Ibanez et al. (2016) who conducted a group difference in which the control group used an AR-based simulation tool with scaffolding and the experimental group used an AR-based simulation tool without the scaffolding. Researchers found that students who used an AR-based simulation tool with a scaffolding strategy based on visual cues spent more time reading the content than students who did not used this type of scaffolding mechanism. However, they found that there was not a statistical difference in terms of the time students spent doing the simulations in both cases using the tool. These findings in the literature suggest that the *Use of scaffolding* might have a positive effect on students' *Time on-task*. These studies also highlight the importance of studying the factors that may increase time-on task behaviours when using AR applications for learning.

As for the *Real-time feedback*, Stark, Kopp, & Fisher (2008) the researchers found that students who learned with elaborated feedback worked significantly more time (higher time on-task) than students who worked in other conditions. Moreover, as mentioned earlier, the UDL guidelines recommend emphasizing the effort and practice to guide students to acquire long-term habits and encourage perseverance. On the other hand, in the study by Hundhausen, Agarwal, Zollars, & Carter (2011) the researchers evaluated a software for learning problem-solving in chemistry and found that the version of the software that provided feedback significantly increase time on-task. These studies and the recommendations of the UDL provide some insights that suggest that the *Real-time feedback* variable may have a positive effect on the *Time on-task*. This relationship may be explained by the fact that the *Real-time feedback* promotes reflection and increase the engagement and therefore the *Time on-task* increases. In consequence, *Time on-task* was also considered as a dependent variable to identify its predictors in mobile AR learning experiences.

Based on the findings in the literature and the opportunities for further research in terms of the *Time on-task* in AR experiences the following hypothesis is suggested in which both the *Use of* *scaffolding* and *Real-time feedback* are the independent variables and the *Time on-task* is the dependent variable:

H_3: Both the *Use of scaffolding* and *Real-time feedback* have a positive and significant effect on *Time on-task* in AR learning experiences.

On the other hand, as described in CHAPTER 3, the Paint-cAR application was also designed with a module for *Watching videos* about the process of repairing paint on a car. This design is the result of the co-creation process and this design decision was suggested by the expert teachers and is based on the UDL (Universal Design for learning) guidelines. The videos are used as an additional mean of representation and to provide expert guidance to students so that they can achieve mastery. Aligned with this design decision, in their research, Zydney & Grincewicz (2011) found that there is a positive correlation between the time that students spend *watching videos* and their ability to identify multiple perspectives of a problem.

In terms of the relationship between the use of videos in distance education and the learning outcomes, in his literature review, Kay (2012) found that one of the most important benefits reported with respect to students' learning outcomes when using video podcast is: higher scores in tests than traditional approaches. Supporting this view, Wieling & Hofman (2010) found that the number of lectures viewed online is a predictor of students' learning outcomes. In their study, De la Flor López, Ferrando, & Fabregat-Sanjuan (2016) found that learning outcomes are increased by the combination of video clips with other interactive technologies in the learning domain of mechanical engineering. According to Traphagan, Kucsera, & Kishi (2010), there is a positive relationship between webcast viewing and higher performance (better learning outcomes). This relationship can be explained by the fact that the webcasting may provide to students more control over their learning process.

Finally, Rutz et al. (2003) found that students that followed a streaming media class spend more time on the task compared to students that followed a traditional class. Likewise, Kay (2012) found that some studies that deal with the use of video podcasts in class reported the following benefits with respect to student behaviour: frequency of viewing, consistent attendance and improvement in study habits. Together these studies jointly with the recommendations of the UDL framework suggest that using videos in online learning (*Watching videos*) may have a positive effect on students' *Learning outcomes* and *Time on-task*.

Based on the findings in the literature the following hypothesis is suggested in which the independent variables are both *Watching videos* and *Time on-task* and the dependent variable is *Learning outcomes*:

H_4: Both *Watching videos* and *Time on-task* have a positive and significant effect on *students' Learning outcomes* in AR learning experiences.

Figure 5-1 shows an overall picture of the research model for the hypotheses defined in sections 5.2.1 and 5.2.2. In short, this research model shows that both the *Use of Scaffolding* and the *Real-time feedback* might affect students' *Degree of success* (H_2) and also affect students' *Learning outcomes* (H_1) and students' *Time on-task* (H_3). Moreover, the research model shows that both *Time on-task* and *Watching videos* might affect students' *Learning outcomes*.

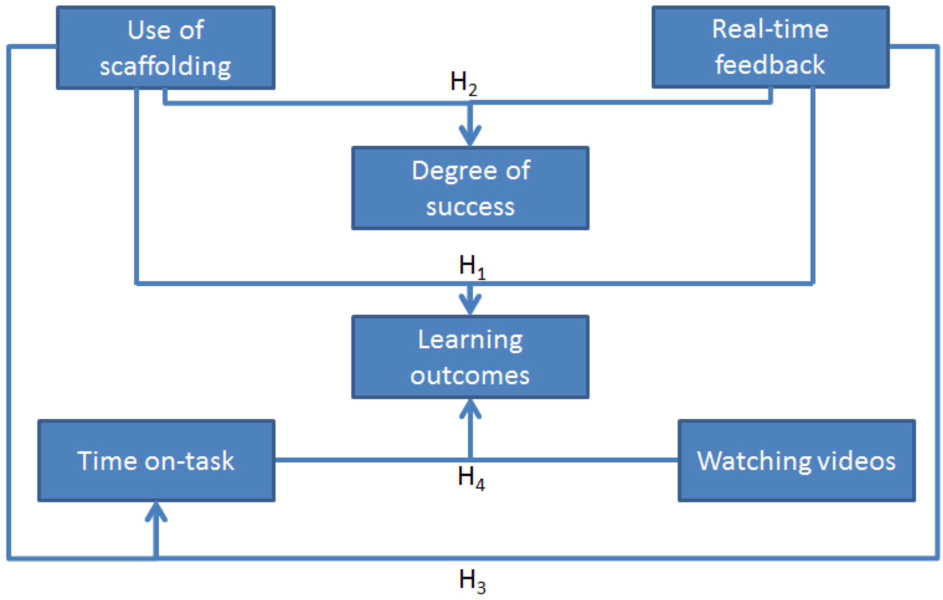

Figure 5-1. Research model for hypotheses H1, H2, H3 and H4.

So far, in sections 5.2.1 and 5.2.2 we described the findings in the literature that may explain the theoretical relationships of each one of the 6-VARLE with the others and we defined a research model that can be empirically validated as shown in **Figure 5-1**. The relationships of the 6-VARLE that have been identified in the literature will help us to have a better understanding on how these variables are related one with the others in mobile AR learning experiences. The validated research model will help us to understand how these variables might subsequently affect the dimensions of the ARCS model of motivation and therefore we might provide insights into how and why these variables affect the dimensions of the ARCS model of motivation. This will provide us with insights to understand why AR applications increase student motivation.

The next step is to determine how the 6-VARLE affect the dimensions of the ARCS model of motivation which is described in section 5.2.3.

5.2.3 Dimensions of motivation from the ARCS model

In this section, we present a research model based on hypotheses that may explain the how the 6-VARLE are related to the four dimensions of the ARCS model of motivation. The purpose of this research model is to identify which variables support each dimension of motivation and therefore to determine which of these variables might be predictors of student motivation in an AR learning experience. This part of the study addresses the need expressed by Li, Chen, Whittinghill, & Vorvoreanu (2014) who claimed that few studies have investigated the effect of AR in students' motivation.

According to the UDL guidelines (Meyer et al., 2014), motivation is a key factor in the learning process. The UDL principle about providing multiple means of engagement emphasizes the need of providing a variety of mechanisms to sustain students' motivation and engagement in the learning process. It is worth noting that students' variability also occurs in terms of their motivation, which means that not all students are motivated in the same way. Thus, instructional design should include strategies to increase and sustain students' motivation and in this regard, the motivational design theory (Keller, 2010) may help to support the implementation of the UDL guidelines to create a curriculum in which all students can be motivated by using different mechanisms and strategies based on a deep understanding of students' needs and preferences.

Moreover, in the UDL guidelines, the definition of a challenge for students to complete is important to motivate them (Meyer et al., 2014). Supporting this view, Keller (2010) also states that students need to be challenged but the challenge should come from the learning materials itself and not from obstacles in the learning process. In the ARCS model of motivation the definition of a challenge is in fact one of the strategies for supporting the *confidence* dimension of motivation.

The relationship between scaffolding and motivation is established from a concept known as "success opportunities". Success opportunities are the opportunities that learners have to succeed in tasks that are challenging (Keller, 2010). These opportunities may be different for students who have some basic knowledge and those who have more advanced knowledge. Scaffolding is a strategy that not only helps students to succeed in the activities in mobile AR learning experiences, but also creates success opportunities so that students can accomplish challenging tasks. In fact, success opportunities are one of the strategies for building *confidence* as pointed out by Keller (2010) in the ARCS model of motivation. This may suggest that the *Use of Scaffolding* has a positive effect on the *confidence* dimension of motivation.

According to the UDL guidelines, graduated scaffolds are considered to be one of the key points for helping novice learners to reach mastery (Meyer et al., 2014). This strategy is highly recommended in the UDL guidelines to design learning environments that consider student variability to achieve expert learning. According to the UDL framework, the aim of education is the development of expert learners. Expert learners are students who identify, organize, use and relate previous knowledge to new experiences and information. Besides that, the expert learners create a plan for learning, organize resources and monitor their progress and are motivated to sustain their effort in the learning activities (Meyer et al., 2014). Thus, the scaffolding strategy could be adjusted to the student's needs and preferences and the scaffolds could be removed as students gain experience and knowledge. In this study we seek to confirm if the *Use of Scaffolding* has a positive effect on the four dimensions of the ARCS model. Therefore, the following hypothesis is suggested in which the independent variable is *Use of scaffolding* and the dependent variables are the four dimensions of the ARCS model:

H_5: The *Use of scaffolding* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

As for the *Real-time feedback*, some studies have reported that the provision of feedback might have a positive effect on student motivation. For instance, Chao, Lan, Lee, et al., (2014b) found that , providing specific feedback to students helps to motivate them. Likewise, in their literature review, Chakraborty & Muyia Nafukho, (2014) found that one of the strategies for student engagement in distance learning is to provide consistent and timely feedback. Moreover, according to Keller (2010), the levels of challenge in learning activities need to be combined with appropriate feedback to help students to succeed and/or confirm their success in the learning tasks. Moreover, feedback is a key aspect in the *confidence* and *satisfaction* dimensions of motivation in the ARCS model (Keller, 2010). These studies suggest that *Real-time feedback* might have a positive effect on students' motivation and the following hypothesis is suggested in which the independent variable is the Real-time feedback and the dependent variables are the four dimensions of the ARCS model of motivation:

H_6: The provision of *Real-time feedback* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Degree of success is another variable of the 6-VARLE. This variable represents the level at which students succeed in the learning activities. In other words it represents the student's progress in the learning activities in the mobile AR experience. In this study we seek to identify if the *Degree of success* has any effect on student motivation to determine if the *Degree of success* can be a predictor of student motivation in mobile AR learning experiences in the VET level of education. The *Degree of success* variable is closely related to the success opportunities. The success opportunities are the opportunities created in the learning activities so that students can succeed in the activity at certain level of challenge (Keller, 2010). The students' Degree of success will increase if students are able to take advantage of the success opportunities taking into account the challenge imposed by the learning activity and their knowledge. The success opportunities are one the key aspects for supporting the *confidence* dimension of motivation (Keller, 2010) and therefore we hypothesize that the students' *Degree of success* in an AR application positively affects the students' levels of motivation during the intervention. This means that the *Degree of success* that students may reach with the use of the AR application may positively affect their levels of motivation during the intervention. Thus, the following hypothesis is suggested in which the independent variable is the *Degree of success* and the dependent variables are the four dimensions of the ARCS model of motivation:

H_7: The students' *Degree of success* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

As for the *Learning outcomes variable,* it represents students' achievement in the tests of the Assessment module in the Paint-cAR application that evaluates the knowledge that students acquire during the mobile AR learning experience.

In the literature it is often reported that the students' levels of motivation positively affect students' achievement (*Learning outcomes*) (Paechter, Maier, & Macher, 2010;Castillo-Merino & Serradell-López, 2014; Eom & Ashill, 2016;Ai-Lim Lee, Wong, & Fung, (2010). This means that the independent variable is student motivation and the dependent variable is student achievement. According to the literature the following hypothesis is suggested in which the independent variables are the four dimensions of the ARCS model of motivation and the dependent variable is *Learning outcomes*:

H_8: Student motivation (ARCS dimensions) has a positive and significant effect on students' *Learning outcomes* in mobile AR learning experiences.

On the other hand, despite of the fact that *Time on-task* is considered to be one of the most important metrics of engagement and that it has been used for the past 50 years (Ghergulescu & Muntean, 2016), to date little research has been done in terms of the aspects of AR that may increase *Time on-task* behaviors, and thus student motivation.

In the literature, *Time on-task* is also known as Academic Learning Time (ALT) which is the amount of time that students spend working on academic activities with the appropriate challenge for them (Berliner, 2007). ALT is also mediated by students' engagement in the learning activity. Thus, the amount of time that students spend on learning activities is not the only factor that determines students' learning outcomes. What really determines students' learning outcomes is the ALT when students are engaged in the learning activities (Berliner, 2007).

However, to date little research has been done on the relationship between the *Time on-task* or ALT and the use of AR in learning experiences. The study of Matcha & Awang Rambli (2015) has focused on studying the relationship between the *Time on-task* and the use of an AR learning activity. The researchers analyzed the interaction of students in a collaborative AR activity about the basic concepts of electricity. By using observational analysis, interviews and a student's perceptions questionnaire the researchers concluded that on average 97% of the time students were focused on the learning activities showing the potential of AR for engagement in terms of the time spent on task. Besides that students reported acceptance and enjoyment towards the use of the collaborative AR experience for learning.

Thus, in this study we seek to explore if the amount of time that students spend on the AR learning experience (*Time on-task*) might affect student motivation after the intervention. This might provide insights into the effect that the amount of time that students are exposed to an AR learning experience might increase or decrease their levels of motivation. In this context, the following hypothesis is suggested in which the independent variable is the *Time on-task* and the dependent variables are the four dimensions of the ARCS model of motivation:

H_9: The amount of time that students spend in the AR learning experience (*Time on-task*) has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

As for the *Watching videos* variable, in the literature the use of video podcast has been widely recognized as an strategy to motivate students (Kay, 2012; Pedrotti & Nistor, 2014; Bolliger, Supanakorn, & Boggs, 2010). These findings in the literature might suggest that *Watching videos* has a positive effect on student motivation and therefore the following hypothesis is suggested in which the independent variable is *Watching videos* and the dependent variables are the four dimensions of the ARCS model of motivation:

H_{10}: *Watching videos* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Figure 5-2 depicts the research model that relates the 6-VARLE and the four dimensions of the ARCS model according to the the hypotheses described in section 5.2.3. In short, this research model shows that the 6-VARLE are related to the four dimensions of the ARCS model of motivation:

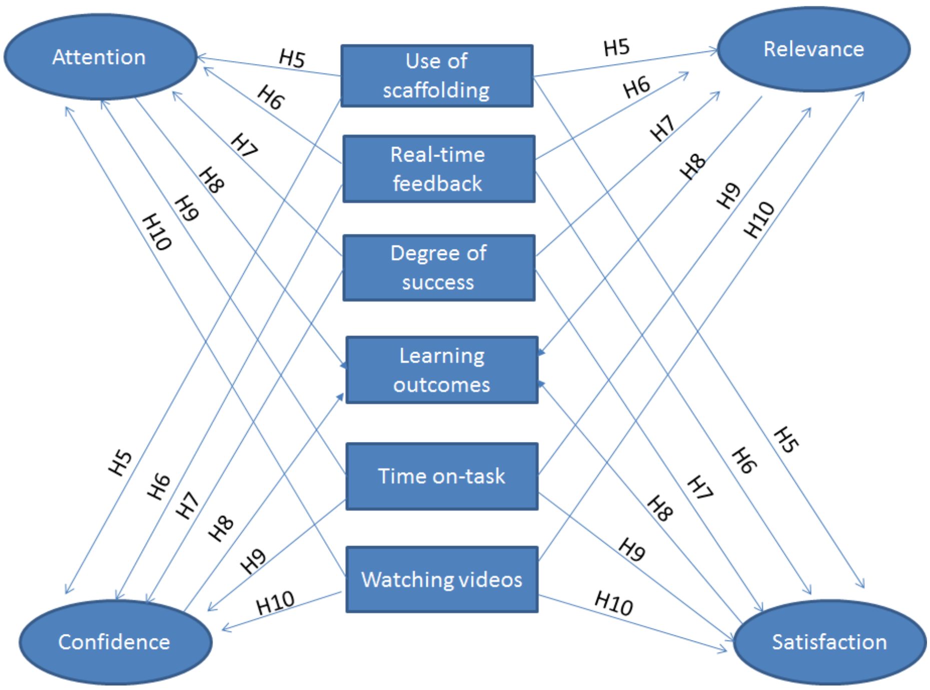

Figure 5-2. Research model for hypotheses H_5, H_6, H_7, H_8, H_9 and H_{10} with respect to the ARCS dimensions of motivation.

5.3 METHOD

Since the aim of this study is to identify the predictors of students' motivation when using a mobile AR application for learning in the VET level of education, we had to validate the hypotheses proposed in the previous sections of this chapter. To validate these hypotheses we used two sources of data: first, the interaction of students with the Paint-cAR application and second, the IMMS instrument as a self-report measure. In this section, the research design, participants and a detailed description of the sources of data to validate these hypotheses are described.

5.3.1 Research design and participants

For the purposes of this study the Paint-cAR application (described in CHAPTER 3 and CHAPTER 4) was used for data collection. Data was collected during the second exploratory study (which is described in CHAPTER 4). This means that the interaction of the students with the Paint-cAR application during the second exploratory study was captured by the Monitoring module and these data was used in this study as one of the data sources. Thus, data collected for this study come from the interaction of the 35 students with the Paint-cAR application in the four vocational education and training institutions in Spain that participated in the second exploratory as the experimental group.

As in the second exploratory study, the participation of students was: 17 students from the Institute 1, 7 students from the Institute 2, 7 students from the Institute 3 and 4 students from the Institute 4. Students used the Paint-cAR application for the 15 to 20 days that lasted the second exploratory study (described in CHAPTER 4) and data was collected during that study. Thus, the research procedure is the same as in the second exploratory study.

It is important to note that this study is classified as a co-relational study (Hernández Sampieri, Fernández-Collado, & Baptista Lucio, 2006) which implies that we sough to describe and explain how a phenomenon occurs based on the association between some variables that we can observe from the phenomenon. In other words, we seek to describe how motivation is affected by 6-VARLE and which are the relationships among the 6-VARLE. We have conducted this study without a control group as in other studies in the literature that followed this approach for validating research models of hypotheses such as Rashid & Asghar 2016;Eseryel, Law, Ifenthaler, Ge, & Miller, 2014; Rubin, Fernandes, & Avgerinou, 2013; Bringula, 2013).

5.3.2 Data sources and data collection

Automatic data sources

As mentioned earlier, the Paint-cAR application was developed with a Monitoring module that continuously tracks students' interaction. Each student has a unique identifier to trace the use of the application for each student. The Monitoring module tracked the interaction of the students with the modules of the Paint-cAR application and stored the information in the 6-VARLE as summarized in **Table 5-1**. More details on these variables and how they were measured are presented as follows:

- Use of scaffolding: Interaction with the scaffolding strategy is detected in order to gather information about the exact moment in which students use to the scaffolding to obtain help in order to complete a learning activity during the AR learning experience. This variable registers the number of times that each student uses the scaffolding module during the AR learning experience. The following data is stored: Student ID, timestamp, step in the process of repairing, mode (guided, evaluation or informative).
- Real-time Feedback: The variable registers the exact moment when students received feedback after a mistake is made during the completion of a learning activity in the AR

experience. Post processing of data collected allowed us to identify if students did not read the feedback based on the amount of time that the feedback was active before it was closed. The following data is stored: Student ID, timestamp, step in the process of repairing, mode (guided, evaluation or informative).

- Learning Outcomes: This variable store a ratio of the number of test approved and the number of test answered in the application. Each test is managed by the Assessment module in the Paint-cAR application and consists of five multiple-choice questions. The questions for each test are randomly selected from a database of 109 questions created by the teacher. Students need to answer all the five questions correctly to approve the test. The following data is stored for each answer that students give to each question in the application: Student ID, Question ID, Test ID, timestamp, time answering the question and the answer provided.
- Degree of success: The module registers when students successfully complete a task in the AR learning experience. This includes selecting the appropriate products or tools to use for each step in the process. This variable stores the number of products or tools that students have successfully selected for each one of the 30 steps in the process of repairing paint on a car. The following data is stored: Student ID, timestamp, step in the process of repairing, mode (guided, evaluation or informative).
- Time on-task: The Monitoring module stored in this variable the amount of time that students spend on the AR learning experience. The selection of a particular *Time on-task* estimation strategy may lead to different interpretations of the research findings (Kovanović et al., 2015). Besides that, the two challenges that need to be tackled in the approaches for *time-on-task* estimation are: the outlier detection and detection of the last action in the system. For the purposes of this study, the outlier detection was carried out during data processing and the detection of the last action in the system was corrected during data gathering from the interaction with the user by capturing events of all possible actions that the user is able to do in the mobile AR application. For example if students close the application in the middle of a task, an event is registered and the time on-task estimation takes into account that event. Moreover, if students send the application to background and engage in other off-task activities the time on-task estimation mechanism registers this event. Students' off-time behaviors outside the use of the mobile AR application were not monitored.
- Watching videos: The module registers the timestamp when students watched the videos in the Paint-cAR application.

Information registered by the monitoring module in the student's smartphone or tablet is sent to a server. As a result, all the interactions with the Paint-cAR application were registered by the monitoring module and data was sent to the server for subsequent analysis. We strived to capture as much interactions as possible in the Paint-cAR application.

In total 32.641 events of interaction for all the students were detected by the monitoring module and sent to the server during the 15 to 20 days of the testing for each VET institute.

Manual data sources

As for manual data sources, the IMMS instrument was used to gather information about students' motivation with respect to the use of the mobile AR application Paint-cAR at the end of the intervention after the 15 to 20 days of using the Paint-cAR application. More details on the IMMS instrument are provided in CHAPTER 2 in section 2.7.

5.4 HYPOTHESES TESTING AND RESULTS

By testing the hypothesis defined on section 5.2, the predictors of students' motivation and related variables can be identified to obtain an empirical model that support the definition of a framework for the design of motivational mobile AR learning experiences.

To validate the hypotheses defined and identify relationships of causality, multiple regression analysis was used. This method has been applied in previous studies such as (Rashid & Asghar, 2016; Eseryel, Law, Ifenthaler, Ge, & Miller, 2014; Rubin, Fernandes, & Avgerinou, 2013; Bringula, 2013; S.-H. Liu, Liao, & Pratt, 2009) to validate research models in order to obtain a model of relationships and causalities between variables.

Since multicollinearity may be present in multiple regression analysis, hypothesis in which multicollinearity occurs among the variables will be validated by using Pearson product-moment correlation (for data drawn from normal distributions) and Spearman rho correlation (for data drawn from non-normal distributions) in order to determine, at least, the association that may exist among the variables. In particular, the hypotheses in which the dimensions of the ARCS model are considered were validated through correlation because of the multicolinearity among the variables. Correlation has also been used in hypothesis validation in previous studies such as (Chou, Hsiao, Shen, & Chen, 2010; Sylaiou, Mania, Karoulis, & White, 2010; Bulu, 2012) to show the association between variables but not explaining causality between them. However correlation may provide insights between the associations of some variables in a model. Coolican (2014, p. 567) states that correlations are useful to provide evidence that supports a theory and are part of the evidence in many theories in social science.

Throughout this section, the results of the hypothesis validation are described and organized according to each hypothesis. Since the Paint-cAR application can be used in Guided Mode and in Evaluation Mode, in the hypothesis validation two models of relationships among variables will be obtained, one for the Evaluation Mode and one for the Guided Mode.

5.4.1 Hypotheses with respect to the *Use of scaffolding* and *Real-time feedback*

H_1: Both the *Use of scaffolding* and the *Real-time feedback* have a positive and significant effect on students' *Learning outcomes* in mobile AR learning experiences.

To validate this hypothesis multiple regression analysis was performed using the enter method for data collected in the Evaluation Mode and the Guided Mode with *Learning outcomes* as dependent variable and *Use of scaffolding* and *Real-time feedback* as independent variables.

<u>Validation in Evaluation Mode</u>

The regression model resulted in R (0,904), R^2(0,818) and R^2 adjusted (0,804). R for regression was significantly different from zero. The results of the ANOVA test were significant: F(2,28)=58,348, sig=0,000; p<0.001. Table 5-2 shows the standardized and unstandardized regression coefficients, signification and collinearity statistics (Tolerance and Variation Inflation Factor - VIF).

Table 5-2. Standardized and unstandardized coefficients, significance and collinearity statistics for hypothesis **H2**.

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	4.396	1.158		3.796	0.001***		
Use of Scaffolding	0.171	0.021	0.944	8.295	0.000***	0.541	1.849
Real-time feedback	-0.017	0.031	-0.060	-0.531	0.600	0.541	1.849

* p<0.1; **p<0,05; ***p<0.001

As a result of the analysis one variable contributed significantly to the prediction of students' *Learning outcomes* in the Evaluation Mode. This variable was the U*se of scaffolding* in the AR experience (β=0,944). This variable predicts 80,4% of variability in the students' learning performance by knowing the values of the *Use of a scaffolding* strategy. The effect size was very large f^2=4,49 and post hoc power was calculated: λ =1.

The results show that in the Evaluation Mode the scaffolding approach is useful for students to achieve in the assessment through the Paint-cAR application. This result demonstrate the usefulness of a scaffolding approach in mobile AR learning experiences because apart from providing assistance to students in the AR tasks, it convey pieces of knowledge that are relevant for achieving in the subsequent examinations in the Paint-cAR application. It is important to note that in the Paint-cAR application the scaffolding strategy is available when students interact with the augmented information but it is not available in the Assessment module. The results also show that students take advantage of the knowledge and skills acquired through the use of a scaffolding approach in the AR learning experience to use them when solving the tests in the assessment module. This result is aligned with the findings of Santos, Cook, & Hernández-Leo (2015) that highlights the importance of providing a scaffolding strategy in mobile assessment systems to assist the learner during the activity and increase the performance. This result is also in line with the findings of Ibanez et al. (2016) in terms of the effectiveness of using scaffolding strategies in AR-based tools. In general this result is also in agreement with the conclusion of Tekedere (2016), Martín-Gutiérrez & Contero (2011) on the positive effect of AR on students' learning outcomes.

However, we found that the *Real-time feedback* was not a predictor of students' *Learning outcomes* in the Evaluation Mode. This result may be due to the rewarding nature of the *Real–time feedback* in this mode because the *Real-time feedback* in this mode aims to encourage students to maintain the effort in the task rather than providing hints or pieces of knowledge to achieve in the assessment. Despite the *Real-time feedback* not being a predictor of students' *Learning outcomes*, we explored if there was any relationship between the *Real–time feedback* and students' *Learning outcomes*. In that regard a Spearman correlation on the use of a R*eal-time feedback* and the students' *Learning outcomes* in the Paint-cAR application was used. The results show that there is a positive strong and significant correlation between the use of a *Real-time feedback* and students' *Learning outcomes* (r=0,829, sig.=0,000, p<0,001, N=30). This result shows that although the students' *Learning outcomes* cannot be explained by the use of a *Real-time feedback*, there is a strong relationship between the variables. This means that the use of a *Real-time feedback* mechanism is important in AR learning experiences. But further research needs to be conducted to determine how the real-time feedback needs to be designed to have a greater effect on students' performance.

Validation in Guided Mode

The ANOVA test was not significant indicating that the *Use of a scaffolding* strategy and the *Real-time feedback* were not predictors of the students' *Learning outcomes* in the Guided Mode. F(2,28)=0,028, sig.= 0,9. The result can be explained because in the Guided Mode students do not needed at all either the scaffolding or the Real-time feedback to complete the task. Students have almost all the information available and it seems that the augmented information is enough to convey the knowledge needed for students to achieve in the assessment in this mode.

However, in order to explore the relationship between the *Use of a scaffolding* strategy and the *Real-time feedback* a Spearman correlation was applied. The results show that there is a positive moderate and significant correlation between the *Real-time feedback* and the student's *Learning outcomes* (r=0,451, sig.=0,012, p<0,05, N=30). However no significant correlation was found between the *Use of a scaffolding* strategy and the students' *Learning outcomes* in the Guided Mode. This result is surprising because it shows that although the scaffolding does not contributed in the Guided Mode to the achievement in the assessment, the feedback contributes to the achievement. This is mainly because in the Guided Mode students have more information available but the *Real-time feedback* is relevant to students because it provide hints to arrive to the augmented information that can be useful to achieve in the assessment.

H_2: Both the *Use of scaffolding* and the *Real-time feedback* have a positive and significant effect on students' *Degree of success* in mobile AR learning experiences.

To validate this hypothesis multiple regression analysis was performed using the enter method for data collected in the Evaluation Mode and the Guided Mode with *Degree of success* as dependent variable and *Use of scaffolding* and *Real-time feedback* as independent variables.

Validation in Evaluation Mode

The regression model resulted in R (0,908), R^2(0,825) and R^2 adjusted (0,812). R for regression was significantly different from zero. The results of the ANOVA test were significant: $F(2,28)=65{,}810$, sig=0,000; $p<0.001$. Table 5-3 shows the standardized and unstandardized regression coefficients, signification and collinearity statistics (Tolerance and Variation Inflation Factor - VIF).

Table 5-3. Standardized and unstandardized coefficients, significance and collinearity statistics for hypothesis **H1**.

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	9.975	2.742		3.638	0.001		
Use of Scaffolding	0.224	0.052	0.473	4.317	0.000***	0.523	1.913
Real-time feedback	0.372	0.079	0.515	4.703	0.000***	0.523	1.913

* p<0.1; **p<0,05; ***p<0.001

As a result of the analysis two variables contributed significantly to predicting *Degree of success* in the Evaluation Mode. These were the *use of a scaffolding* strategy in the AR experience (β=0,473) and the *Real-time feedback* provided to students in the AR experience (β=0,515). Altogether 81,2% of variability in the *Degree of success* was predicted by knowing the values of the *use of a scaffolding* strategy and the *Real-time feedback* provided to student. The effect size was very large f^2=4,72 and post hoc power was calculated: $\lambda=1$.

The results show that two the predictors of the students' *Degree of success* are the *use of a scaffolding* strategy and the *Real-time feedback* provided to students in the AR learning experience. This means that a scaffolding strategy and the *Real-time feedback* are key components in mobile AR learning experiences that provide success opportunities for students in challenging tasks. The success opportunities created by these components are important in building students' confidence (Keller, 2010) and therefore motivating them to learn. It is important to note that these results were obtained from the Evaluation Mode and this shows that students took advantage of the scaffolding strategy and the *Real-time feedback* to complete the task and that these components contributed significantly to predicting the students' *Degree of success*. In short, if students used the scaffolding strategy and the *Real-time feedback*, their *Degree of success* increases.

Validation in Guided Mode

The ANOVA test was not significant indicating that the *use of a scaffolding* strategy and the *Real-time feedback* were not predictors of the students' *Degree of success* in the Guided Mode. $F(2,28)=0{,}463$, sig.= 0,63. The result can be explained because in the Guided Mode the challenge provided to students is lower than in the Evaluation Mode. As a result students did not need to use the scaffolding strategy or the real-time feedback in order to complete the task. Most of the information provided to students in the Guided Mode is enough to complete the task without using the scaffolding strategy or the real-time feedback.

However, a Spearman correlation on the *Use of a scaffolding* strategy and the *Real-time feedback* with respect to the *Degree of success* was used to explore any relationship between the variables. The results show that there is a positive moderate and significant correlation between the *use of* *a scaffolding* strategy and the *Degree of success* (r=0,442, sig.=0,018, p<0,05, N=30). Besides that, a positive weak and significant correlation was found between the *Real-time feedback* and the *Degree of success* (r=0,399, sig.=0,036, p<0,01, N=30). The results show that there is a significant relationship between the variables and therefore the scaffolding strategy and *Real-time feedback* could be beneficial for some students even though they are in the Guided Mode with almost all the information for completing the task in the mobile AR experience.

5.4.2 Hypotheses with respect to the *Time on-task*

H_3: Both the *Use of scaffolding* and *Real-time feedback* have a positive and significant effect on *Time on-task* in AR learning experiences.

To validate this hypothesis Multiple regression analysis was performed using the enter method for data collected in evaluation and Guided Mode with *Time on-task* as dependent variable and *Use of scaffolding* and *Real-time feedback* as independent variables.

<u>Validation in Evaluation Mode</u>

The regression model resulted in R (0,859), R^2(0,737) and R^2 adjusted (0,719). R for regression was significantly different from zero. The results of the ANOVA test were significant: F(2,28)=39,299, sig.=0,000, p < 0.001. Table 5-4 shows the standardized and unstandardized regression coefficients, signification and collinearity statistics (Tolerance and Variation Inflation Factor - VIF).

Table 5-4. Standardized and unstandardized coefficients, significance and collinearity statistics for hypothesis **H3**.

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	438.30	128.53		3.410	0.002***		
Use of Scaffolding	7.055	2.430	0.389	2.903	0.007***	0.523	1.913
Real-time feedback	15.027	3.710	0.543	4.050	0.000***	0.523	1.913

* p<0.1; **p<0,05; ***p<0.001

As a result of the analysis the two variables contributed significantly to the prediction of the student's *Time on-task*: the *Use of scaffolding* (β=0,389) and the R*eal-time feedback* provided to student in the AR learning experience (β=0,543) in the Evaluation Mode. Altogether 71,9% of variability in the *Time on-task* was predicted by knowing the values of the interaction with the *scaffolding* strategy and the *Real-time feedback* provided to student. The effect size was very large f^2=2,55 and post hoc power was calculated: λ =1.

Since the *Time on-task* is a direct measure of motivation (Keller, 2010), these results show that in a mobile AR learning experience the *Use of a scaffolding* strategy helps students to be focused on the task and therefore increases the time that student's spend on a task. This results are in line with the recommendations of Kim & Frick (2011) with respect to the support that need to be provided for learning activities in relation to the *Time on-task*. In this regard, the scaffolding approach is a key component in a mobile AR learning experience. The scaffolding strategies create "success opportunities" which are, according to Keller (2010), one of the strategies for building confidence and therefore for increasing motivation. The success opportunities emerge when students take advantage of the scaffolds to achieve in challenging tasks. As a result, students feel that they can influence their environment and focus their efforts on pursuing their goals (Keller, 2010).

From the perspective of the UDL, the use of graduated scaffolds not only helps novice learners to reach mastery but also assist students with different backgrounds, special educational needs and preferences to succeed in challenging tasks (Meyer et al., 2014). The importance of using a scaffolding strategy in mobile AR learning experiences is that the scaffolding provides assistance to learners with different educational needs to complete a task. The assistance and help provided to learners can have, according to our experience, two different purposes:

1. To provide key pieces of knowledge needed to complete the task according to students' needs in the mobile AR learning experience. For example to achieve in the assessment by using the scaffolding strategy as discussed before. Scaffolding can also guide students' attention to the information that learners need at any point in the mobile AR learning experience.
2. To guide students by using prompts or hints according to the students' needs to find, filter and organize key augmented information needed to complete the task in the mobile AR learning experience. In short, the scaffolding strategy guides students' to the key augmented information to complete the task. Moreover, scaffolding can be used to reduce the "extraneous cognitive load" (Bujak et al., 2013) so that students can focus on the augmented information and focus their efforts on task completion and not in other tasks that may distract students from the relevant information.

As for *Real-time feedback*, the results show that this is another predictor of students' *Time on-task* and therefore is a key component of mobile AR learning experiences. It is worth noting that the *Real-time feedback* variable (β=0,543) contributed more to the prediction of students' *Time on-task* than the *Use of a scaffolding* variable (β=0,389). This means that the real time-feedback is a key component for increasing on-task behaviors and therefore needs to be carefully designed to achieve this goal jointly with the scaffolding approach. According to Keller (2010) feedback should be positive and attributional which means that student's should know that they succeed because they work hard. This is another strategy for building confidence.

Moreover, the rewarding nature of *the real-time feedback in* mobile AR applications encourages students to focus on the task. The results with respect to the *Real-time feedback* are also in line with the recommendations of the UDL in which the provision of feedback is one of the key strategies to help students to maintain perseverance (Meyer et al., 2014). In general these results are in line with the findings in other studies with respect to the importance of feedback and real-time feedback in learning experiences (Ibanez, Villaran, & Delgado-Kloos, 2015;Li, Tsai, Chen, Cheng, & Heh, 2015; Chao et al., 2014a; Ternier, Klemke, Kalz, van Ulzen, & Specht, 2012).

Validation in Guided Mode

The ANOVA test was not significant indicating that the *Use of scaffolding* and the *Real-time feedback* were not predictors of the students' *Time on-task* in the Guided Mode. F(2,25)=0,247, sig.= 0,78.

However, in order to explore the relationship between the *Use of a scaffolding* strategy and the *Real-time feedback* a Spearman correlation was applied. The results show that there is a weak but no significant correlation between the *Use of a scaffolding* strategy (r=0,204, sig.=0,2, p>0,05) and the *Real-time feedback* (r=0,278, sig.=0,1, p>0,05) in the Guided Mode. As mentioned before in the Guided Mode students had more information available (apart from the augmented information) compared to the Evaluation Mode. Thus, the information available was enough for completing the task and the level of challenge was lower than in the Evaluation Mode so not all the students used the scaffolding strategy or the real-time feedback to complete the task. The results suggest that the level of challenge with the appropriate scaffolding strategy and real-time feedback need to be balanced to maintain on-task behaviors.

H_4: Both *Watching videos* and *Time on-task* have a positive and significant effect on students' *Learning outcomes* in AR learning experiences.

To validate this hypothesis multiple regression analysis was performed using the enter method for data collected in the Guided Mode with the *Learning outcomes* as dependent variable and use of the module for *Watching videos* and *Time on-task* as independent variables. Since the module for *Watching videos* is only available in the Guided Mode and not in the Evaluation Mode, the validation of this hypothesis in the Evaluation Mode was conducted with the *Time on-task* as independent variable and the learning performance as dependent variable.

Validation in Evaluation Mode

To validate this hypothesis in the Evaluation Mode, multiple regression analysis was applied using the enter method for data collected in the Evaluation Mode with the *Learning outcomes* as dependent variable and the *Time on-task* as independent variable. The regression model resulted in R (0,716), R^2(0,513) and R^2 adjusted (0,493). R for regression was significantly different from zero. The results of the ANOVA test were significant: F(1,25)=26,283, sig=0,000; p<0.001. Table 5-5 shows the standardized and unstandardized regression coefficients and collinearity statistics (Tolerance and Variation Inflation Factor - VIF).

Table 5-5. Standardized and unstandardized coefficients, significance and collinearity statistics for hypothesis H_4 in Evaluation Mode.

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	3.077	2.317		1.328	0.196		
Time on-Task	0.007	0.001	0.716	5.127	0.000	1.000	1.000

* p<0.1; **p<0,05; ***p<0.001

As a result of the analysis, *Time on-task* was found to be a predictor of students' *Learning outcomes* in the Evaluation Mode (β=0,716). This variable explained 51% of the variability in the students' *Learning outcomes*. The effect size was very large f^2=1,05 and post hoc power was calculated: λ =0,95. The result shows that in augmented reality learning experiences the *Time on-task* is a predictor of students' *Learning outcomes*. This result is in line with the findings in the study conducted by Matcha & Awang Rambli (2015) in which they found that by using AR, on average, students spent 97% of the time engaged in the learning activity. Besides that, this result is also in line with the findings of other researchers in terms of the relationship between the *Time on-task* and students' *Learning outcomes* (Kovanović et al., 2015; Margarida Romero & Barberà, 2011). This result is relevant because it confirms the potential of AR for increasing time on-task behaviors in learning activities.

Validation in Guided Mode

The regression model resulted in R (0,971), R^2(0,944) and R^2 adjusted (0,940). R for regression was significantly different from zero. The results of the ANOVA test were significant: F(2,32)=268,480, sig=0,000; p<0.001. Table 5-6 shows the standardized and unstandardized regression coefficients and collinearity statistics (Tolerance and Variation Inflation Factor - VIF).

Table 5-6. Standardized and unstandardized coefficients, significance and collinearity statistics for hypothesis **H4** in Guided Mode.

Model	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	-2.102	1.348		-1.560	0.129		
Time on-task	0.015	0.005	0.208	2.973	0.006***	0.358	2.791
Watching Videos	0.482	0.042	0.797	11.375	0.000***	0.358	2.791

* p<0.1; **p<0,05; ***p<0.001

As a result of the analysis the two variables contributed significantly to the prediction of the student's Learning outcomes: the *Time on-task* (β=0,208) and the use of the module for *watching videos* (β=0,797). Altogether 94% of variability in the students' learning performance was predicted by knowing the values of the use of the module for *watching videos* and the students' *Time on-task*.

The β coefficient for the variable about the use of the module for *watching videos* has a higher value than the variable for *Time on-task* which means that the contribution of that variable is higher for explaining the students' learning performance. This situation occurs because the videos provided information that helps students to achieve in the assessment (answering the multiple-choice questions). These results confirm the findings of Kay (2012) in terms of the benefits of using video podcast for improving learning performance. In his literature review, one of the most important benefits reported with respect to students' learning performance when using video podcast is: higher scores in tests than traditional approaches. Furthermore, the results are consistent with the findings in the study of Wieling & Hofman (2010) who found that the number of lectures viewed online is a predictor of students' *Learning outcomes*.

Although the β coefficient for the variable *Time on-task* is lower than the other variable, the *time on-task* was nonetheless a significant predictor of students' *Learning outcomes*. This means that the amount of time that students spend in the mobile AR learning experience also benefits their *Learning outcomes* jointly with the activity for *watching videos* about the topic. In that regard, a design recommendation would be to include videos as augmented information, not only as a complement to the instruction besides other formats of augmented information such as text, images and 3D interactive models in order to provide multiple forms of representation as recommended by the UDL guidelines (Meyer et al., 2014). Students would benefit from diverse forms of representation and they should have the possibility of personalize the type of augmented information they want to see according to their preferences or even the application may have a mechanism for adapting the information according to their needs.

5.4.3 Hypothesis with respect to the dimensions of motivation from the ARCS model

In this sub-section we present the validation of the hypotheses that establishes a relationship between the 6-VARLE (*Use of Scaffolding*, *Real-time feedback, Degree of success, Learning outcomes, Time on-task and Watching videos*) and the four dimensions of the ARCS model of motivation (*Attention*, *Relevance*, *Confidence* and *Satisfaction*). As mentioned earlier, the hypotheses related to the dimensions of motivation from the ARCS model were validated by using correlations due to collinearity issues between the variables. This validation provides insights into the effect of the 6-VARLE on student motivation and therefore it might provide insights into how the modules associated to the 6-VARLE might affect student motivation in an AR learning experience. In this section the validation of hypotheses is organized according to each hypothesis.

H_5: The *Use of scaffolding* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality. Thus, a Spearman correlation was used.

Validation in Evaluation Mode

A Spearman correlation on the *Use of a scaffolding* strategy and the four dimensions of the ARCS model was used to explore any relationship between the variables. There is a positive moderate correlation between the *Use of a scaffolding* strategy in the Evaluation Mode and the *relevance* dimension of motivation ($r=0,564$, sig.= 0,012, $p<0,05$) and the *satisfaction* dimension of motivation ($r=0,642$, sig.=0,003, $p<0,01$). However, no significant relationship was found between the *Use of scaffolding* and the *attention* and *confidence dimensions*.

The results show that, in terms of motivation, the *Use of scaffolding* strategy supports the *relevance* dimension and *satisfaction* dimension of motivation in the Evaluation Mode in mobile

AR learning experiences. This result may be explained by the fact that *Use of scaffolding* strategy helps students to complete the learning tasks, which means that it provides the resources, such as information or instructions that students need to accomplish the task. In that regard, according to the UDL guidelines, if the learning environment provides the appropriate challenging tasks along with the resources to complete those tasks, students will be able to find the tasks that are motivating for them (Meyer et al., 2014). Our results, are in line with the results obtained by C.-H. Chen et al. (2016) who found that the scaffolding strategy integrated in an AR application with concept maps supported the four dimensions of motivation in particular the confidence dimension and satisfaction dimension. Our results also support the findings of D. Furió, Juan, Seguí, & Vivó (2015) on the positive effect of AR on student satisfaction.

We confirmed that providing scaffolds in mobile AR learning experiences in the VET level of education may help to create in students a positive view and perception of the learning task because the scaffolds help students to accomplish the task and reduce the levels of frustration and/or discouragement. In particular a scaffolding strategy may help to support the relevance and satisfaction dimensions of motivation in the VET level of education.

Validation in Guided Mode

In the Guided Mode the results showed no significant correlation between the *Use of scaffolding* approach and the four dimensions of the ARCS model. These results can be explained because in the Guided Mode students have more hints and information in order to complete the augmented reality activities so the need for asking for help in this mode is minimum.So there is no relationship between the U*se of scaffolding* strategy in the Guided Mode and the students' motivation.

H_6: The provision of *Real-time feedback* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality. Thus, a Spearman correlation will be used.

Validation in Evaluation Mode

A Spearman correlation on the use of the *Real-time feedback* and the four dimensions of the ARCS model in the Evaluation Mode showed that there is a positive and significant moderate correlation between the feedback provided to the student in the AR activities in Evaluation Mode in the mobile AR application and the *satisfaction dimension* of motivation ($r=0,408$, sig.= 0,021, $p<0,05$).

The results show that the use of the *Real-time feedback* has a relationship with the *satisfaction dimension*. One of the strategies suggested by Keller (2010) for promoting feelings of satisfaction is the "intrinsic reinforcement". This implies using positive feedback to reinforce students' positive feelings to improve satisfaction. These results are also in line with the recommendations of the UDL with respect to providing feedback that encourage perseverance (Meyer et al., 2014). In this regard, the UDL recommends providing mastery-oriented feedback which means that the feedback helps students to reach mastery rather than just confirm their success or remark the errors. Moreover, Chakraborty & Muyia Nafukho, (2014) found that one of the strategies for engagement in distance learning is to provide timely and consistent feedback. Thus, the provision of timely and consistent feedback in AR learning experiences may help to increase motivation in the *satisfaction* dimension. To the best of our knowledge, little research has previously evaluated the effect of real-time feedback on student motivation in mobile AR learning experiences. Consequently, our results contribute to the knowledge in the effect that real-time feedback has on student motivation in mobile AR learning experiences in he VET level of education. Moreover, further studies should explore the relationship between R*eal-time* *feedback* and the *attention*, *relevance* and *confidence dimensions* in mobile AR learning experiences.

No significant correlations were found between the use of the *Real-time feedback* and the *attention*, *relevance* and *confidence dimensions* of the ARCS model in the Evaluation Mode.

<u>Validation in Guided Mode</u>

A Spearman correlation on the use of the *Real-time feedback* and the four dimensions of the ARCS model in the Guided Mode showed that there is a positive and significant moderate correlation between the feedback provided to the student in the AR activities in the mobile AR application and the *satisfaction* dimension of motivation (r=0,417, sig.= 0,043, p<0,05, N=30). This result corroborates the findings obtained in the validation of this hypothesis in the Evaluation Mode.

In summary, the real-time feedback promotes feelings of satisfaction in mobile AR learning experiences in the VET level of education if the feedback is designed in a way that provides intrinsic reinforcement and rewarding reinforcement.

No significant correlations were found between the use of the real-time feedback and the *attention*, *relevance* and *confidence dimensions* of the ARCS model in the Evaluation Mode.

H_7: The students' *Degree of success* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk test for normality. Thus, a Spearman correlation will be used.

<u>Validation in Evaluation Mode</u>

A Spearman correlation on the students' *Degree of success* and the four dimensions of the ARCS model in the Evaluation Mode showed that there is a positive moderate and significant correlation between the students' *Degree of success* and the *satisfaction dimension* of the ARCS model (r=0,4, sig.=0,029, p<0,05, N=30). The correlations, with respect to the other dimensions of motivation (*attention, relevance and confidence*), were not significant. The results show that student *Degree of success* has a moderate relationship with the *satisfaction dimension*. This can be explained by the success opportunities that are created by the *Use of scaffolding* and the *Real-time feedback*, both of which increase student *Degree of success* and therefore the *satisfaction* dimension. In general, it seems that the students' *Degree of success* in AR learning experiences in the VET level of education has a positive effect on the *satisfaction* dimension of motivation.

In hypothesis H_2 we found that there is a positive and significant effect of both the *Use of scaffolding* and the *Real-time feedback* on student's *Degree of success*. In this hypothesis we found that the Degree of success has a relationship with the satisfaction dimension of motivation. Moreover, according to Keller (2010) rewarding outcomes form one of the strategies for promoting feelings of *satisfaction*. In that regard, the success opportunities that are supported by the *Use of scaffolding* and the *Real-time feedback* seem to be a rewarding experience for the students and therefore the students' Degree of success increases and at the same time this has a positive effect on the satisfaction dimension of motivation. This means that in mobile AR learning experiences in the VET level of education, completing challenging tasks with the support of scaffolding and real-time feedback is a rewarding outcome for students that will increase their *satisfaction*.

Our results contribute to the understanding of the relationship between the students' *Degree of success* and the *satisfaction* dimension of motivation in mobile AR learning experiences in the

VET level of education as well as the implications of the mechanisms needed to support the students' *Degree of success* (scaffolding and real-time feedback) .

Validation in Guided Mode

A Spearman correlation on the students' *Degree of success* and the four dimensions of the ARCS model in the Guided Mode showed that there is a positive moderate and significant correlation between the students' *Degree of success* and the *relevance dimension* of the ARCS model (r=0,488, sig.=0,016, p<0,05, N=30). The correlations with respect to the other dimensions of motivation (*attention, confidence and satisfaction*) were not significant. Compared to the Evaluation Mode, in the Guided Mode the student's *Degree of success* is moderately correlated with the *relevance dimension* of motivation. The *relevance dimension* of motivation is related to the extent to which students perceive the learning content or the learning experience as being important and related to their life, personal interests, needs, goals and experiences. Keller (2010) argues that one of the tactics for supporting *relevance* is to provide personal achievement. In the mobile AR learning experience the personal achievement corresponds to the student's *Degree of success.* One interpretation of these results is that the success opportunities created in the mobile AR learning experience as well as the information that students have available in the Guided Mode help them to connect the new content they are learning with previous experiences and knowledge which is indeed one of the strategies for supporting the *relevance* dimension in motivational design (Keller, 2010).

In consequence, a mobile AR learning experience in the VET level of education can support the *relevance dimension* of motivation if the AR learning experience is designed in a way that creates success opportunities that at the same time increase student's *Degree of success*. The success opportunities need to be balanced so as to have the appropriate level of challenge.

It is worth noting that in the Evaluation Mode, there was a significant correlation between the students' *Degree of success* and the *satisfaction dimension* of motivation but in the Guided Mode there was a significant correlation with respect to the *relevance dimension*. These results can be explained by nature of each mode. This means that in the Evaluation Mode students feel that they were evaluated and the success opportunities created by the components of the application created a feeling of satisfaction when completing the task. On the contrary, in the Guided Mode students felt that they were learning at their own pace and the success opportunities created in the application helped them to feel that the content was important. In this mode students did not feel that they were being evaluated.

H_8: Student motivation (ARCS dimensions) has a positive and significant effect on students' *Learning outcomes* in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk test for normality. Thus, a Spearman correlation will be used.

Validation in Evaluation Mode

A Spearman correlation on the students' *Learning outcomes* and the four dimensions of the ARCS model in the Evaluation Mode showed that there is a positive and significant moderate correlation between the students' *Learning outcomes* in the mobile AR application in the Evaluation Mode and the *relevance dimension* of motivation (r=0,493, sig.= 0,023, p<0,05) and the *confidence dimension* of motivation (r=0,475, sig.=0,029, p<0,05).

According to Keller (2010) relevance means that students perceive that the learning content is meaningful and meets their learning needs. If students recognize the learning content as relevant they will be more motivated to learn it (Keller, 2010). Our results confirm that there is a relationship between the relevance dimension of motivation and the student learning outcomes in mobile AR learning experiences in the VET level of education.

On the other hand, in terms of the *confidence dimension* the results are in line with the findings in the study of Hsieh, (2014) who found that students with higher levels of confidence and expectancy of success report better *Learning outcomes*. In general, learning motivation is an important predictor of students' *Learning outcomes* (T.-L. Hsieh, 2014). Our result is also in line with the findings of Ibanez, Di-Serio, et al. (2015). This finding is also consistent with the study by Fonseca, Martí, Redondo, Navarro, & Sánchez (2014) who found that AR through student motivation might help to improve student achievement (learning outcomes).

No significant correlations were found between the students' *Learning outcomes* and the *attention* dimension and *satisfaction* dimension of the ARCS model in the Evaluation Mode.

<u>Validation in Guided Mode</u>

A Spearman correlation on the students' *Learning outcomes* and the four dimensions of the ARCS model in the Guided Mode showed that there is a positive and significant moderate correlation between the students' *Learning outcomes* in the mobile AR application in the Guided Mode and the *attention dimension* of motivation (r=0,503, sig.= 0,006, p<0,01, N=30).

This means that, in the Guided Mode, the support for the *attention* dimension increase the students' learning outcomes. So mobile AR learning experiences should provide support for the *attention* dimension in order to improve students' learning performance. In particular mobile AR learning experiences should provide a mechanism for directing students' attention to the relevant information that students need at that time. Biocca, Owen, Tang, & Bohil (2007) introduced a technique for AR interfaces that is called omnidirectional attention funneling with the aim of guiding user's attention by using some attention cues. The authors claim that the attention funnel technique can support user's performance in terms of physical and virtual object selection as well as in navigation. In their study, Di Serio, Ibáñez, & Kloos (2013) suggest that AR help students to have higher levels of attention and the concentration that students achieve in the AR experience has a positive effect on learning performance. This finding is in agreement with the conclusion of Wei, Weng, Liu, & Wang (2015) on the positive effect of AR on the attention dimension of motivation.

These results might suggest that the scaffolding strategy can also be used as a strategy for directing students' attention to the information they need at a specific moment during the mobile AR learning experience in the VET level of education.

No significant correlations were found between the students' *Learning outcomes* and the *relevance*, *confidence* and *satisfaction dimensions* of the ARCS model in the Evaluation Mode.

H_9: The amount of time that students spend in the AR learning experience (*Time on-task*) has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk test for normality. Thus, a Spearman correlation will be used.

<u>Validation in Evaluation Mode</u>

A Spearman correlation on the students' *Time on-task* and the four dimensions of the ARCS model in the Evaluation Mode showed that there is a positive moderate and significant correlation between the *Time on-task* in the Evaluation Mode and the *attention* dimension (r=0,424, sig=0,024, p<0,05, N=30). Besides that, a positive moderate and significant correlation was found between the T*ime on-task* and the *relevance* dimension (r=0,417, sig=0,027, p<0,05, N=30). Finally, a positive moderate and significant correlation was found between the *Time on-Task* and the *satisfaction* dimension (r=0,482, sig=0,009, p<0,01, N=30). Interestingly, the student *Time on-task* variable has a moderate relationship with the *attention*, *relevance* and *satisfaction dimensions,* although no relationship was found with respect to the *confidence* dimension. Keller (2010) states that *Time on-task* is a direct measure of motivation. Thus, the overall results suggest that if students spend more time on the mobile AR learning experience, their levels of motivation in the dimensions of *attention*, *relevance* and *satisfaction* increase. This result is in line with the findings of Matcha & Awang Rambli (2015) who found that AR has the potential of increasing the time that students spend on a learning task.

It is worth noting that, this result was obtained in the Evaluation Mode, where students have a small amount of information available and they are challenged to complete the task with the knowledge acquired in the Guided Mode and by using the scaffolding and *real-time feedback*. It seems that an increased Time on-task was not the result of having a small amount of information available for completing the task. Instead, the increased Time on-task might be the result of students being engaged in the learning activity.

No significant correlation was found between the *Time on-task* and the *confidence dimension* of motivation. This result may be explained by the fact that an increase in the time spent in the Evaluation Mode is not perceived as positive. The amount of time that someone spends on evaluation is often perceived as a measure of the skills or abilities that the person has for solving the problem or completing the assessment test. In other words, if the time spent on evaluation is high, confidence may be decreased because of a negative perception in terms of a lack of ability to solve the problem. This may be stronger in a group where some students perceive their classmates as solving the problems more quickly than them. Thus, *confidence dimension* may be decreased. However, this situation needs to be analyzed in detail in future studies.

Validation in Guided Mode

A Spearman correlation on the students' *Time on-task* and the four dimensions of the ARCS model in the Evaluation Mode showed that there is a positive moderate and significant correlation between the *Time on-task* in the Guided Mode and the *confidence dimension* (r=0,435, sig=0,030, p<0,05, N=30).

Compared to the Evaluation Mode, in the Guided Mode the *Time on-task* is moderately related to the *confidence dimension*. The results suggest that in terms of the *Time on-task* with respect to the motivation, the Guided Mode and the Evaluation Mode are complementary because the *Time on-task* in the Evaluation Mode supports the *attention, relevance and satisfaction dimensions* and the *Time on-task* in the Guided Mode supports the *confidence dimension* of motivation. Jointly the Evaluation Mode and the Guided Mode support the four dimensions of the ARCS model of motivation. In terms of motivational design, the Guided Mode supports two strategies proposed by Keller (2010) for building confidence:

- Success opportunities: In the Guided Mode the amount of information available, the scaffolding approach and the real-time feedback provide opportunities so that students can succeed in the mobile AR learning experience.
- Personal control: Is partially supported by the rewarding nature of the real-time feedback in the mobile AR learning experience.

No significant correlations were found between the *Time on-task* and the *attention, relevance and satisfaction dimensions* of the ARCS model in the Guided Mode.

H_{10}: *Watching videos* has a positive and significant effect on the ARCS dimensions of motivation in mobile AR learning experiences.

Skewness and Kurtosis of the distribution of data used for validating this hypothesis were analyzed and the results show that the data do not follow a normal distribution. The results were corroborated by the Kolmogorov-Smirnov and Shapiro-Wilk test for normality. Thus, a Spearman correlation will be used.

Validation in Guided Mode

Taking into account that the module for *watching videos* only is available in the Guided Mode, this hypothesis was validated only in Guided Mode. A Spearman correlation on the use of the module for *watching videos* and the four dimensions of the ARCS model in the Guided Mode showed that there is a positive and significant moderate correlation between the use of the module for *watching videos* about the process and the *confidence dimension* of motivation (r=0,4, sig.= 0,031, p<0,05, N=30). This result shows that students feel more confident in terms of their knowledge about the topic. Our result is in line with the study by Bolliger et al. (2010) who found that the use of video podcast increases the *confidence* dimension of motivation. Moreover, this result is in line with other studies that suggest the positive effect of using video podcast in education to improve student motivation (Kay, 2012).

Our results provide insights to understand the effect that the use of videos might have on student motivation in AR learning experiences in the VET level of education. It can thus be suggested that a mobile AR learning experience may include videos about the topic that address one or more of the strategies suggested by Keller (2010) for building confidence: Success expectations, success opportunities and Personal responsibility.

No significant correlations were found between the use of the module for *watching videos* and the *attention*, *relevance* and *satisfaction dimensions* of the ARCS model in the Guided Mode.

5.5 VALIDATED MODELS FROM HYPOTHESES VALIDATION

As a result of the hypotheses validation four models were obtained: two for the Evaluation Mode (Figure 5-3 and Figure 5-4) and two for the Guided Mode (Figure 5-5 and Figure 5-6). Figure 5-3 shows the validated model for hypotheses H_1, H_2, H_3 and H_4 in Evaluation Mode. Likewise, Figure 5-4 shows the validated model for hypotheses H_1, H_2, H_3 and H_4 in Guided Mode.

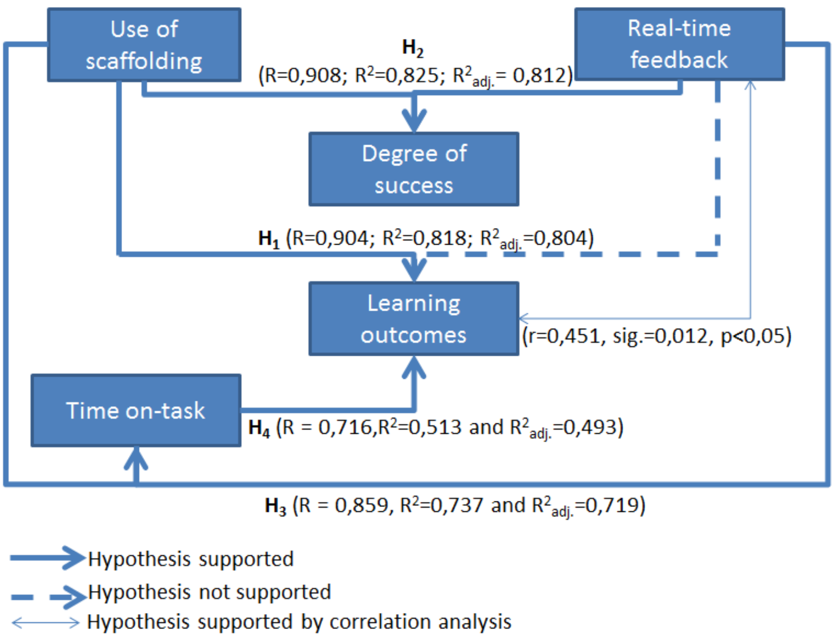

Figure 5-3. Validated model for hypothesis H_1, H_2, H_3 and H_4 in Evaluation Mode.

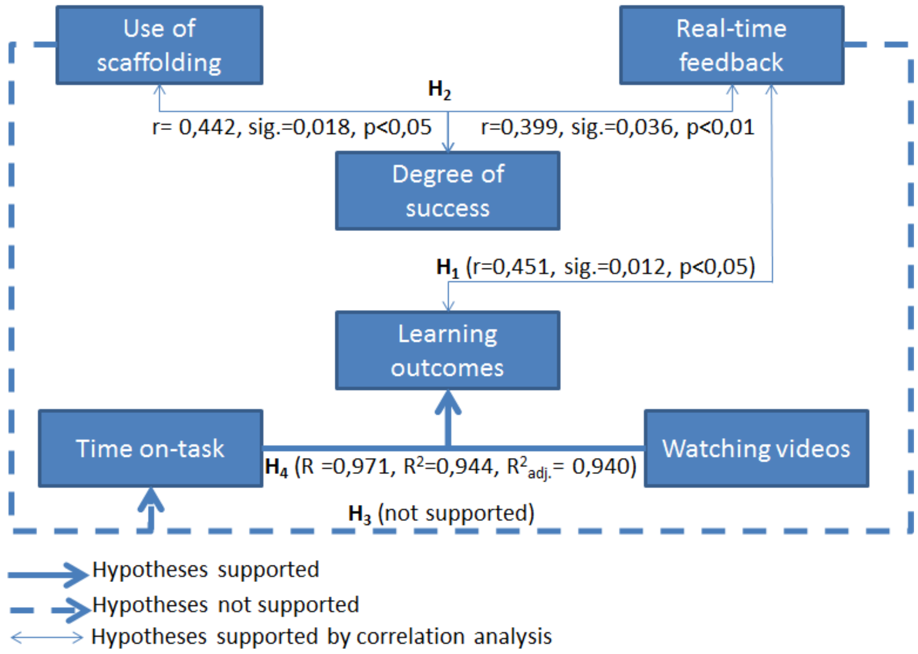

Figure 5-4. Validated model for hypotheses H_1, H_2, H_3 and H_4 in Guided Mode.

Figure 5-5 shows the validated model for hypotheses H_5, H_6, H_7, H_8, H_9 and H_{10} in Evaluation Mode. It is important to note that the *watching videos* variable does not appear in this model because this variable was validated only in the Guided Mode. Figure 5-6 shows the validated model for the same hypotheses but in the Guided Mode.

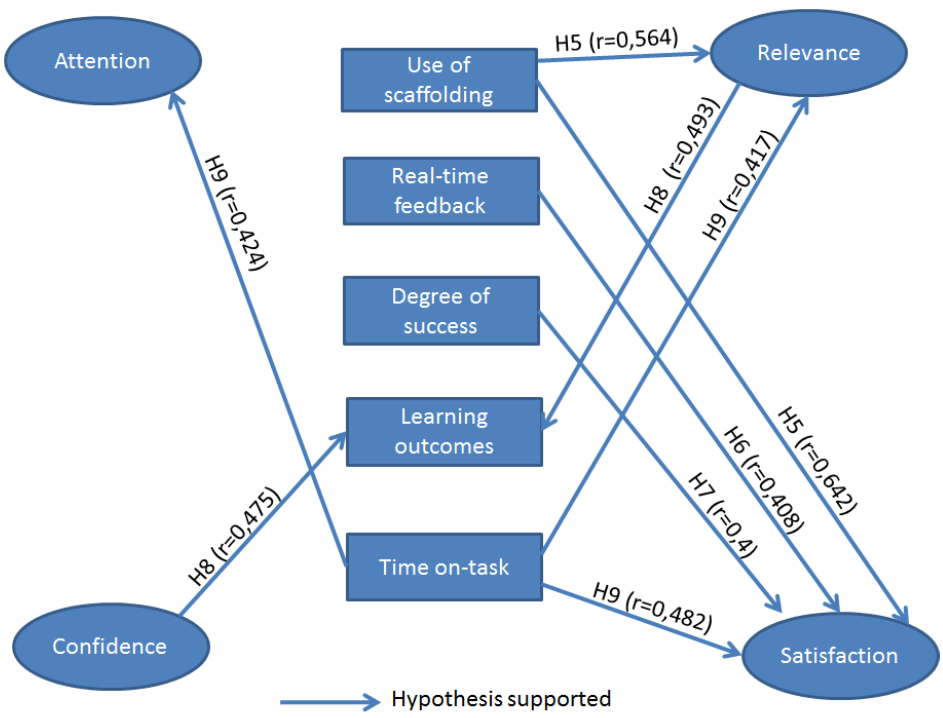

Figure 5-5. Validated model for hypotheses with respect to the ARCS dimensions of motivation in Evaluation Mode.

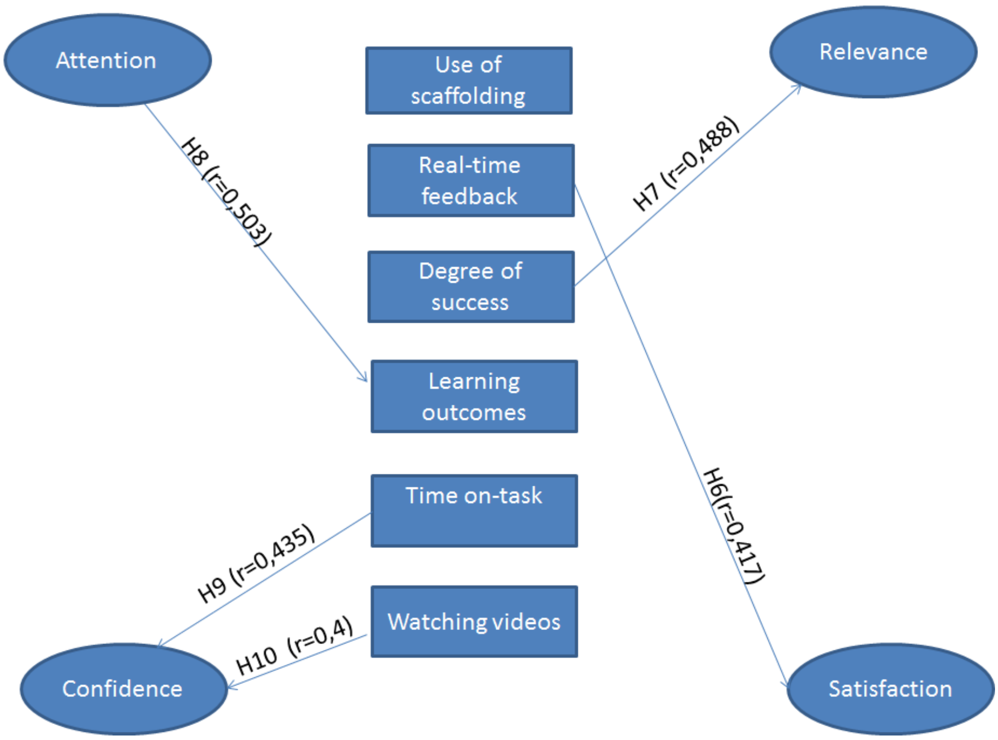

Figure 5-6. Validated model for hypotheses with respect to the ARCS dimensions of motivation in Guided Mode.

5.6 IMPLICATIONS OF THIS STUDY FOR THE DESIGN OF MOTIVATIONAL AR LEARNING EXPERIENCES

This section summarizes the main implications and findings obtained from the hypotheses validation and provides some recommendations on how to design motivational mobile AR learning experiences for the VET level of education and in particular for the VET programme of Car's Maintenance. Since these implications have been obtained from a mobile AR learning experience, the recommendations provided are intended for the design and development of mobile AR learning experiences. Some of the recommendations might be extended to desktop AR but further research is needed to confirm if the recommendations are valid for other types of AR or for other educational levels. Moreover, this study had some limitations that are described in section **¡Error! No se encuentra el origen de la referencia.**.

Sub-section 5.6.1 describes the implications of this study with respect to the relationships identified between the 6-VARLE (*Use of scaffolding, Real-time feedback, Time on-task, Degree of success and Learning outcomes* and *Watching videos)*. This section also reports on the implications of the relationships between these variables and provides recommendations for designing motivational mobile AR learning experiences.

Section 5.6.2 describes how the 6-VARLE positively affect the dimensions of the ARCS model of motivation. This section also provides recommendations on how these predictors should be included in the design and development of motivational mobile AR learning experiences.

5.6.1 Implications with respect to the *Use of scaffolding*, *Real-time feedback*, *Degree of success*, *Time on-task* and *Learning outcomes* (H_1, H_2, H_3 and H_4)

In this study, we found that the *Use of scaffolding* is a predictor of students' *Learning outcomes* but the *Real-time feedback* was not a predictor of students' *Learning outcomes (see hypothesis* H_1*).* Based on this result we suggest that mobile AR applications for the VET level of education might include a scaffolding mechanism for providing assistance to students to succeed in the learning activities in the AR learning experience and therefore to increase *Learning outcomes*. Although we found that the *Real-time feedback* was not a predictor of students' *Learning outcomes* in mobile AR learning experiences in the VET level of education (see hypothesis H_1), we found that there is a moderate correlation between the two variables which might imply certain association between them. However, further research is needed to confirm if *Real-time feedback* positively affect students' *Learning outcomes*.

We also found that the *Use of scaffolding* and *Real-time feedback* are predictors of students' *Degree of success* (see hypothesis H_2). Based on this finding, we recommend that mobile AR learning experiences for the VET level of education include a scaffolding strategy and a mechanism for providing real-time feedback as key components for providing success opportunities. Success opportunities, which will, in turn, allow students to boost their *Degree of success* in the learning experience and, therefore, increase or sustain their motivation and learning outcomes. This recommendation is also in line with the UDL guidelines, in which the use of graduated scaffolds can be used not only to help learners to reach mastery, but also to assist those learners with different educational needs and preferences to succeed in challenging tasks (Meyer et al., 2014).

Based on our findings, the literature on scaffolding in AR and our experience during this study, we think that scaffolding in mobile AR might have two purposes. The first, which is in line with the findings of Ibanez et al. (2016) and C.-H. Chen et al. (2016), is to provide pieces of knowledge that are relevant to students at the appropriate moment during the experience so that students can complete the learning task in the mobile AR experience and increase their learning outcomes. We recommend that, for those students who have more background knowledge, the scaffolding strategy could show less information, while for those who need to improve some specific skills, the scaffolding strategy could give more information and hints to help them understand and acquire those necessary skills. In this regard, personalization and adaptation based on a students' model could be used to generate the adaptive scaffolding. The second purpose of scaffolding strategies in mobile AR might be to guide students by using prompts, cues or hints (Tsai & Huang, 2014), to find the augmented information . For example, in location-based AR the scaffolding may help students to find points of interest. In marker-based or marker-less AR, the scaffolding may help students to filter or organize the augmented information according to their needs, preferences or the context to successfully complete the task.

An important implication here is that mobile AR learning experiences for the VET level of education should provide different levels of challenge in keeping with a student's knowledge, background, context, preferences and needs. However, the levels of challenge need to be accompanied by the resources and assistance (scaffolding) so that students can succeed in the tasks and therefore increase their *Degree of success*. Moreover, mobile AR learning experiences should include an explanation of the challenge posed to students so that they understand exactly what they are expected to do and what type of problems they will be able to solve.

Use of scaffolding and *Real-time feedback* were also found to be predictors of students' *Time-on task* (see hypothesis H_3). Thus, we think that mobile AR learning experiences might provide a better support for increasing students' *Time on-task* if the applications are designed with scaffolding and real-time feedback mechanisms. In that regard, Meyer et al. (2014) states that one of the strategies for promoting expectations and optimizing beliefs is to increase on-task behaviors to face distractions. This means that scaffolding and real-time feedback might be useful for focusing the attention of students in the learning task and therefore increase students' Time on-task. . As for the design of the real-time feedback, Keller (2010) recommends that the feedback should be positive and attributional. This means that in mobile AR learning experiences for the VET level of education, the applications could provide messages or show actions in the user interface that make students feel they can succeed. Real-time feedback should also provide rewards and information to encourage students to continue with the task and thus, increase student *Time on-task*. Keller (2010) also states that it is important to consider that many students may be motivated by the rewards that can be obtained after the completion of a task (i.e. extrinsic motivation) and this emphasizes the need of rewarding feedback, while others may be motivated by the pleasure of doing the task (intrinsic motivation). On the other hand, according to the UDL guidelines, providing differentiated feedback is important to direct students' efforts and emotions to succeed in the tasks (Meyer et al., 2014). This highlights the importance of *Real-time feedback* which should include mastery-oriented feedback (i.e. the kind of feedback that guide learners to succeed in the task and reach mastery) rather than a simple confirmation of completing a task well or bad (Meyer et al., 2014).

Since the hypotheses in this study were validated in Evaluation Mode and in Guided Mode, we can conclude that in mobile AR learning experiences the level of challenge needs to be balanced with the appropriate scaffolding and real-time feedback so that it can be effective in terms of motivation and learning outcomes. For instance, if the level of challenge is low but the amount of information available through the scaffolding strategy is high, students will not use the scaffolding strategy to complete the task and they may even be demotivated because the task will be easy to complete. A design consideration to deal with this issue in mobile AR learning experiences can be to provide an adaptive mechanism that sets the appropriate level of challenge for each student according to their needs or preferences and provide adaptive scaffolding that meets students' needs to help students to succeed in the tasks.

The *Time on-task* and *watching videos* in the mobile AR learning experience are predictors of students' *Learning outcomes* (see hypothesis H_4). Videos recorded can be the augmented information of objects in the real world and this form of information may provide a different experience compared to text, audio recordings, images or 3D models. This finding is in line with the benefits reported in other studies with respect to the effectiveness of video podcast to improve learning outcomes (Kay, 2012). Moreover, videos can be a different form of representation that can be used in mobile AR learning experiences jointly with other forms of representation. This is in-line with the UDL in terms of providing different forms of representation (Meyer et al., 2014) so that all students can access the information according to their preferences and needs. Based on our findings and based on the UDL guidelines, we suggest that mobile AR learning experiences for the VET level of education might be designed with a wide variety of resources to convey the same concept and the system might be personalized according to students' needs, preferences or according to the context.

Moreover, we also found that students' *Time-on task* is a predictor of their *Learning outcomes* (see hypothesis H_4). This result is in line with the findings of Kovanović et al. (2015) and therfore we recommend that mobile AR learning experiences for the VET level of education should promote on-task behaviors to increase students' learning outcomes.

5.6.2 Implications with respect to the dimensions of the ARCS model of motivation (H_5, H_6, H_7, H_8 and H_9)

As mentioned earlier, the ARCS model provides an overview of the major categories of human motivation, divided into four dimensions: *attention*, *relevance*, *confidence* and *satisfaction* (Keller, 1987). In section 5.6.1, we described how the 6-VARLE are related one with each other, and in this section, we explain how the 6-VARLE are related to the dimensions in the ARCS model.

The *Use of scaffolding* was found to be related to the *relevance* dimension and *satisfaction* dimension of motivation in the Evaluation Mode (see hypothesis H_5). This finding suggest that mobile AR learning experiences for the VET level of education might include a scaffolding mechanism to support the *relevance* and *satisfaction* dimensions of motivation. Based on the main characteristics of the *relevance* dimension in the ARCS model of motivation, the scaffolding mechanism would need to be designed in a way that helps to create a positive perception of the learning task in terms of usefulness and meaningfulness (Keller, 2010) so that students can feel that the learning task is connected to their life and personal needs or interests. On the other hand, the scaffolding mechanism should be designed in a way that provides positive reinforcement and to provide an effective assistance to students to achieve in the learning task. However, in the guided mode we did not find any relationship between the Use of scaffolding and the four dimensions of the ARCS model of motivation. This result might be explained by the fact that the Guided Mode was designed for students to have all the information available and the level of challenge is low. For this reason, students do not need to use the scaffolding mechanism to complete the learning task.

Real-time feedback in mobile AR learning experiences was found to be related to the *satisfaction* dimension of motivation (in the Guided Mode and Evaluation Mode – see hypothesis H_6) in mobile AR learning experiences. Hence, we recommend that real-time feedback should provide intrinsic reinforcement, meaning that feedback should be positive and reinforce students' feelings of achievement and engagement (Keller, 2010) throughout the task. We also recommend that mobile AR learning experiences should include a mechanism for real-time feedback designed according to the recommendations of Keller (2010) to promote *satisfaction*. Moreover, Keller (2010) states that, among others, one of the strategies to provide personal control is to allow students to work at their our own pace. This is one of the advantages of mobile AR learning experiences, because each student can work on their mobile device at any time they like.

As for the *Degree of success*, this variable was also found to be associated to the *satisfaction* dimension of motivation in the Evaluation Mode (see hypothesis H_7). This might suggest that a mobile AR application for the VET level of education which allows students to succeed in challenging tasks (*Degree of success*) might help to promote a positive perception of satisfaction in students. Despite of the fact that this relationship between *Degree of success* and *satisfaction* might be present in other learning experiences different from AR, our finding confirm that students *Degree of success* is also a factor that positively affect motivation in AR learning experiences. However, in the Guided Mode the *Degree of success* was found to be related to the *Relevance* dimension of motivation. This might suggest that in the Guided Mode, when the learning process is taking place for those who are becoming expert learners, the possibilities of success in the AR learning experience help to reinforce the fact that the content can be perceived as relevant and connected to the students' learning needs.

We also found that in AR learning experiences, the students' *Learning outcomes* are highly related to the *relevance* dimension and *confidence* dimension of motivation in the Evaluation Mode (see hipothesis H_8). This result suggest that the mobile AR learning experiences that support the *relevance* dimension and *confidence* dimension of motivation might also increase students' learning outcomes. For instance, the *Use of scaffolding* was also found to be related to the *relevance* dimension of motivation as mentioned earlier. Therefore, the implementation of a scaffolding module might support the relevance dimension of motivation and at the same time contribute to increase students' learning outcomes. In this regard, the three strategies suggested by Keller (2010) to support the *relevance dimension* are: goal orientation, motive matching and familiarity. *Confidence dimension*, also has three strategies: expectations of success, success opportunities, and personal control (Keller, 2010). With regard to the *confidence* dimension of motivation, our findings suggest that a mobile AR learning experience for the VET level of education might need to address two aspects: success opportunities and personal control (Keller, 2010). Success opportunities can be created with scaffolding by adjusting the appropriate level of challenge for each student's requirements. As for personal control, the real-time feedback should be mastery-oriented (Meyer et al., 2014) and positive attributional (Keller, 2010).

According to our findings, when the level of challenge is lower (in this study: the Guided Mode), the *attention* dimension of motivation is highly related to students' learning outcomes. This means that when the amount of information available in the mobile AR learning experience is high and the level of challenge is low, it is important to direct students' attention to the information that is most relevant for them or the information that students need at that specific time. In contrast, when the level of challenge is high (in this study: the Evaluation Mode), it is important to support the *confidence* and *relevance* dimensions of motivation to effectively support students' *Learning outcomes*.

We also found that the *Time on-task* variable in mobile AR learning experiences is moderately related to the *attention*, *relevance* and *satisfaction* dimensions of motivation (see hypothesis H_9). This means that the amount of time that students spend on the AR learning experience is highly related to the *attention*, *relevance* and *satisfaction* dimensions of motivation. Although it is generally recognized that student motivation is needed to increase student *Time on-task,* in this study we seek to identify if the amount of time that students spend on the AR learning experience might have any effect on student motivation. This finding provides insights into the effect that the time that students spend on the AR learning experience might have on student motivation. In particular, this might suggest that the mobile AR applications that are able to capture the interest of the students and increase their time on the learning activities are the applications that better support student motivation. However, further research is needed in other educational levels to validate this claim.

On the other hand, in the Guided Mode we found that the Time on-task variable is associated to the *confidence* dimension of motivation. This means that in the Guided Mode, when students are exploring the learning content, in particular when the learning process is taking place, the amount of time that students spend in the AR learning experience is directly related to the confidence dimension of motivation.

Moreover, according to the results, the use of videos in mobile AR learning experiences for the VET level of education supports the *confidence* dimension of motivation (see hypothesis H_{10}). In particular the information that the videos convey helps students to feel more confident to succeed in the assessment. It is important to note that the videos were only available in the Guided Mode and for that reason this hypothesis was validated in this mode only.

5.7 CONCLUDING REMARKS

In this chapter we identified the predictors of student motivation for AR learning experiences in the VET level of education. This means that we identified the factors that positively affect student motivation during an AR learning experience. These predictors may help researchers, software developers and educational technology experts to develop authentic motivational AR learning experiences. We also uncovered the relationships between these predictors and we identified how these predictors affect the dimensions of the ARCS model of motivation. A summary of the relatioships uncovered as a result of this study is presented as follows:

- The *Use of scaffolding* positively affects the *relevance* and *satisfaction* dimensions in the Evaluation Mode. There were no relationships identified for the Guided Mode.
- The *Real-time feedback* positively affects the *satisfaction* dimension in the Evaluation Mode and in the Guided Mode.
- The *Degree of success* positively affects the *satisfaction* dimension in the Evaluation Mode and the *relevance* dimension in the Guided Mode.
- *Learning outcomes* are positively affected by the *confidence* and *relevance* dimensions in the Evaluation Mode. Learning outcomes are positively affected by the *attention* dimension in the Guided Mode.
- The *Time on-task* positively affects the *attention*, *relevance* and *satisfaction* dimensions in the Evaluation Mode. *Time on-task* positively affects the *confidence* dimension in the Guided Mode.
- *Watching videos* positively affects the *confidence* dimension in the Guided Mode.

Moreover, in section 5.6 we presented the implications of this study for the design and development of motivational AR learning experiences in which we described how the relationships uncovered may be considered in the design and development of motivational AR learning experiences.

The main contribution of the results presented in this chapter is the identification of the predictors of student motivation in AR learning experiences for the VET level of education which addressed and contributes to tackle the first open issue identified in the literature review (see CHAPTER 2): "**OI1:** Research studies on AR in education do not clearly define how and why AR increases student motivation.".

The identification of the predictors of student motivation in AR learning experiences is one of the main sources for the definition of the framework for the design of motivational AR learning experiences which is completely described in CHAPTER 6. This led us to the next chapter in which we describe the framework for the design of motivational AR learning experiences.

The limitations associated to this study are reported in CHAPTER 8 in section **¡Error! No se encuentra el origen de la referencia.**.

5.8 PUBLICATIONS ASSOCIATED TO THIS STUDY

The validation process of hypotheses in the Evaluation Mode only together with the results, discussion and implications of this study were published in the following paper:

Jorge Bacca, Silvia Baldiris, Ramon Fabregat, Kinshuk. **Predictors of student motivation in augmented reality learning experiences in vocational education.** [Submited]

CHAPTER 6
THEORETICAL DEFINITION OF THE FRAMEWORK

6.1 INTRODUCTION

In CHAPTER 5 we identified the predictors of student motivation in AR learning experiences and we discussed the implications of these predictors for the design and development of motivational AR learning experiences. In this chapter we present the framework for the design of motivational AR learning experiences. The aim of this framework is to inform the design and development of motivational AR learning experiences and therefore this framework contributes to the knowledge in the design and development of AR learning experiences that support motivation.

The definition of the framework presented in this chapter relies on two main sources: the study of predictors of student motivation and the review of literature on AR frameworks and literature relevant for each component of the framework. On the one hand, the study of predictors of student motivation (described in CHAPTER 5) feeds the definition of the framework because it provides the factors or aspects that positively affect motivation in AR learning experiences and on the other hand the literature review on AR frameworks in education (described in CHAPTER 2) together with a review of literature for each module of the framework provide a theoretical perspective for the definition of this framework as well as collecting the research conducted by other authors.

The framework described in this chapter corresponds to the second activity of the Hypothetico-deductive and Explanatory Phase (**AHEP2**) followed in this thesis. Moreover, the definition of the framework addressed the specific objective “**SO4:** To define the framework for the design and development of motivational AR learning experiences”. Besides that, in this chapter we addressed the first research question of this thesis: “**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?” and finally we contributed to tackle the third open issue identified in the literature review: “**OI3:** Very little has been done in terms of the definition of AR frameworks in education”.

This chapter is organized as follows: section 6.2 describes the theoretical underpinnings of this framework, section 6.3 presents the complete description of the framework and section 6.4 presents the conclusions of this chapter.

6.2 THEORETICAL UNDERPINNINGS OF THE FRAMEWORK

The ARMotiD framework is a framework for guiding the design of motivational Augmented Reality (AR) learning experiences for the VET level of education. The framework is built upon the theories of: motivational design (Keller, 2010), Universal Design for Learning (UDL) (Rose & Meyer, 2002; Meyer, Rose, & Gordon, 2014) and Co-Creation (Sanders & Stappers, 2008).

Figure 6-1 shows the theoretical foundations that support the ARMotiD framework and these theories are described in the following sub-sections.

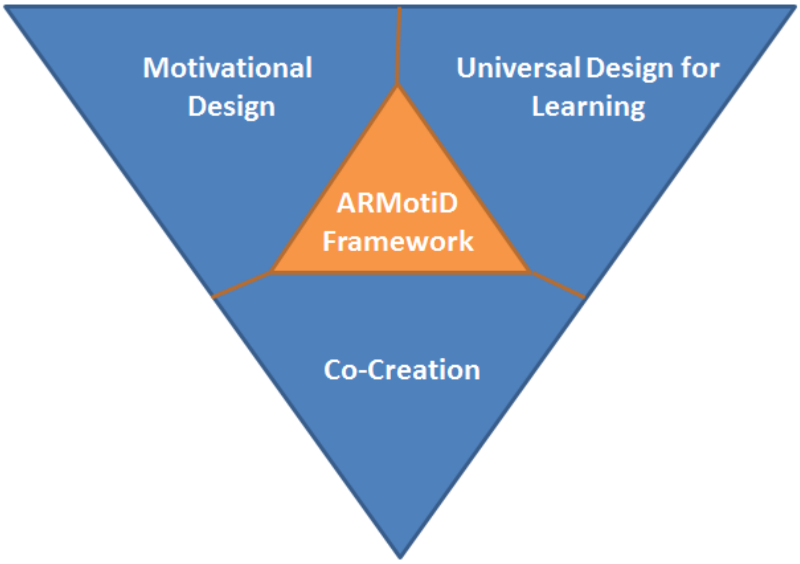

Figure 6-1. Theoretical foundations of the framework.

6.2.1 Motivational Design Theory

The motivational design theory provides recommendations on how to support the four dimensions of the ARCS model of motivation. More details about the motivational design theory are provided in section 2.7.1.

We draw on the motivational design theory to define recommendations on how the modules in the ARMotiD framework address the guidelines provided by the motivational design. Consequently, the ARMotiD framework addresses the recommendations from the motivational design theory so that these recommendandations can be applied to the design and development of motivational AR applications.

6.2.2 Universal Design for Learning

As mentioned earlier in section 2.7.3, one of the UDL principles is to provide multiple means of engagement. This principle is directly connected to students' motivation and some recommendations provided by the UDL are essential to inform the design of motivational AR learning experiences. Thus, the ARMotiD framework draws on the UDL by incorporating and adapting some of its recommendations to inform the design of motivational AR learning experiences.

6.2.3 Co-creation and Co-design

The ARMotiD framework draws on the concept of Co-creation and Co-design because we hypothesize that AR learning experiences are the result of a joint work between teachers, software developers, educational technology experts and students. More details on the definition of Co-creation and Co-design that we adopted are presented in section 2.7.4.

In CHAPTER 3 and CHAPTER 4 we presented and applied a methodology that we defined for the co-creation of mobile AR applications. In particular, we applied the methodology for the design and development of the Paint-cAR application. In those chapters the phases of the methodology were explained and the development of each phase was described. The methodology was in line with the definitions of co-design and co-creation that we have mentioned earlier. From this experience, we identified the advantages of a co-created mobile AR learning experience.

To conclude, according to the literature and according to our experience in the design and development of the Paint-cAR application (described in CHAPTER 3 and CHAPTER 4), the concepts of co-creation and co-design are of great value in the development and design of AR learning experiences. In the ARMotiD framework we draw on the concept of co-creation and co-design (as a specific instance of a co-creation process) to refer to the process of collective creativity that involves different actors such as teachers, software developers and educational technology experts in the process of creating motivational AR learning experiences. The concepts of co-creation and co-design represents the joint work of teachers, software developers, designers and other actors for creating effective motivational AR learning experiences.

6.3 ARMotiD FRAMEWORK

The ARMotiD framework is divided into 3 major sections: Supporting applications, Augmented Reality applications (Mobile or Desktop) and Input, Sensing & registration. Figure 6-2 shows these three major sections of ARMotiD framework. Each major section is divided into modules and the section Augmented Reality Applications (Mobile or Desktop) is divided into four layers: UI and Interaction Layer, Augmented Reality Activities/Experiences Layer, Students support Layer and Assessment Layer. For each module of the framework a group of recommendations on how to develop the module are provided, as well as reasons on how the module supports the UDL and how the module supports the design of motivational AR learning experiences. In this section the following notation will be used:

- H-UDL-XXX-YY: Where H stands for “How?”, UDL stands for Universal Design for learning, XXX corresponds to the letters that identify the module of the framework (see Figure 6-2) and YY is a consecutive number for numbering the items. This code represents the reasons on how the module of the framework supports the UDL.
- H-Mot-XXX-YY: Where H stands for “How?”, Mot stands for Motivational Design, XXX corresponds to the letters that identify the module of the framework (see Figure 6-2) and YY is a consecutive number for numbering the items. This code represents the reasons on how the module of the framework supports the motivational design theory and therefore the design of motivational AR learning experiences.
- R-D-XXX-YY: Where R stands for “recommendation”, D stands for “development”, XXX corresponds to the letters that identify the module of the framework (see Figure 6-2) and YY is a consecutive number for numbering the recommendation. This code represents the recommendations for developing the corresponding modules of the framework.

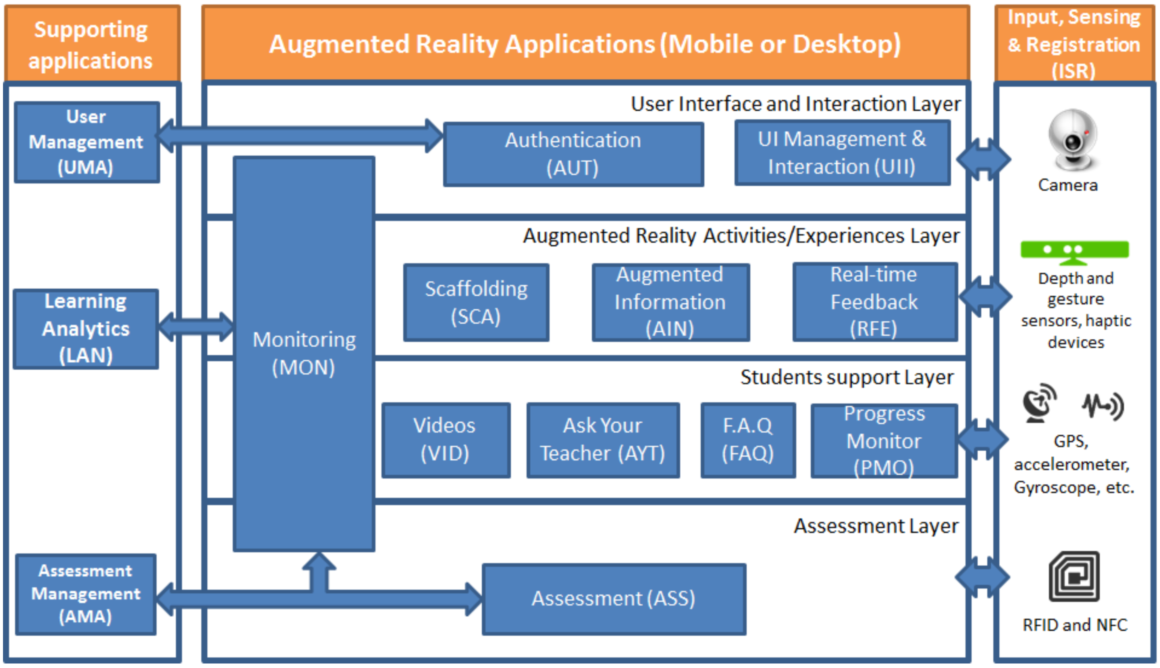

Figure 6-2. Detailed view of ARMotiD Framework.

6.3.1 Section 1: Supporting applications

This section of ARMotiD framework includes mobile applications or other web-based applications that manage information externally (outside the AR application). Supporting applications receive outputs from the AR application or provide inputs to the AR application as shown in Figure 6-2.

This section of the framework is based on the predictors of students motivation presented in CHAPTER 5 and is based on the theoretical underpinnings from the literature as described later. This section of the framework contains the following three modules: User Management, Learning Analytics and Assessment Management as shown in Figure 6-3. For each one of these modules, recommendations on how to implement or develop the module are provided.

Figure 6-3. Supporting applications section of the ARMotiD framework.

User Management (UMA)

The UMA is a module that consists of authorizing the access of users to the application and managing users (create, delete, update, and retrieve). Since it is important to identify which instance of the application is being used by each student, the User Management module assigns a unique code to each student.

This module was defined according to our experience in the co-creation of the Paint-cAR application as described in CHAPTER 3 and CHAPTER 4. During the co-creation process, teachers suggested that it would be important to record students' progress in the application. Hence, the user management module was needed to identify each student with the corresponding instance of the application. In general, we think that this module is an important component to record students' progress in the AR applications.

- **Recommendations on how to develop the User Management module:**
  - **R-D-UMA-01:** The UMA module can be implemented in any programming language as a web application. However it is important to note that this module will be connected to other modules and will have to send and receive information from and to the mobile AR application or the desktop AR application. Thus, the module should support transmission over HTTP in any format such as JSON or XML to provide interoperability and support concurrent connections. As shown in Figure 6-2 the Authentication module sends information to this module for validating students' access in the AR application.
  - **R-D-UMA-02:** The UMA module will use a database to store information about the students and data about application usage, so a database management system with good performance can be used.
  - **R-D-UMA-03:** Since the UMA module will be used by teachers to authorize or not the access to students it is important to achieve an easy to use user interface (usability).

- **R-D-UMA-04:** If the UMA module is implemented as a web application, it would desirable that the application can be responsive so that teachers can use it from a mobile device like a tablet or a smartphone.
- **R-D-UMA-05:** It would be important that the design of the UMA module follow the accessibility guidelines (WCAG) (W3C, 2012) so that teachers can use it without any restriction.

Learning Analytics (LAN)

This module displays analytics about students' progress from data collected by the Monitoring module (MON) when students interact with the application. Students can see analytics about students' progress in the application, their grades obtained in the self-assessment module and a comparison with the rest of the group. On the other hand, teachers may also have some visualizations. For instance, teachers may see information about the students' progress in the application with detailed views for each student and information regarding to the sections in the learning content or learning activities where students are experiencing difficulties. The learning analytics are visualized in mobile devices and in desktop PC. These analytics may help teachers to make decisions on their classes (Avila, Baldiris, Fabregat, & Graf, 2017) or at the institutional level (Dawson & Siemens, 2014). On the other hand, according to the UDL guidelines, it is important to provide mechanisms to help students monitor their behaviours and to identify the progress they are doing or the aspects in which they need to improve (Meyer et al., 2014). Hence, learning analytics may help students to recognize their progress and help them to self-regulate their learning process.

The recommendations for the development of this module come from the literature and our experience.

- **Recommendations on how to develop the Learning Analytics module:**
  - **R-D-LAN-01:** The LAN module should be usable so that teachers and students can understand and use the information provided through this module. The information provided should be accurate and can be differentiated by using colors (Yigitbasioglu & Velcu, 2012).
  - **R-D-LAN-02:** Since the LAN module uses the information collected by other modules such as the Monitoring module and the Progress Monitor, according to our experience this module should have interfaces for providing interoperability with these modules and to request information from these modules.
  - **R-D-LAN-03:** The LAN module should take advantage of software libraries for data visualization with the possibility of customizing the display of information. For additional recommendations on how to develop a dashboard for visualizing information please refer to the review of literature by Yigitbasioglu & Velcu, (2012).

Assessment Management (AMA)

This module provides functionalities for the management of the assessment but the module does not work in the AR application. The AMA module works in an external application that can be a web application, a mobile application or both. Teachers use this external application to configure or adjust parameters related to the assessment process in the AR application. For instance, teachers might have functionalities for creating tests to evaluate students' learning outcomes. In this case the system may have a database of different types of questions, classified according to their level of difficulty and the system may provide an adaptive mechanism to send certain questions to the AR application to be answered by students according to the students' expertise or knowledge. Teachers might also be able to enable or disable certain functionalities of the AR application in order to increase or decrease the level of challenge posed to students in the AR application. If the AR application provide support for a peer assessment process as reported in the study by Chao, Lan, Kinshuk, Chang, & Sung (2014), the AMA module may provide functionalities for teachers to supervise that the peer assessment process with the AR application is being carried out as expected.

According to our experience in the design and development of the Paint-cAR application and the web application for teachers, the AMA is relevant for teachers because they want to have control over the assessment process of students so that they can adapt the process according to the students' needs, according to specific needs in the teaching process at certain times or with the aim of collecting information about the students' learning process. There is a flow of information between the AMA and the Assessment (ASS) Module of the AR application to send and receive information related to the assessment process. In particular, if the assessment strategy can be automatically revised, the Assessment Management module should be in charge of this process and send the results to the ASS. Thus, the design of both modules needs to be carefully planned to provide as much parameterization as possible so that the assessment can be adjusted to the needs of the teacher. Hence, based on our experience in the development of the Paint-cAR application the following recommendations are suggested:

- **Recommendations on how to develop the Assessment Management module:**
    - **R-D-AMA-01:** The AMA module can be developed in any programming language as a web application. This module will be used mainly by teachers, so an easy to use (usable) site is preferred.
    - **R-D-AMA-02:** Since the AMA module should allow the storage of multiple-choice questions or other type of questions an appropriate database management system is needed.
    - **R-D-AMA-03:** A mechanism for randomly choosing the questions from the repository in the AMA module is needed to provide a different test each time for each student. This mechanism will provide a test that is different for each student.
    - **R-D-AMA-04:** Each question can be identified with a level of challenge or difficulty level. This mechanism will provide the possibility of creating adaptive test according to students' performance so that the application can adjust to the appropriate level of challenge for each student. This is in-line with one of the checkpoints of the UDL that supports the guideline of "Providing multiple means of representation": "Differentiate the degree of difficulty or complexity within which core activities can be completed" (Meyer et al., 2014, p. 31). This is also in-line with the findings of Lai & Hwang (2015) in which they claim that language teachers prefer the provision of adaptive learning content because this lead to an improvement in teaching quality and students' learning outcomes.
    - **R-D-AMA-05:** The system should be able to create a test with a specified number of questions and should be able to send the test to each student as requested. Besides that, the system should store each answer provided by the students and should maintain the state of the test until the student finishes the test in the same session or in subsequent sessions. Thus, the module should support transmission over HTTP in any format such as JSON and XML for data interchange between the system and the AR application.

6.3.2 Section 2: Augmented Reality Applications (mobile or Desktop)

This section of the ARMotiD framework defines the layers and modules that support the dimensions of the ARCS model. These layers and modules were defined according to the predictors of student motivation identified in CHAPTER 5 and according to the literature on AR applications. The layers of the ARMotiD framework (shown in Figure 6-4) are:

1. User Interface and Interaction Layer
2. Augmented Reality Activities/Experiences Layer
3. Student Support Layer
4. Assessment Layer

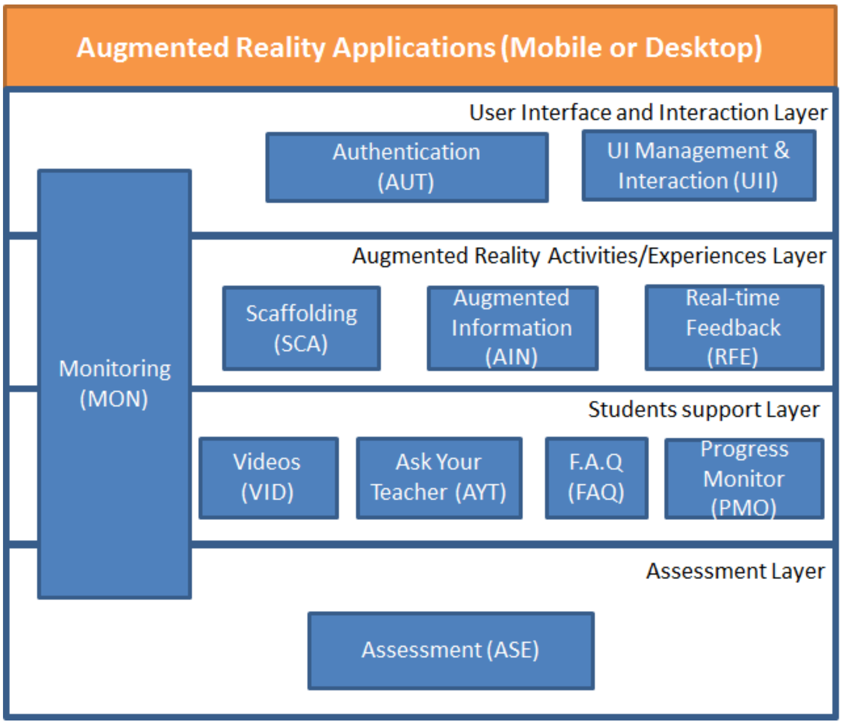

Figure 6-4. Augmented reality applications section of the ARMotiD framework.

How this section of the framework is organized?

The following sub-sections are organized according to the four layers and each layer is organized according to the modules contained in. For each layer a description of the layer is provided and for each module contained in the layers, the following information is provided: A description on how the module appears in the literature and why the module is important for AR applications, a description of its functionalities, details on how the module support the implementation of the UDL guidelines and the reasons on how the module supports the design of motivational AR learning experiences as well as recommendations on how to develop the module. In terms of the support for the design of motivational AR learning experiences, it is important to note that the UDL guidelines also support the motivational design, so some of the recommendations for supporting the motivational design also come from the UDL. For each module, the descriptions on how the module addresses the UDL guidelines, how the module supports the motivational design and the recommendations on how to develop each module come from the following sources of information:

1. The literature on AR in education that is described together with the description of each module. In particular, we identified how each module has been considered in the development of the AR applications reported in the literature.

2. The recommendations on the UDL guidelines (Meyer et al., 2014) in which there are many aspects that can be applied to the development of AR applications in education.
3. The recommendations on the Motivational design theory (Keller, 2010) in which there are some recommendations for supporting student motivation.
4. Our experience in the co-creation process of the Paint-cAR application and the tests we did with students and the suggestions of the supervisors of this thesis in the field of technology-enhanced learning.

User Interface and Interaction Layer

This layer contains the modules that manage the user interface and the interaction processes of the application. In general, since there is a wide variety of devices that are used in AR applications such as haptic devices, special projectors, sensors of depth and movement, RFID, NFC, etc., this layer is an abstraction of the modules and processes that manage the interaction with these devices and redirect the flow of input and output information from and to these devices and the other layers of the ARMotiD framework. Moreover, this layer manages the output of information to the user interface. The following subsections describe the modules included in this layer: Authentication module and the UI (User Interface) management & Interaction module.

Authentication (AUT)

The AUT module manages the processes of registering the student and its device to the system with the aim of identifying the instance of the application associated to each user. This module also verifies if the student is allowed to use the application.

The recommendations for this module emerged from our experience in the development of the Paint-cAR application.

- **Recommendations on how to develop the Authentication Module:**
    - R-D-AUT-01: The AUT module should send information to the server and more specifically to the web application that contains the User's Management module to validate if students are authorized to use the mobile AR application.
    - R-D-AUT-02: The AUT module should support transmission over HTTP in formats like JSON or XML to send and receive information from and to the mobile AR application.
    - R-D-AUT-03: The AUT module needs to store information in the device to identify the student that is using the instance of the application.

UI Management & Interaction module (UII)

This module manages the user interface with the purpose of showing the information to the user. This module also manages the interaction mechanisms with the application. Since this module renders the information to the user, it is important to consider accessibility features so that all users including those with disabilities can be able to access to the information. In that regard, the user interface and interaction mechanisms of this module should be developed by following the Web Content Accessibility Guidelines (WCAG) (W3C, 2012) and the recommendations for applying these guidelines to the design of mobile applications (W3C, 2015). Some examples of applying these guidelines are: To provide the possibility of adjusting the size of the text according to the screen size and providing a correct level of contrast for different light conditions. Besides that, it is important to provide a mechanism so that users can have a clear understanding of the navigation in the application.

Although AR has been extensively used in education and other fields, little attention has been paid to the UI in AR applications (Jamali, Shiratuddin, & Wong, 2015). Jamali et al. (2015) also states that a mobile AR interface should be intuitive and should have interactive characteristics. The authors state that in mobile AR systems the mobile device "acts as a magnifying glass to see what is occluded behind an object" (Jamali et al., 2015, p. 2). Besides that, the authors identified four types of AR interfaces: tangible interface, collaborative interface, hybrid interface and multimodal interface. In education, the hybrid interface and the multimodal interface are the two types of mobile AR interfaces that are not being used by current mobile AR applications (Jamali et al., 2015). The authors also hypothesize that if current mobile AR applications use these two types of mobile AR interfaces the learning process will improve (Jamali et al., 2015).

In terms of the user interface, by its nature AR interfaces are immersive. Dede, (2009) argues that immersive interfaces enhance learning because they provide multiple perspectives (exocentric and egocentric) of a phenomenon. Egocentric perspectives enable motivation through embodied and concrete learning because they provide a view of the phenomenon from inside the phenomenon (Dede, 2009). On the contrary, the exocentric perspective allows to observe a phenomenon from outside the phenomenon.

Dede (2009) also claims that one of the advantages of immersive interfaces is that they improve the "near-transfer" which means that students transfer the knowledge learned in a specific context to solve real-world problems in similar contexts. As a result, immersive interfaces also promote situated learning. It is worth noting that immersive interfaces may help to create conditions for situated learning experiences because the immersive interfaces emulate authentic activities in which students learn by doing activities that are closer to the real activities in real environments.

In some models, architectures and frameworks of AR applications in education, the AR interface and the AR interaction have been considered as modules with well-defined functions and not only as modules that are inherent to the system. For instance, in their framework for mobile peer assessment with AR, Chao, Lan, Kinshuk, Chang, & Sung (2014) consider the AR interaction as a module in the framework in order to increase the quality and suitability of the peer assessment process. In terms of interaction, Yusoff & Dahlan, (2013) states that a learning engagement indicator that is supported by AR is the interactive, collaborative and generative approach because students are able to manipulate the content in the virtual world but in a realistic way as if it were the real learning space. Another example of interaction in AR is the framework proposed by Margetis et al. (2015) in which natural interaction with physical objects is provided in the context of education by taking advantage of computer vision techniques in order to provide a marker less AR experience and avoiding obstructive objects.

In their study, Stanimirovic et al., (2014) introduced a mechanism that is called freeze mode and live mode in AR interfaces. In the freeze mode the UI is blocked so the last image captured from the real world with the augmented information is maintained in the user interface so that the user can put aside the mobile device and do another task but the information is maintained in the user interface. The live mode is the normal mode of live view of the real world with the superimposed information in real time. The use of the freeze mode is useful in AR applications for training maintenance operations where the trainee can get the augmented information and put aside the mobile device and read the information in the device to perform the maintenance operations in the real world objects. On the other hand, in their study, C. Chen & Wang, (2015) explored the use of a multi-display for showing different perspectives of the tidal effects. The researchers found that students perceived the system as easy to use and they were satisfied with the system in terms of the interaction. This strategy of using a multi-display for showing different perspectives of the phenomena may help to support the UDL guideline about providing multiple means of representation.

However, Dankov, Rzepka, & Araki (2011) claim that the three issues that current AR systems have are: Ubiquity of object presence, object persistence and ubiquity of object interactivity. The authors introduce a framework to tackle these issues in order to build interactive interfaces. They defined the User-Object interaction and Object-Object interaction paradigms that model the interaction in AR environments and at the same provide flexibility for the developer to specify how the users interact with the objects and how the objects interact with other objects. Some years before, Ledermann & Schmalstieg (2005) had defined the APRIL (AR Presentation and Interaction Language) language for AR environments considering different devices in an effort of standardizing the interactivity in AR interfaces.

Bujak et al. (2013) claim that intuitive interactions (natural interactions) in AR experiences reduce the cognitive load and benefit the learning process. The author suggests that the interaction in AR applications should be natural so that students can transfer the knowledge they already have when they interact with the real world to the interaction with the virtual objects. In the same vein, Rogers, Scaife, Gabrielli, Smith, & Harris (2002) argue that the interactions in mixed reality environments "fit naturally" the way we act in the real world. The interactions are movements that we use in the real world such as grasping, dragging, dropping, etc. (Rogers et al., 2002). In their study the authors conclude that by combining the "unexpected" with the "highly familiar" it is possible to create rich experiences that increase the interest and provide more reflection.

In terms of the content provided through the AR interfaces, in their study, Chen & Liao (2015) compared an AR application for chemistry with dynamic content (including animations) and an AR application with static content (no animations). They concluded that it seems that the static content reduces the visual cognitive load and facilitates learning in AR applications for chemistry. They also concluded that a procedure-guided strategy is recommended for conceptual understanding. Likewise, Syberfeldt, Danielsson, Holm, & Wang (2016) state that the learning is a dynamic and individual process so the content should also be dynamic and individual for each learner. This suggests the possibility of including strategies for the personalization of the content showed in the AR learning experiences.

In another study conducted by Lin & Chen (2015), it was concluded that new AR systems should include characteristics from the media richness theory to increase the users' acceptance. Some of these characteristics are: timely feedback, multiple cues, language variety and personal focus. Another study conducted by Diaz (2015) explored in a comparative study the use of the cognitive theory of multimedia learning for creating AR content for learning about drones. They found that the content developed with the guidelines of the cognitive theory of multimedia learning improve the learning process.

Tangible AR interface or Tangible User Interfaces (TUIs) have also been used in AR applications in education. The notion of tangibles is described by Rogers et al. (2002) as the physical artifacts embedded or closely coupled with a digital response. In their study, R. Chen & Wang (2008) state that "Tangible AR can enable learners to acquire concrete learning experiences through active experimentation." (R. Chen & Wang, 2008, p. 698). The authors also point out that one of the advantages of tangible interaction is the connection with the physical world and that it helps to create a sense of space and the relationship of the objects with the space. R. Chen & Wang, (2008) also claims that the combination of visual and haptic feedback in tangible AR systems expose learners to multiple channels for sensory input. On the other hand, in their framework, Quint, Sebastian, & Gorecky (2015) used a projection interface to provide a tangible learning experience. However, Seo & Lee (2013) claim that tangible AR interface need to be able to support direct and more sophisticated interactions with the augmented information. The researchers state that the use of glove-based interactions is an advantage because of the use of natural and intuitive interactions.

In the survey conducted by Krevelen & Poelman (2010) haptic devices that are used in tangible user interfaces are compared to tele-operation but in the TUIs the slave system is not a physical system, is a virtual system in which all the events occur.

In their study, Starcic, Cotic, & Zajc, (2013) conducted a longitudinal study of 2 years with three iterations and 145 students in which they explored the use of TUIs for teaching geometry to students with special educational needs and learning difficulties. The results showed that TUIs helped students with reduced fine motor skills and students with learning difficulties to increase their reasoning. Besides that, the TUIs created new forms of cooperation between students and promotes the inclusion of students with special educational needs.

Together these studies demonstrate the importance of the UI and the interaction mechanisms in AR applications. The studies also describe the different types of UI in AR applications and some of its implications in the learning process. Based on these studies from the literature, the following subsections describe how the UI and interaction module address the UDL guidelines, how it supports the design of motivational AR and provide some recommendations on how to develop this module.

- **How does the UI Management and Interaction Module address the UDL guidelines?**
  - **H-UDL-UII-01:** As described in the literature, the perspectives provided by immersive interfaces are an alternative form of representation of information in AR applications and therefore a mechanism that supports the UDL principle of providing multiple means of representation. Consequently, the use of immersive interfaces is one of the strategies to provide multiple means of representation of information and this helps to overcome barriers in the access to information. The egocentric perspectives of immersive AR interfaces (Dede, 2009) helps to address the UDL checkpoint # 3.4 "Maximize transfer and generalization" due to the support provided to the near-transfer.
  - **H-UDL-UII-02:** According to Jamali et al., (2015) and Dede (2009), the use of hybrid and multimodal AR interfaces enhance the learning outcomes and promotes motivation.
  - **H-UDL-UII-03:** The interaction with real and virtual objects in AR applications facilitates exploration and experimentation which are recommended in the checkpoint # 7.2 "Optimize relevance, value, and authenticity" from the UDL guidelines about "Provide Multiple means of engagement" (Meyer et al., 2014).
  - **H-UDL-UII-04:** As pointed out by Chen & Liao (2015) a procedure-guided strategy in AR applications helps to increase the conceptual understanding. This recommendations helps to support the checkpoint # 3.3 "Guide information processing, visualization, and manipulation" from the UDL guidelines. The design of the UI and interaction mechanism should be aligned with this recommendation to increase conceptual understanding.
  - **H-UDL-UII-05:** The content in the AR user interface should be adaptive and personalized to the user according to their needs and preferences. This recommendation is in line with the UDL checkpoint # 5.3 "Build fluencies with graduated levels of support for practice and performance". This recommendation will also support the UDL checkpoint # 3.2 "Highlight patterns, critical features, big ideas, and relationships".
  - **H-UDL-UII-06:** Depending on the type of learning content to be taught and depending on the learning objective, tangible AR can be a good option for manipulating physical objects that create a digital or augmented response. This type of interaction creates unique possibilities for the learning process. This type of interaction supports the UDL principle about "Providing multiple means of action and expression" because this type of interaction offers possibilities so that learners can express what they know in different ways.

- **How do the UI Management and Interaction Module support motivational design?**
  - **H-Mot-UII-01:** The use of egocentric perspectives (Dede, 2009) in AR interfaces enable motivation due to the experience of being inside of a phenomenon.

- **H-Mot-UII-02:** The UI needs to capture students' attention and maintain the attention as much as possible so that students remain focused on the task. This will also increase on-task behaviors.
- **H-Mot-UII-03:** A UI that contain a lot of text are not recommended for some students. It is important to identify students' needs and preferences before designing the user interface.
- **H-Mot-UII-04:** The UI needs to convey information in a way that can be tied to the students' interests so that this helps to sustain attention.
- **H-Mot-UII-05:** In their study, Ahmed, Hamdy, Hegazy, & El-Arif (2015) found that intangible interaction (using marker-based AR or marker-less AR) is more engaging than tangible interaction (using touch). This highlights the possibilities of increasing engagement using intangible interaction in AR learning experiences.
- **H-Mot-UII-06:** The AR applications should combine "unexpected situations" with "highly familiar" ones to provide richer experiences and foster reflection as recommended by Rogers et al., (2002).This is also in-line with the UDL checkpoint # 9.1 "Promote expectations and beliefs that optimize motivation".

- **Recommendations on how to develop the UI Management and Interaction Module:**
  - **R-D-UII-01:** AR interaction should be natural, especially if the AR application will be used by children because they will use natural gestures that they use in the real world and there will not be an extra cognitive load for learning how to interact with the system (Bujak et al., 2013). This also reduces cognitive load and facilitates learning since the use of the application does not require the learning and use of special gestures.
  - **R-D-UII-02:** The UI need to be easy to understand or a tutorial should be provided so that the user gets familiar with the application (Dünser, Grasset, Seichter, & Billinghurst, 2007).
  - **R-D-UII-03:** AR applications may take advantage of the freeze view (Ahmed, Hamdy, Hegazy, & El-Arif, 2015; Bai, Lee, & Billinghurst, 2012) and live view (Stanimirovic et al., 2014) interactions mechanism for AR to improve the user experience.
  - **R-D-UII-04:** The type of interaction need to be adjusted to the learning needs and testing with real users are recommended to be sure that the interaction mechanism works well.
  - **R-D-UII-05:** It is recommended to find a correct balance between virtual and real world information. The excess of one of these types of information may affect the learning outcomes and motivation. This recommendations is in line with one of the six design principles for designing handheld AR (also known as the 6 Ps) introduced by (M. E. C. Santos et al., 2015) who assert that the augmented information should not obstruct user's view of the real world.
  - **R-D-UII-06:** The use of TUIs may help to increase the participation of people with reduced fine motor skills and facilitates the inclusion of people with special needs in AR experiences (Starcic, Cotic, & Zajc, 2013b). In this regard, depending on the learning domain and students' needs the use of TUIs may be a good strategy for promoting inclusion.
  - **R-D-UII-07:** Santos et al. (2015) introduced 6 design principles for the design of handheld AR applications for learning. These principles, also known as the 6 Ps are: Present context-aware information, provide content controls, preempt

technical difficulties, preserve intuitive icons and menus, promote social interactions and pay attention to manipulability. We recommend software developers to follow these guidelines to improve user experience in AR applications for learning.

- **R-D-UII-08:** Kourouthanassis, Boletsis, & Lekakos (2015) introduced the following 5 design principles for the design of AR applications: Use the context for providing content, Deliver relevant-to-the-task content, Inform about content privacy, provide feedback about the infrastructure's behavior and support procedural and semantic memory. We recommend to follow this guidelines in the design of the UI management and interaction module.

Augmented Reality Activities/Experiences Layer

This layer of the ARMotiD framework contains the modules that were identified through the hypothesis validation process as the modules that promote students' motivation in AR learning experiences. These modules are: the Scaffolding module, Augmented Information and the Real-time Feedback module. These modules are described as follows:

Scaffolding (SCA)

The scaffolding is a strategy to provide assistance and help students so that they can complete a learning activity. This strategy works as follows: at the beginning of the learning activity students have a complete assistance by means of scaffolds, which will be gradually removed as the student gain enough expertise and skills to complete the activity until they reach mastery.

As a result of the study in which we identified predictors of student motivation (see CHAPTER 5), we empirically found that the use of a scaffolding strategy in mobile AR applications is a predictor of students' time on-task and students' degree of success. Taking into account that time on-task is a direct measure of motivation (Keller, 2010), a scaffolding strategy helps to sustain students' motivation. It is worth noting that the scaffolding strategy is indeed recommended in the UDL guidelines in order to support the guideline about "providing multiple means of action and expression". The reason is that curricula should offer different degrees of freedom depending on the students' expertise (Meyer et al., 2014), which means that the scaffolds may be removed as students gain expertise in the learning activity and therefore providing more degrees of freedom.

The scaffolding strategy has been used in AR applications to assist the learner in different learning activities. For instance, in their framework for participatory simulations in mobile learning Yin, Song, Tabata, Ogata, & Hwang (2013) scaffolding and fading strategies are used to enhance student's experiential learning. In their research, the scaffolding strategy consists of three stages: the first stage is to point out mistakes that assist students with the task of finding mistakes during the simulation process. The second stage is help to correct, in which students have 3 options: Hint, Illustration and Teacher's help. The third stage is the discussion in which students can discuss with their partners by using the mobile device. For the fading strategy 3 levels were designed by the authors considering the zone of proximal development: 1) Do not provide hints, 2) Do not point out mistakes and 3) Do not provide help and discussion. The authors also evaluated students' attitudes towards the scaffolding and fading strategies implemented in a mobile system for participatory simulations and found that most of the students agreed that these strategies are helpful for learning and students were satisfied with them.

In their framework, Bujak et al., (2013) suggests that AR helps to understand the relationships between the symbolic representations of physical manipulatives by adding augmented information to the physical manipulative. This process can be scaffolded according to the student needs by increasing or decreasing the symbolic content. The scaffolding can also be controlled by monitoring student's tasks and adjust the contextual information presented at the appropriate level and aligned with the physical objects.

Another study that explored the use of scaffolding strategies in augmented reality was the study of Quarles, Lampotang, Fischler, Fishwick, & Lok, (2009). The authors explored the use of a scaffolding strategy in a mixed-reality system for anesthesia education and concluded that the scaffolding strategy combined with the mixed-reality system facilitates the transfer from abstract to concrete domains and they suggest that "mixed reality maybe an effective educational scaffolding tool that can bridge abstract and concrete knowledge in the learning process" (Quarles et al., 2009, p. 45). The authors also introduced the scaffolding-space continuum to classify the scaffolding tools in three continuums according to the virtuality, information and interaction.

C.-H. Chen, Chou, & Huang, (2016) highlight that one of the drawbacks of current AR applications is the lack of instructional scaffolds to assist learners to structure and organize the information to be learned. The authors combine concept maps as scaffolds in an AR system for science learning called CMAR (Concept Map Augmented Reality). The authors concluded that when a new technology is introduced, the support of scaffolds and the appropriate instructional method can improve the learning outcomes. Thus, the introduction of AR in the classroom should be supported by an adequate scaffolding strategy. C.-H. Chen et al. (2016) also applied the IMMS instrument to evaluate motivation and as a result they found that the CMAR system improved the *confidence* dimension of motivation which means that students feel more self-confident about their learning.

The scaffolding strategy has also been related to prompting systems. In this regard, Chang, Kang, & Huang (2013) developed an AR-based prompting system for training people with cognitive disabilities in a vocational task that consisted in preparing meals in a university cafeteria. In their system, the researchers used the System of Least Prompts (SLP) strategy which consists in introducing stimulus that will be more intrusive if the participant does not respond. The results showed that the system help participants to gain autonomy in vocational jobs. Moreover, the authors assert that a prompting strategy is useful for task engagement of people with cognitive disabilities (Y.-J. Chang et al., 2013). On the other hand, the study of Tabuenca, Kalz, Ternier, & Specht, (2015) considered a prompting system that consist on "reflection amplifiers" by using mobile notifications. The reflection amplifiers are strategies to foster reflection and evaluation of the learning in students. The researchers concluded that the use of mobile SMS notifications were useful for promoting reflections on the learning process. This is indeed aligned with the UDL guidelines, in particular with the checkpoint # 6.2 "Support planning and strategy development".

Together these studies jointly with results of the study of predictors of student motivation (described in CHAPTER 5), highlight the importance of the scaffolding strategy as an important element in AR learning experiences. For this reason, in the ARMotiD framework the use of a scaffolding strategy takes the form of a module: the Scaffolding module.

The following descriptions and recommendations associated to the scaffolding module come from the literature discussed before in this section, from the UDL guidelines, from the motivational design theory and from our experience in the co-creation of the Paint-cAR application.

- **How does the Scaffolding module address the UDL guidelines?**
    - **H-UDL-SCA-01:** The UDL recommends to introduce graduated scaffolds to support information processing strategies**.** This is aligned with the checkpoint # 3.3 "Guide information processing, visualization, and manipulation" (Meyer et al., 2014).
    - **H-UDL-SCA-02:** The introduction of AR learning experiences in the classroom may increase the learning outcomes if a proper scaffolding strategy is used (C.-H. Chen et al., 2016).

- **H-UDL-SCA-03:** In AR applications the Scaffolding module may be used to guide students in the process of finding the appropriate information they need for completing a task.
- **H-UDL-SCA-04:** The UDL recommends providing explicit prompts for sequential processes. In this regard the Scaffolding module may help to provide these prompts just in time for students.
- **H-UDL-SCA-05:** The UDL recommends releasing information progressively to students and remove distractions or information that may be distracting at different moments of the learning process. The scaffolding module may help in this task.
- **H-UDL-SCA-06:** The UDL recommends highlighting patterns, critical features and relationships. The Scaffolding module needs to be designed to support these recommendations. For instance, the Scaffolding might draw students' attention to the critical features of a concept that they are learning.

- **How does the Scaffolding module support the motivational design?**
  - **H-Mot-SCA-01:** The use of concept maps as a scaffolding strategy combined with AR increases students' motivation, especially in the *confidence* dimension of the ARCS model (C.-H. Chen et al., 2016)**.**
  - **H-Mot-SCS-02:** According to the study of predictors of student motivation (see CHAPTER 5), the use of a scaffolding strategy in AR learning experiences, create success opportunities that allow students to increase their degree of success in the learning experience and therefore increase or sustain their motivation and learning outcomes.
  - **H-Mot-SCA-03:** The integration of a Scaffolding module may help to build confidence in AR learning experiences thanks to the provision of success opportunities in challenging tasks (see CHAPTER 5).
  - **H-Mot-SCA-04:** The integration of a Scaffolding module may help to increase students' time on-task thanks to the assistance provided by the scaffolding strategy to complete challenging tasks. It is important to note that time on-task is a direct measure of motivation so increasing time on-task positively affects motivation (see CHAPTER 5).
  - **H-Mot-SCA-05:** According to study of predictors of student motivation (see CHAPTER 5), in the Evaluation Mode, the provision of the scaffolding module helps to increase *relevance* and *satisfaction* dimensions of motivation.

- **Recommendations on how to develop the scaffolding module:**
  These recommendations come from our experience in the co-creation of the Paint-cAR application and the tests with students (see CHAPTER 3 and CHAPTER 4).
  - **R-D-SCA-01:** The SCA module should be available to be used by students when they need assistance for completing a task.
  - **R-D-SCA-02:** The SCA module may be used at least for two main purposes: First is to provide the pieces of knowledge that are relevant to students at the appropriate moment during the experience to complete the task and the second is to guide students by using prompts, cues or hints to find key pieces of information to complete the task. The use of any of these strategies will depend upon the purpose of the learning experience and its characteristics.
  - **R-D-SCA-03:** It is very common to talk only about scaffolding strategy as the mechanism for assisting students to complete the task by giving the information

and help when they need it. However a fading strategy can be also used. The fading strategy is about providing all the information to the student at the beginning of the learning experience but remove it progressively as the student gains expertise. Both strategies can be used depending upon the learning objectives and the learning experience.

- **R-D-SCA-04:** The SCA module should be easily identified by the students in the application so that they can use it when they needed.
- **R-D-SCA-05:** The SCA module may take advantage of personalization and adaptive mechanisms for providing adaptive scaffolding that can take into account students' needs and preferences and provide more personalized information.
- **R-D-SCA-06:** The SCA module may include a prompting system based on notifications or based on strategies like SMS notifications or the System of Least Prompts (SLP) that support learners to complete the learning activity.
- **R-D-SCA-07:** According to Santos et al. (2015), AR applications for learning should provide content controls so that the content can be personalized to the user. Besides, a mechanism for adjusting the quality and amount of the content is recommended. The design of the scaffolding mechanism should follow this guideline to adjust the content to students.
- **R-D-SCA-08:** This module should follow the recommendations of web accessibility for mobile applications (W3C, 2015) in order to make the information accessible for all.

Augmented Information (AIN)

The AIN module in the ARMotiD framework represents the information that is shown to students by using AR features. This means that, the information is overlaid in real world objects and this information can be presented in form of text, images, videos, 3D models, sounds and other multimedia content with educational purposes. This module considers different types of AR such as marker-based AR, marker-less AR and location-based AR (indoor and outdoor). According to the systematic literature review conducted in the context of this thesis, the type of AR that has been mostly used in education is the marker-based AR, followed by the location-based AR and the marker-less AR (Bacca et al., 2014).

To make the information shown by using augmented information accessible for all, the design of this module should follow the recommendations for the development of accessible mobile applications (W3C, 2015).

In their work, Yusoff & Dahlan, (2013) the AR is considered to be the visualization part of the content. This means that the augmented information is the strategy that can be used in mobile AR applications to show the content to students considering aspects like the suitability of the content, the type of content (videos, 3D objects, images, sounds, etc.) and the didactical strategies.

Augmented books are used in educational AR applications as one of the strategies used to present the learning content to students. Augmented books are books that include some markers or QR codes that provide additional digital content or resources as a support of the learning process. In their work, Prieto, Wen, Caballero, & Dillenbourg, (2014) highlight that the intrinsic advantages of paper in the classroom help to introduce the connection between the paper and the digital information because the interaction with traditional paper require less effort and the paper is cheap, versatile and can be found in every classroom.

In this regard, other frameworks have considered augmented books or AR books as a way to convey supporting information to students. For instance, the framework introduced by Yang, Hwang, Hung, & Tseng, (2013) consider the use of QR codes for showing additional learning materials to students. The researchers concluded that the system was effective for learning achievement and was helpful in terms of cognitive load and promoted technology acceptance. In the same vein, Behzadan & Kamat (2013) used AR books for learning about construction job sites. In their framework the AR books are used for interacting with the components of a construction job site and for providing additional information.

In terms of augmentation, another perspective was introduced by Margetis et al. (2015): in their framework, the researchers state that the augmentation occurs over physical assets like a book or a pencil. The researchers state that the framework supports natural interaction with physical objects like a pen and a book in order to show augmented information depending on the type of interaction. The interaction could be pointing to a particular section in a book. Likewise, Bujak et al. (2013) point out that AR facilitates observation and manipulation of content that students would not observe using only physical objects. This means that augmented information can be used to show information that cannot see without the use of specialized equipment (David Furió et al., 2013). Some examples in this context can be: magnetic forces, molecules, cells, etc. An example of this feature of augmented information is described and validated in the study of Ibáñez, Di Serio, Villarán, & Delgado Kloos (2014).

According to Azuma et al. (2001) AR is not only restricted to the sense of sight but it can be applied to other senses such as smell, hearing or touch. Thus, augmented information can be presented in other forms different from visual information such as tactile, auditory or through the smell. An example of the auditory augmented information is the ReduCat (Alessandrini, Loux, Serra, & Murray, 2016). ReduCat is a system for audio-augmented paper drawings for interventions with children with autism.

The Augmented Information module can be one of the mechanisms for conveying information to students and as such it should be aligned with the UDL guidelines. In this regard, the framework introduced by Zimmerman & Land (2014) consider the following guideline as a key component in the framework: "Amplify Observations to See the Disciplinary-Relevant Aspects of a Place" (guideline number 2). Within this guideline the authors state that it is important that the mobile application helps students to focus on relevant aspects of the field of study and to provide contextualized expert guidance. These requirements are aligned with the UDL in the checkpoint # 7.3 "Minimize threats and distractions". Thus, the augmented information should be presented to students in a way that helps them to focus on the important information.

Based on the literature discussed so far and based on the UDL guidelines, the motivational design theory and our experience in the co-creation of the Paint-cAR application, the following descriptions and recommendations are provided:

- **How does the Augmented Information module address the UDL guidelines?**
    - **H-UDL-AIN-01:** The augmented information can be presented to students in a way that help them to stay focused on the tasks so that they can concentrate on relevant information. This is directly connected with the UDL checkpoint # 3.3 "Guide information processing, visualization, and manipulation" (Meyer et al., 2014). This checkpoint recommends to provide strategies to help students to deal with information and to help them to effectively process the information. This is important for some students that may not have all the skills needed to process the information.
    - **H-UDL-AIN-02:** According to Azuma et al., (2001) AR is not only restricted to the sense of sight but it can be applied to other senses such as hearing, smell or touch. Based on this assumption, AR can be used to provide multiple means of presentation which is one of the main principles of the UDL. In this regard, the augmented information can be conveyed using haptic interfaces, tangible user interfaces, visual information (images, videos, 3D models, text), sounds among others.

- **H-UDL-AIN-03:** The augmented information can also be an alternative form of information, which means that the AR is used as another form of representation. For example instead of showing plain text an interactive 3D model could be shown or a 2D image. This recommendation also supports the UDL checkpoint # 2.5 "Illustrate through multiple media" (Meyer et al., 2014).
- **H-UDL-AIN-04:** Following UDL checkpoint # 2.1 "Clarify vocabulary and symbols" (Meyer et al., 2014), AR can be used to show clarifications and additional information about symbols, equations or complex expressions and vocabulary.
- **H-UDL-AIN-05:** Another checkpoint in the UDL is "Guide information processing, visualization, and manipulation" (Meyer et al., 2014) and one of the recommendations in this checkpoint is to provide interactive models to facilitate exploration and understandings. In this regard, the augmented information showed in a AR learning experience, can be an interactive 3D model that students can explore and interact with it.
- **H-UDL-AIN-06:** The UDL recommends providing differentiated models to explain a phenomenon. In this sense the AR can be used as an interactive model taking advantage of the possibility for linking the information to the real world to show alternative ways to explain a phenomenon.

- **How does the Augmented Information module support the motivational design?**
  - **H-Mot-AIN-01:** In general, many studies have highlighted that one of the advantages of AR in education is that it increases motivation (Radu, 2014; Chiang et al., 2014). The nature of AR in terms of the way in which the content is presented is a feature that may capture the interest of students and create curiosity. Interest and curiosity are two important elements for capturing students' attention (Keller, 2010), which is one of the dimensions of human motivation. In this regard, the augmented content could be one of the elements that create curiosity and capture the interest of students.
  - **H-Mot-AIN-02:** In their research, Chen, Fan, & Wu (2016) claim that one of the recommendations for the design of effective activities and materials for mobile AR learning is that all activities must be connected to the learning goals and need to be challenging and engaging. The authors also point out that the augmented information is a support for students to succeed in the learning activities (Chen et al., 2016).

- **Recommendations on how to develop the Augmented Information module**
  - **R-D-AIN-01:** The AIN module can be used to convey information that cannot be seen without the use of specialized equipment (S. Yoon et al., 2017). Some examples of this content can be: magnetic forces, molecules, cells, etc. Moreover, the augmented information can be useful for conveying abstract concepts or concepts that are difficult to explain with other approaches.
  - **R-D-AIN-02:** One of the limitations of AR that is often reported in the literature is that sometimes students pay too much attention to the virtual information (Bacca et al., 2014) and lose details in the real objects. In this regard, it is important to maintain a correct balance between real and virtual information. This is also in line with one of the design principles introduced by Santos et al. (2015) who recommend to provide context-aware content that do not obstruct the user's views of the real world.

- **R-D-AIN-03:** It is important to choose the appropriate type of augmented information (3D models, animations, videos, images, plain text) according to students' needs and preferences. The selection of the appropriate resources comes from a collaborative work with teachers and designers in the context of a co-creation process. Ideally, the system should be able to automatically provide different content alternatives according to the students' needs and preferences.
- **R-D-AIN-04:** Chen et al. (2016) recommend to articulate the augmented information with the learning activities proposed. This means that the learning activities should require the use of the augmented information to complete them. This is useful for taking advantage of the AR experience to obtain the information needed to complete the learning activity.
- **R-D-AIN-05:** The design principles introduced by Santos et al. (2015), also known as the 6 Ps are relevant for the design of effective AR learning experiences in terms of the user experience. We recommend software developers to follow these guidelines when designing the augmented information for the AR learning experience.
- **R-D-AIN-06**: AR activities must be connected to the learning goals and need to be challenging and engaging at the appropriate level. This is important because it implies that AR activities need to be aligned with the learning goal. From our experience, we think that this can be only possible by working together with the teachers and educational technology experts in a co-creation process.
- **R-D-AIN-07:** As mentioned earlier, accessibility is an important feature in this module because this module conveys relevant information to students. The recommendations for designing mobile accessible applications (W3C, 2015) should be followed.

The Real-time Feedback (RFE)

This module manages the feedback as a response of the system when students perform different actions (interact) in the AR system. According to the study of predictors of student motivation (see CHAPTER 5), the *Real-time feedback* provided to students in AR learning experiences was found to be a predictor of students' *Degree of success* and students' *Time on-task*. This means that the RFE is a key module for providing success opportunities and to increase time on-task behaviors.

Some frameworks of AR in education have considered the feedback as a key module in the framework. For instance, Ternier, Klemke, Kalz, van Ulzen, & Specht, (2012) state that contextualized feedback is provided to students in the AR-based game created as an instance of the framework when the players provide a wrong answer to a question and the feedback provided was relevant to the learning process since the authors state that "learning takes place as part of the decision/feedback/consequence process". (Ternier et al., 2012, p. 2162). This view is also supported by Quint et al., (2015) who assert that direct feedback is continuously provided with the augmentation of the physical world.

In the framework introduced by Chao, Lan, Lee, et al., (2014) real-time feedback is used to provide feedback to learners during the assessment of works. The researchers found that providing real-time feedback during the assessment phase facilitated positive impressions toward the feedback and the incorporation of the feedback in students' future work. Moreover, Nadolny (2016) found that instant feedback is a key element for maintaining flow in learning experiences. The framework introduced by Li, Tsai, Chen, Cheng, & Heh (2015) is based on the flow theory and considers the provision of instant feedback and rewards to stimulate the flow experience. Besides that, in the framework agents are presented as augmented avatars that provide emotional support and rewards to keep learners focused on the task.

In terms of the presentation of feedback to students, Chen & Liao (2015) included a feedback strategy in an AR learning experience with an application in chemistry. The researchers found that in dynamic AR (AR with animations) the provision of feedback may increase the cognitive load during the animation because students may need to pay attention to the animation and the feedback at the same time. In this environment a static AR (AR without animations) would be preferred. According to Huang & Liaw (2014) an AR system offers real-time feedback from the information captured from input devices to show a sense of immediacy. Moreover, Liu, Huot, Diehl, Mackay, & Beaudouin-Lafon (2012) concluded that real-time feedback in mobile AR improves the user experience and task performance. Following this view, in their framework for developing assessment tasks supported by AR, Ibanez, Villaran, & Delgado-Kloos, (2015) assert that the interactive capabilities of AR provide the possibility of offering real-time feedback that is important for formative assessment.

From the perspective of the UDL, Tolentino, Birchfield, & Kelliher (2008) introduced SMALLab (Situated Multimedia Arts Learning Lab) which is a mixed-reality environment for learning chemistry. The authors included in the system multiple modes of feedback taking into account the UDL guidelines and the results showed gains in learning outcomes as well as in motivation and engagement.

Chakraborty & Muyia Nafukho, (2014) conducted a systematic literature review on strategies for engagement in distance learning and classified the strategies into five categories: creating and maintaining positive learning environment, building learning community, giving consistent feedback in timely manner, use the right technology to deliver the right content and providing proper support system. With regard to the giving consistent feedback in timely manner, the strategies related to the feedback for online engagement are: provide individualized feedback, provide immediate feedback, provide corrective feedback and peer review, provide personalized feedback according to the level of engagement (Chakraborty & Muyia Nafukho, 2014). The researchers assert that positive feedback can create extrinsic motivation among learners. Besides that they pointed out that students often have positive perceptions of feedback from peers and instructors.

From the perspective of Smart Learning Environments (SLE), Kinshuk, Chen, Cheng, & Chew (2016) point out that technologies for students' monitoring in smart learning environments will evolve and the instantaneous review of students learning progress would be possible to provide instant feedback to assist learners. Besides that, the possibility of mining students' information from various sources will facilitate the provision of real-time recommendations. These opportunities in this field also open possibilities for improving real-time recommendations and feedback in AR learning experiences as part of SLE.

Together the studies cited so far remark the importance of the real-time feedback in AR learning experiences. Hence, based on these studies and based on the UDL guidelines, the motivational design theory and our experience in the co-creation of the Paint-cAR application, the following recommendations and descriptions are provided:

- **How does the Real-time Feedback module address the UDL guidelines?**
  - **H-UDL-RFE-01:** UDL checkpoint # 8.4 "Increase mastery-oriented feedback" (Meyer et al., 2014) refers to the fact that the assessment is productive and helps students to be engaged if the feedback is "constructive, accessible, consequential and timely" (Meyer et al., 2014). Mastery-oriented feedback guides the learner to reach mastery instead of just confirming their success or compliance with competences. In this regard, the feedback in the RFE needs to guide the learner and emphasize the effort, persistence and rehearsal.
  - **H-UDL-RFE-02:** According to the UDL the feedback needs to be frequent, specific and timely. This emphasizes the need of providing real-time feedback in response to the students' interaction with the system, i.e. feedback that can be customized to each student (checkpoint # 5.3 "Build fluencies with graduated levels of support for practice and performance" and checkpoint # 6.4 "Enhance capacity for monitoring progress" (Meyer et al., 2014)).

  - **H-UDL-RFE-03:** The UDL recommends providing informative feedback rather than competitive or comparative feedback (from checkpoint # 8.4 "Increase mastery-oriented feedback" (Meyer et al., 2014)). This type of feedback emphasizes students' effort rather than feedback that express comparison with others or with a standard.
  - **H-UDL-RFE-04:** The UDL recommends using activities in which learners can have feedback to support reflection and self-assessment (from UDL checkpoint # 9.3 "Develop self-assessment and reflection" (Meyer et al., 2014)).

- **How does the Real-time Feedback module support the motivational design?**
  - **H-Mot-RFE-01:** According to some findings in the literature the feedback helps to create engagement in online learning activities (Chakraborty & Muyia Nafukho, 2014). As a result the provision of real-time feedback helps to support engagement so that students keep focused on the tasks.
  - **H-Mot-RFE-02:** The levels of challenge in AR applications needs to be combined with appropriate levels of feedback to help students to succeed in the tasks or to confirm their success in tasks and help them to keep engaged.
  - **H-Mot-RFE-03:** According to the study of predictors of student motivation (see CHAPTER 5), the *Real-time feedback* and the *Use of scaffolding* were found to be predictors of students' degree of success. From the motivational design perspective, the degree of success and success opportunities are key aspects for building *confidence* which is one of the dimensions of motivation (Keller, 2010).
  - **H-Mot-RFE-04:** According to the study of predictors of student motivation, the *Real-time feedback* and the *Use of scaffolding* were found to be predictors of students' *Time on-task*. Since the time on-task is a direct measure of motivation (Keller, 2010), the real-time feedback is important for supporting a motivational design in AR learning experiences.
  - **H-Mot-RFE-05:** According to Keller, (2010) feedback should be positive and attributional which means that student's should know that they succeed because they worked hard and not just because the teacher gave them a grade for the task. This is another strategy for building confidence.
  - **H-Mot-RFE-06:** Feedback needs to be rewarding (Keller, 2010). This characteristic of feedback helps to increase extrinsic motivation and encourages students to focus on the task.
  - **H-Mot-RFE-07:** According to Keller (2010) rewarding outcomes are part of one of the strategies for promoting feelings of satisfaction. In that regard, the students' success opportunities that were supported by the scaffolding approach and the real-time feedback seems to be rewarding for the students in the mobile AR learning experience and therefore the satisfaction increases.

- **Recommendations on how to develop the Real-time Feedback module**
  - **R-D-RFE-01:** In AR applications where dynamic AR is used (AR with animations) the presentation of feedback needs to take into account the students' cognitive load to avoid increasing it (M.-P. Chen & Liao, 2015).
  - **R-D-RFE-02:** The feedback in the RFE should be provided in the appropriate form of presentation according to the students' needs (Meyer et al., 2014). For example in form of texts, images, videos, animations, sounds, etc. If the feedback is provided only in form of text some students may not read it.

- **R-D-RFE-03:** The feedback in the RFE needs to be provided according to the level of challenge of the learning activity.
- **R-D-RFE-04:** As discussed earlier in this module, UDL recommends to provide timely feedback that can be at the same time constructive and consequential with students' actions in the system. Meyer et al. (2014) states that students need be aware of the progress they are making so that students can have an idea of what they need to do differently in their learning process. "Learning cannot happen without feedback" (Meyer et al., 2014, p. 26). In this regard, feedback needs to be provided in response to students' interactions with the system so that they can identify if they are making good progress in the learning activity.
- **R-D-RFE-05:** The development of the RFE module should follow the recommendations for the development of mobile accessible applications (W3C, 2015).

Students Support Layer

This layer contains the modules that provide additional support to the students so that they can complete the learning activity. This layer contains the following modules: Module of Videos, Ask Your Teacher, Frequently Asked Questions and Progress Monitor. These modules are described as follows:

Videos (VID)

The aim of this module is to show videos about the learning domain. Its main purpose is to show another form of presentation of information taking into account the UDL guidelines. The videos included in this module convey information that complement the information conveyed through other forms in the AR learning experience.

During the co-creation process of the Paint-cAR application (described in CHAPTER 3 and CHAPTER 4), the teacher that worked with us in the design of the application recommended for this kind of topic the use of videos as a strategy to explain some tasks that students should learn to do. Students have access to the videos in the mobile AR application. In these videos an expert student perform the task and processes to be taught so that other can learn how to perform a task by imitating the way in which an expert classmate complete the task. This mechanism supports the process of enculturation from the situated learning theory (Brown et al., 1989) because students are learning from experienced classmates.

Apart from the text, 2D interactive demo, 3D interactive demo and assessment, the framework introduced by Wang, Vincenti, Braman, & Dudley, (2013) considers a module of videos in which a video tutorial is used to present examples and illustrate some concepts in the context of computer science domain.

In the framework introduced by Park & Kim (2013), in the field of education in construction videos and photos are used in the education module of the framework in order to provide training about construction safety. On the contrary, in the framework introduced by Behzadan & Kamat, (2013) instead of using pre-recorded videos, real-time video is transmitted from a remote jobsite in the context of education in construction and projected in a large screen and students are able to interact with the video and objects in the video. As a result students are able to discuss and work collaboratively in a wide variety of concepts.

In their evaluation of the student's perceptions about a mobile learning system for participatory simulations, Yin et al. (2013) found that students agreed that videos help them to reflect on their learning progress. Likewise, in their research Zydney & Grincewicz, (2011) found that there is a positive and significant correlation between the time that students spend watching videos and their ability to identify multiple perspectives of a problem in the context of socio-scientific issues.

In terms of the relationship between the use of videos in distance education and the learning outcomes, in his literature review, Kay (2012) found that one of the most important benefits reported with respect to students' learning outcomes when using video podcast is: higher scores in tests than traditional approaches. Supporting this view, Wieling & Hofman (2010) found that the number of lectures viewed online is a predictor of students' learning outcomes. In their study, De la Flor López, Ferrando, & Fabregat-Sanjuan (2016) found that learning outcomes are increased by the combination of video clips with other interactive technologies in the learning domain of mechanical engineering. In the literature the use of video podcast has been widely recognized as an strategy to motivate students (Kay, 2012; Pedrotti & Nistor, 2014; Bolliger, Supanakorn, & Boggs, 2010).

Together these studies highlight the importance of using videos for improving students' outcomes. Aligned with these findings in the literature, from the study of predictors of student motivation we found that the use of the module for watching videos is a predictor of students' learning outcomes.

Based on the literature discussed so far, and based on the UDL guidelines and the motivational design theory as well as our experience in the co-creation of the Paint-cAR application, the following recommendations and descriptions are provided:

- **How does the VID module address the UDL guidelines?**
  - **H-UDL-VID-01:** The most important advantage of videos with respect to the UDL is that videos are another form of presentation of information. This means that videos can be used jointly with texts and other formats to convey information. This recommendations supports the UDL principle about providing multiple means of representation (Meyer et al., 2014).
  - **H-UDL-VID-02:** In AR learning experiences, videos may help to clarify vocabulary, expressions, equations, processes and other aspects (checkpoint # 2.1 "Clarify vocabulary and symbols" (Meyer et al., 2014)) linked to real objects so that the videos can be showed as augmented information.
  - **H-UDL-VID-03:** As discussed earlier in this module, some studies in the literature have reported that the use of videos has a positive impact on students' learning outcomes. Thereby, the use of videos as a complement to the learning content may help to increase learning outcomes.

- **How does the VID module support the motivational design?**
  - **H-Mot-VID-01:** From the study of predictors of student motivation (described in CHAPTER 5) we found that there is a positive and moderate correlation between the use of the module for *Watching videos* and the *confidence* dimension of motivation. This means that the videos in the AR learning experience help students to increase conceptual understanding which at the same time increases students' confidence to complete the task.
  - **H-Mot-VID-02:** Depending on the type of videos, this module may capture the interest and maintain attention (Kay, 2012; Pedrotti & Nistor, 2014; Bolliger, Supanakorn, & Boggs, 2010).

- **Recommendations on how to develop the VID module**

  The following recommendations come from out experience in the co-creation of the Paint-cAR application:
  - **R-D-VID-01:** The player that is used in the VID module should support video playing in different devices.
  - **R-D-VID-02:** If the videos are made with high quality, the file size will be high and therefore the application will need more space in memory. A strategy may

be to download the video from the internet but the data consumption will be higher.

- **R-D-VID-03:** Integrating videos in the AR application require that those videos need to follow the Web Content Accessibility Guidelines (W3C, 2012), to make sure that videos are accessible. This ensures that people with different needs and preferences are able to access the content conveyed through the videos. In short, the videos should have subtitles or at least an explanation of the content in the video for people with low vision or blind people.

Ask Your Teacher (AYT)

The aim of this module is to provide a mechanism so that students can send questions to the teacher as doubts arise during the AR learning experience. Each question is sent to a server and the teacher is notified in a web application or in a mobile application that a new question was posted by a student. The teacher can use the web application or the mobile application to answer the question. If the teacher considers that the answer can be interesting for the rest of the class, the answer can be posted to the module of Frequently Asked Questions (FAQ) that will be described later in this document. The module "Ask Your Teacher" can be used by students when they use the AR application at home or at times in which the teacher is not present. This module can also be useful for students who felt embarrassed of asking questions in the classroom.

A similar strategy was introduced by Zarraonandia, Aedo, Díaz, & Montero (2013) in which students used a mobile application for sending questions to the teacher or answering to questions asked by teachers at any time during the lecture and the teacher used AR glasses that recognized the location of each student and showed augmented information to the teacher about the current state of the students in terms of their understanding of the topic.

Based on the literature discussed so far, and based on the UDL guidelines and the motivational design theory, the following recommendations and descriptions are provided:

- **How does the AYT module address the UDL guidelines?**
  - **H-UDL-AYT-01:** The AYT module aims to provide a mechanism for students' expression. This is aligned with the UDL principle of providing multiple means of action and expression (Meyer et al., 2014).
  - **H-UDL-AYT-02:** The UDL recommends in checkpoint # 8.3 "Foster collaboration and community "to "provide prompts to guide learners in when and how to ask peers and/or teachers for help" (CAST, 2011, p.31). In this sense, the AYT module supports this recommendation by providing a mechanism to support the communication between students and teachers so that students can ask for help at any time.

- **How does the AYT module support the motivational design?**
  - **H-Mot-AYT-01:** From the perspective of motivational design, one of the strategies to promote feelings of satisfaction is to build perceptions of fair treatment of students (Keller, 2010). This tactic can be supported by the module "Ask Your Teacher", because the module provides equal opportunities for all students to ask the teacher at any time during the learning activity.

- **Recommendations on how to develop the AYT module:**
  These recommendations are based on our experience in the co-creation of the Paint-cAR application:

- R-D-AYT-01: The AYT module should be available at any time in the application so that students can send questions to the teacher from any user interface in the application.
- R-D-AYT-02: The AYT module should support transmission over HTTP in formats like JSON or XML to send and receive information from and to the mobile AR application.
- R-D-AYT-03: The web application and mobile application used by teachers needs to support notifications (by mail or push notifications) and needs to notify teachers when they receive a new question from the students.
- R-D-AYT-04: Teachers should be able to answer the questions and post the answer to the F.A.Q module if they consider that the questions are interesting for most of the students.
- R-D-AYT-05: The development of the AYT module should follow the recommendations for the development of mobile accessible applications (W3C, 2015) to make the information accessible for all.

Frequently Asked Questions (FAQ)

The aim of this module is to provide in advance answers to questions that are common for the learning domain or questions that are typically asked by students for a particular learning task. This module is updated with new questions and its corresponding answers when teachers decide to post the questions sent by students through the module "Ask Your Teacher".

The FAQ module and the AYT module together can be considered as a Q&A (Question and Answering 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 been also integrated with AR systems. For example, Lin & Chen (2015) developed a Q&A system with an AR navigation system for a virtual tour guide in museums. Users can ask questions to the system in natural language and the system provides answers in natural language also. The system is based on the media richness theory.

The following recommendations have been defined according to the literature, and according to the UDL guidelines, the motivational design and our experience in the co-creation of the Paint-cAR application.

- **How does the FAQ module address the UDL guidelines?**
  - **H-UDL-FAQ-01:** In the UDL checkpoint 6.3 "Facilitate managing information and resources", Meyer et al. (2014) states that one of the limitations in the executive functions is the working memory capacity. Thus, to cover this limitation in some learners that may have difficulties with the working memory capacity, it is recommended to provide mechanisms for organizing the information and the resources to solve a problem. In this regard, the FAQ module is a mechanism to support learners to remember relevant concepts and help them to solve common problems during the learning activity.
  - **H-UDL-FAQ-02:** One of the barriers in the classroom is that some of the students do not have the prior knowledge needed for the topic or some of them have it but they did not give it the importance that it should have. In this sense the UDL recommends to use mechanisms to activate prior knowledge and link the information that is conveyed with previous knowledge that students have about the topic. In this regard, the FAQ module is a module that helps to provide and activate the prior knowledge and help students to remember important things to learn the topic.

  - **H-UDL-FAQ-03:** The FAQ module addresses the checkpoint # 3.2 "Highlight patterns, critical features, big ideas, and relationships" (Meyer et al., 2014) because the module can be used to remark important concepts for the topic. This is relevant because expert learners should be able to locate the important information and assimilate the most important aspects. In this regard, the FAQ module may help students to become expert learners and acquire this ability by showing them the most important information.

- **How does the FAQ module support the motivational design?**
  - **H-Mot-FAQ-01:** From the perspective of the ARCS model the FAQ module may help to increase the *confidence* dimension of motivation. The FAQ module provides key information that helps to reduce uncertainty in the learning task and increase the perceived level of control that students have with respect to the activity. Therefore, the internal locus of control (Keller, 2010) may increase.

- **Recommendations on how to develop the FAQ module**
  The following recommendations are defined according to our experience in the co-creation of the Paint-cAR application:
  - **R-D-FAQ-01:** Students should be notified by using push notifications of new answers published in the FAQ module.
  - **R-D-FAQ-02:** Students should be able to view all the frequent questions in the FAQ module in a way that can be easy to search for a question and its answer (usability).
  - **R-D-FAQ-03:** The FAQ module should support transmission over HTTP in formats like JSON or XML to send and receive information from and to the AR application.
  - **R-D-FAQ-04:** The FAQ module should be able all the time during the AR application so that students can use the FAQ at any time.
  - **R-D-FAQ-05:** The FAQ module may have a mechanism to specify the questions and answers that are most relevant for certain parts of the learning content so that students can find the relevant questions easily.
  - **R-D-FAQ-06:** Teachers should have a mechanism to define which questions should be published in the FAQ module taking into account the quality and relevance of the questions. Quality and relevance of the questions might be defined by the teacher.
  - **R-D-FAQ-07:** If the AR application stores a user model, it might be possible to personalize the questions in the FAQ module according to the user model so that students can have the most relevant questions according to their needs.
  - **R-D-FAQ-08:** The FAQ module should follow the recommendations for the development of mobile accessible applications (W3C, 2015) to make the information accessible for all.

Progress Monitor (PMO) and Monitoring (MON)

The PMO is a module that monitors student activity and interaction with the application. The PMO works in conjunction with the MON. The MON captures students' interaction in the four layers of the Augmented Reality Applications section in the ARMotiD framework. This module also provides the information about students' interaction to the Progress Monitor to generate the reports.

The PMO measures students' progress with respect to the following variables by using the data provided by the MON: Overall progress in the content, learning outcomes, time using the application among other variables that can be defined by teachers and educational technology experts during the co-creation process. The PMO should be able to report the information to students in a comprehensible way so that they can be aware of their progress and performance in the learning task. Moreover, the PMO should be able to present reports to the teacher about the general course performance as well as detailed performance metrics for each student.

From the literature review on AR frameworks in education, only the framework of Yang et al., (2013) was found to have a mechanism for monitoring progress. In this framework the progress monitor showed the progress using different colors of an activity about reading.

The following recommendations have been defined according to the literature, and according to the UDL guidelines, the motivational design and our experience in the co-creation of the Paint-cAR application.

- **How does the PMO address the UDL guidelines?**
    - **H-UDL-PMO-01:** The UDL checkpoint # 6.4 recommends to "Enhance capacity for monitoring progress" (Meyer et al., 2014). Aligned with this recommendation the purpose of the PMO is to show graphics and reports of students' progress. The aim of these reports is that students reflect and identify what to change and what to do to improve their performance in particular aspects of the learning process.
    - **H-UDL-PMO-02:** The PMO can provide a form of feedback and according to the UDL "learning cannot happen without feedback" (Meyer et al., 2014). The Progress Monitor provides feedback on students' learning outcomes in the learning activity.
    - **H-UDL-PMO-03:** The UDL recommends to "Emphasize process, effort, improvement in meeting standards as alternatives to external evaluation and competition" (Meyer et al., 2014). For this specific checkpoint, the PMO may help to highlight the aspects of the learning process in which students are having a good performance and could be able to emphasize the effort and show the progress of the learning process. This is especially relevant when the application is able to vary the challenge to students.
    - **H-UDL-PMO-04:** From the UDL perspective with respect to students' motivation, self-regulation processes are important so that students learn to monitor their emotions successfully. Meyer et al., (2014) also states that for some students the recognition of making progress toward independence is highly motivating during the learning process. Taking into account these considerations the Progress Monitor may provide the support so that students improve their self-regulation processes.

- **How does the PMO support the motivational design?**
    - **H-Mot-PMO-01:** From the perspective of motivational design, a key component of *confidence* is that people need to have control over their performance and need to be sure that they can succeed in any task (Keller, 2010). This is part of the strategies for supporting personal control. Based on this consideration, the PMO helps students to control their performance and progress and help them to reflect on it.

- **Recommendations on how to develop the PMO:**
  - **R-D-PMO-01:** The reports provided by the PMO should be informative, explicit, accessible (Meyer et al., 2014) and easy to understand so that students can identify their strengths and weaknesses in the learning process. The reports should be designed to be meaningful for students according to their age and with a mechanism to be customized by students. The usefulness of the reports provided by the PMO is that students will be able to identify if they are making progress or not and why. The reports can be provided in form of visualizations (graphics, charts, etc.), in form of textual feedback or both to facilitate its interpretation and to increase the usefulness of the report.
  - **R-D-PMO-02:** The reports provided by the PMO to teachers should be easy to understand and informative so that teachers can be able to make decisions on the learning process (Yigitbasioglu & Velcu, 2012).
  - **R-D-PMO-03:** At low level the PMO should be able to capture students' interaction with the application and should be able to send it to the server to generate the reports for the teacher. An automatic analysis of students' interaction with the application will be useful to present reports to the teacher about the specific actions of students in the application.
  - **R-D-PMO-04:** If the application is used off-line (without internet connection) the MON should store the information about the interaction in the device's persistence storage in which the application is installed and should be able to send the information to the server when the internet connection can be available.
  - **R-D-PMO-05:** The PMO module should support transmission over HTTP in formats like JSON or XML to send and receive information from and to the AR application.
  - **R-D-PMO-06:** The recommendations for the development of mobile accessible web applications (W3C, 2015) may help to design reports that can be accessible for all and therefore understandable for most of the intended audience.

<u>Assessment Layer</u>

This layer only contains the module that manages the assessment in the AR application. The module in this layer is called Assessment module.

Assessment (ASE)

The ASE 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 collect data that might be relevant for the teacher such as the time that students spend answering the question or data about any other interaction with the module. For this example, the ASE may have tests of different types such as test with multiple-choice questions, true or false questions, open ended questions and fill-in-the-blank questions among others. Whenever possible the Assessment module should correct the answers automatically so that students can have immediate and automated feedback.

For any assessment strategy followed, the information required for the assessment process is downloaded from the Assessment Management. When students answer the questions, the Assessment module is able to check the answers and show the answers that are correct or not. However, the module can be implemented in a way that can show customized feedback depending on students' answers.

Using multiple-choice questions in mobile AR applications has also been a strategy used by Ternier et al. (2012), in their framework for location-based applications. Multiple-choice questions can be bound to a location and showed when students arrive to that location. Besides that, when students answer the questions it is possible to monitor their progress or to use the questions to simulate a dialog and take different actions depending on the student's answers. The results of the framework evaluation showed that students appreciated the use of multiple-choice questions in the application. In the ARICE framework, created by Wang et al., (2013), the assessment is one of the components of each main module of content. Students need to obtain certain score greater than a threshold in the quiz to continue with the next module of content.

On the other hand, the framework introduced by Chao, Lan, Kinshuk, et al. (2014) enriches a peer assessment process with AR to enhance interaction. The results showed a positive acceptance of this strategy and confirmed the usefulness of AR in assessment processes. Besides that AR facilitated the flow of information in the peer assessment activity.

The study of Kuo-hung, Kuo-en, Chung-hsien, Kinshuk, & Yao-ting (2016) concluded that AR technology overcome some of the limitations of current performance assessment systems. AR can be used in performance assessment for improving the visualization of students' works and facilitating the comprehension of their work by assessors. Besides that, the authors concluded that AR is convenient for showing information based on environmental parameters or based on particular objects.

A broader perspective has been adopted by Ibanez, Villaran, & Delgado-Kloos (2015), who introduce a framework for developing assessment tasks in AR learning environments. The researchers conceptualize the three elements that an AR assessment activity should have: real elements, digital elements and events. Moreover, the types of learner interaction (Selection, placement and digital interaction) and the types of events (ordered and unordered) in AR tasks of assessment are described. Three learning scenarios illustrate the use of the framework in assessment tasks in the context of electric circuits and interpreting circuit diagrams (Ibanez, Villaran, et al., 2015).

The following recommendations have been defined according to the literature, and according to the UDL guidelines, the motivational design and our experience in the co-creation of the Paint-cAR application.

- **How does the ASE module address the UDL guidelines?**
    - **H-UDL-ASE-01:** Assessment is one of the four components of a UDL curriculum (Meyer et al., 2014). The purpose of assessment is to gather data about (CAST, n.d.):
        - Accountability: Students performance with respect to the program goals and pre-requisites.
        - Student progress: changes in student performance over the time.
        - Instruction: Identify the impact of instruction on students.
        - In this sense, the main purpose of the Assessment module is to capture this information and to show it to the teacher so that the teacher can make decisions with respect to the impact of the learning activity. The information can be also showed to students so that they can reflect on their progress.
    - **H-UDL-ASE-02:** The Assessment module needs to be designed and developed by taking into account the UDL principles to consider student's variability. For instance, the Assessment module needs to take into account the multiple means of engagement so that students feel that they can be successful in the learning task and motivate them to make an effort to complete the learning activity. Besides that the Assessment module should take into account the principle that recommends providing multiple means of expression which means that the assessment should provide different ways in which students can express what they learnt. For example to provide different types of questions and types of

evaluation (peer assessment, co-assessment or self-assessment) and varied mechanisms of interaction so that they can express their knowledge. Finally, the Assessment module should take into account the recommendation of providing multiple means of representation to provide alternatives to learning material that may impose barriers in the learning process.

- **How does the ASE module support the motivational design?**
  - **H-Mot-ASE-01:** In terms of motivational design the Assessment module needs to include rewards and feedback that can be relevant for students so that they feel that they succeed in the assessment because of their abilities (Keller, 2010). If the Assessment module includes these characteristics, students' feelings of satisfaction will rise.
  - **H-Mot-ASE-02:** When the assessment module is supported by AR, students may engage in the activity at the same time they learn from the assessment process. (Kuo-hung et al., 2016).

- **Recommendations on how to develop the ASE module:**

Some of the recommendations provided in this sub-section come from our experience in the development of the Paint-cAR application:

  - **R-D-ASE-01:** The ASE module should be easy to use so that students can understand how to answer the tests (usability).
  - **R-D-ASE-02:** The ASE module should support transmission over HTTP in formats like JSON or XML to send and receive information from and to the AR application.
  - **R-D-ASE-03:** The ASE module should support additional resources to complement the questions such as images, videos, animations among others, to support the multiple means of representation principle from the UDL.
  - **R-D-ASE-04:** The ASE module may take advantage of personalization and adaptation processes to provide personalized assessment which implies to provide different levels of challenge according to students' learning outcomes.
  - **R-D-ASE-05:** The ASE module might be developed with interaction only at the digital level as described in the framework of Ibanez et al. (2015) or the assessment can be included in AR tasks in which the digital and real information are used as part of the assessment process.
  - **R-D-ASE-06:** The ASE module may show different questions for each student to avoid cheating.
  - **R-D-ASE-07:** The ASE module should store as much information as possible with respect to the questions and tests that students solve in the application. This will allow teachers to have information about the time that students spend for each question, the number of errors for each test, the question that is more difficult to answer among others.
  - **R-D-ASE-08:** Since accessibility is important for providing access to the information for all people including those with disabilities, this module should be developed taking into account the Web Content Accessibility Guidelines (WCAG 2.0) (W3C, 2012). These guidelines can also be applied to the development of mobile applications (W3C, 2015).

6.3.3 Section 3: Input, Sensing & Registration (ISR)

This section of the ARMotiD framework represents the inputs of information from a wide variety of devices that can be used to register information from the real world in order to overlay the digital information. Figure 6-5 shows the Input, Sensing & Registration (ISR) section of the ARMotiD framework.

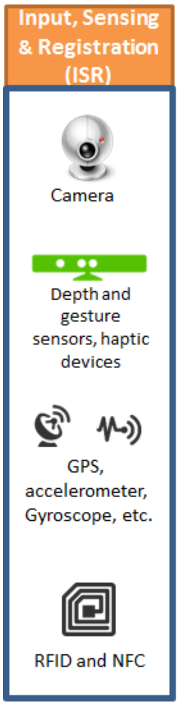

Figure 6-5. Input, Sensing & Registraction section of the ARMotiD framework.

According to Mekni & Lemieux (2014) registration error and occlusion detection are two of the most important limitations of current AR applications. In this sense, many studies have been conducted on these issues and many strategies have been tested for overcoming these barriers. For example, in the literature review conducted by Papagiannakis, Singh, & Magnenat-Thalmann (2008) the authors highlight different approaches used for registration and tracking in AR such as: GPS in which the GPS is used for identifying users' location but it is only useful in open environments (outdoor AR). The Global System for Mobile Communications (GSM) is another approach used that is based on the triangulation of the mobile signal. Finally the authors argue that the Universal Mobile Telecommunications System (UMTS) can be used to improve accuracy (Papagiannakis et al., 2008).

Another approach identified by these authors is the outside-in tracking in which external cameras and sensors are used ouside the tracked object and the inside-out tracking which corresponds to head mounted displays. Moreover, another approach dentified by the researchers is sensor-based tracking in which sensors like infra-red LEDs (Light-Emitting diodes) are used for tracking as well as ultra wide band (UWB) sensors. In this regard, UWB were used in the work of Behzadan & Kamat, (2013) to identify students' interaction with the augmented objects.

Finally, Papagiannakis et al. (2008) state that Wireless-LAN (Local Area Network) trackingis another approach for tracking. This approach is based on received signal strength indication (RSSI) from the access points in the LAN network to improve tracking and registration. The researchers also claim that another type of tracking is the hybrid tracking in which inertial sensors (gyroscope and accelerometer) are used with the camera for tracking and for estimating the position of objects when their movements are fast.

In addition to the tracking techniques mentioned before, in the literature review conducted by Krevelen & Poelman (2010) they identified another category of tracking systems that groups magnetic sensors. This type of sensors measure distances based on electromagnetic fields.

In terms of registration, in their literature review, Saidin, Abd Halim, & Yahaya (2015) claim that the problems in registration and tracking are one of the disadvantages of AR for conveying information to students. This is also recognized as a time-consuming task when the tracking processing is done in the server side and not in the client side. This view is also supported in the literature review conducted by Krevelen & Poelman (2010) in which they claim that tracking in environments that have not been prepared before is a challenge. Besides that they identified that the latency is one of the major problems during registration and the cause of most of the errors. Another problem in registration is depth perception that is the cause of showing objects with a different size with respect to the real world (Krevelen & Poelman, 2010).

The following recommendations for this section of the framework come from the literature and our experience in the co-creation of the Paint-cAR application:

- **Recommendations on how to integrate the Input, Sensing & Registration section:**
    - **R-D-ISR-01:** Since there is a wide variety of devices for input, sensing and registration of information from the real world, the selection of the devices depends on many factors such as the educational objectives, the type of AR application (indoor, outdoor), the budget and the availability of the infrastructure in the educational institution as well as the student's needs and preferences.
    - **R-D-ISR-02:** If the budget is limited and the infrastructure in the institution is not available, the most common type of sensing device to be used may be the mobile phone's camera or the PC camera and the sensing approach to be used will be image-based. This provides and advantage because most of the students will have a mobile device or a PC equipped with a camera.
    - **R-D-ISR-03:** If the learning objectives require the use of advanced input devices such as depth sensors, or ultra wide band sensors it is important to test the efficacy of the sensors and calibrate them before the learning activity to avoid difficulties and therefore frustration in students when they use the system.

6.4 CONCLUSIONS

In this chapter we presented the ARMotiD framework for the design of motivational AR learning experiences. The aim of this framework is to inform the design and development of motivational AR learning experiences and to contribute to the knowledge with the provision of recommendations for the design of motivational AR learning experiences for the VET level of education. This framework is the major contribution of this thesis. The ARMotiD framework is built upon three theories: Motivational Design, UDL and Co-creation. These theories are the conceptual underpinnings for this framework. The framework is also based on the identification of predictors of student motivation (described in CHAPTER 5) which corresponds to an empirical process that feed the identifications of the factors or aspects that positively affect student motivation and that were subsequently represented in modules in this framework.

The ARMotiD framework is also based on the literature on AR applications in education (described together with each module) as well as on the literature review of current AR frameworks in education presented in CHAPTER 2. This literature feeds the definition of the ARMotiD framework presented in this chapter from a theoretical perspective.

The framework was divided into three main sections: Supporting applications, Augmented Reality Applications (Mobile or Desktop) and Input, Sensing and registration. Each one of these sections contain some modules that are intended to support the dimensions of the ARCS model of motivation and address the UDL to create AR applications that increase motivation.

The framework presented in this chapter addressed part of the first research question in this thesis: "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?" and contributed to reach the general objective of this thesis: "**MO:** To define a framework for the design and development of motivational AR learning experiences.". Moreover, the definition of this framework is one of the most important contributions of this thesis since this framework addressed the third open issue "**OI3**: Very little has been done in terms of the definition of AR frameworks in education" identified in the literature review (see CHAPTER 2) and therefore this framework contributes to the knowledge in the design and development of motivational AR learning experiences.

The definition of the framework led us to the next phase in the research methodology that we followed in this thesis: **Validation Phase.** Thus, the next chapter (CHAPTER 7) presents the validation of the framework.

CHAPTER 7
VALIDATION OF THE FRAMEWORK

7.1 INTRODUCTION

The purpose of the framework (described in CHAPTER 6) is to inform the design and development of motivational AR learning experiences for the VET level of education. This means that the framework should provide recommendations on how to create an AR learning experience that support motivation in the VET level of education. In other words, the framework needs to provide guidance on which are the modules or components that an AR application or various AR applications should have to create an AR learning experience that positively affect student motivation. The validation of the framework needs to consider that the framework was conceived as a decoupled framework which means that some modules, layers or sections of the framework can be used independently or may be implemented in separated applications that together create the motivational AR learning experience.

The purpose of the validation of the framework is to determine if the ARMotiD framework informs the design and development of motivational AR learning experiences. In other words we want to determine if the framework is useful for creating an AR learning experience that increases motivation in the VET level of education. In this chapter we present the validation of the framework which corresponds to the first and second activities in the Validation Phase (**AVP1** and **AVP2**) of the research methodology followed in this thesis. Moreover, this study addressed the fifth specific objective of this thesis: "**SO5:** To validate the framework for the design and development of motivational AR learning experiences" and addressed the second research question "**RQ2:** Can the design and development of motivational AR learning experiences based on the framework positively impact student motivation?".

This chapter is organized as follows: section 7.2 presents the definition of the concept of validation and how other frameworks have been validated. Section 7.3 presents the validation methodology that we defined for the validation of the ARMotiD framework. Section 7.4 describes how we applied the methodology for conducting the validation and also the results and discussion of results are presented. Finally section 7.5 presents the conclusions of the validation and section 7.6 presents recommendations for stakeholders with respect to the results obtained in this thesis.

7.2 DEFINITION OF VALIDATION AND VALIDATION PROCEDURES IN OTHER STUDIES

To conduct the validation of the framework, first we analyzed what is meant by validation in the literature regarding frameworks in e-learning. We searched in the literature and we found that most of the literature that deals with the topic of validating frameworks is related to quality frameworks for e-learning. Quality frameworks for e-Learning are frameworks defined to deal with variables that measure and define aspects of quality in e-learning processes. Since this was the field that is most related with our field of research, we adopted the definition stated in this field. The term validation "can be regarded as a process by which a judgment is made as to whether a tool is fit for purpose" (Inglis, 2008). By drawing on this definition, the validation process of the ARMotiD framework sought to determine if the modules defined in the ARMotiD framework increase students' motivation in augmented reality learning experiences.

Secondly, we analyzed the validation procedures of the 35 AR frameworks that we identified in the literature review (presented in section 2.5) and we found that these frameworks do not use a validation method beyond the instantiation of the framework in an application and the subsequent validation of the application in a real scenario. This means that the frameworks are validated through the application that instantiates the framework. This application integrates, in general, all the components defined in the framework. Thus, we called this approach as the "holistic approach". We think that the holistic approach relies in one of the assumptions in the validation of quality frameworks for e-Learning that is recognized by Inglis (2008), who claims that a general assumption seems to be that if the creator of a framework has thought enough about its design and deployment, the quality of the framework is assured. However, aspects that are important in a framework for a researcher are not important for other researchers (Inglis, 2008).

Following a holistic approach for the validation of the ARMotiD framework would require the instantiation of the ARMotiD framework in a tailor-made application for a specific field. However, this might not be suitable to demonstrate that the ARMotiD framework is a decoupled framework. Thus, we considered that the common strategy for validating the frameworks was not suitable for our purposes.

On the other hand, it is worth noticing that current AR applications and AR applications that are being developed may consider only one or more modules of the ARMotiD framework due to:

1. Restrictions in the development process such as budget, time, technological restrictions, design restrictions, etc.
2. The fact that current AR applications might not have been developed with the purpose of supporting motivational design and therefore the application is developed without all the modules defined in the framework.
3. The fact that the learning experience that is being addressed does not need some of the modules that the framework defines.
4. The fact that teachers are able to create a learning experience that involves the use of different applications that implement different modules defined in the framework.

With this in mind, we did not adopt a holistic approach for validating the framework as a whole (considering all the modules in the ARMotiD framework in only one application), but a validation process based on modules is proposed.

7.3 VALIDATION METHODOLOGY AND VALIDATION SCENARIO

In this validation, as discussed in section 6, we adopted a validation based on modules. This means that the modules of the framework are **not** validated together as part of a unique tailor-made application but they are validated as part of various applications that together create a motivational AR learning experience. Following this approach we can be able to demonstrate that the framework is decoupled. Moreover, we hypothesize that teachers can be able to create a motivational AR learning experience with the use of existing applications thanks to a decoupled framework.

For this validation methodology we defined four phases:

1. Preliminary meetings with teachers
2. Identify applications that integrate one or more modules defined in the framework.
3. Conduct the validation in the VET programme with the applications identified in the previous phase.
4. Analysis of results and conclusions.

The validation was conducted in the context of a VET programme called "Laboratory Operations". This is an intermediate training cycle VET programme in which students are trained about procedures in a chemistry laboratory and students are prepared to work as tecnicians or assitants in chemistry laboratories and related areas. In this training programme we identified, jointly with teachers, opportunities for using AR to explain abstract concepts and engage students in the learning tasks with the aim of improving the learning experience. In terms of mobile applications for learning chemistry, one of the advantages reported in the literature is that using apps for learning chemistry increase safety in chemistry laboratories and reduce costs associated to lab equipment and supplies (L. Huang, 2015). Moreover, according to the study of Nachairit & Srisawasdi (2015), students' motivation towards chemistry does not influence students' perceptions toward AR. Therefore, students' perceptions toward AR can be identified better and be more reliable if they are not influenced directly by the students' perceptions toward the field of study (chemistry).

In terms of using AR applications for learning chemistry, Huang (2015) points out that AR and collaborative learning will enrich mobile apps and therefore the learning experience and the process of learning chemistry topics will be painless and enjoyable. Moreover, Boonterng & Srisawasdi (2015) introduced an instructional strategy based of model-based inquiry for learning chemistry with mobile AR. Other studies that explore the use of AR for learning chemistry are being carried out (Cheng & Chu, 2016; Merino, Pino, Meyer, Garrido, & Gallardo, 2015; Sudana, Setiawan, & Pratama, 2016).

The VET programme of laboratory operations is suitable for the validation of the framework because:

- The topic in which the validation was carried out (inorganic nomenclature) is an abstract topic in which, according to the teachers, students often face some difficulties in the learning process because they need to learn some rules and analyze each chemical compound formula to give the appropriate name or to analyze the name to infer its corresponding formula. This process of analysis requires a lot of work and students need to gain experience in this process of analysis. The experience can be obtained by doing many exercises and by learning the rules to identify the formulas and to identify the names. In this sense students need resources that help them to gain the experience and that facilitate the learning process of this rules. Teachers also reported a lack of motivation in some students when they are learning this topic.
- Together with teachers, we identified some opportunities for using AR in this topic as described later in sections 7.4.1 and 7.4.2.

The following sub-sections describe the phases of the validation process.

7.4 CONDUCTING THE VALIDATION

This section presents the results of each one of the four steps of the methodology defined for the validation process.

7.4.1 Preliminary meetings with teachers

In the first meeting with teachers, they explained to us how the curriculum of the VET programme of Laboratory operations was organized and the topics that students learn. Then, we explained what AR is, how it works and its opportunities in education. Moreover, we showed to them the Paint-cAR application and we explained how the application was integrated in the curriculum of the VET programme of Car's Maintenance so that they can have an idea on how this technology can be used as a support of the learning process.

Consequently and jointly with teachers we identified the topics in which this technology can provide a support for the learning process in the VET programme of Laboratory operations. In conclusion, the topics suggested by the teachers were:

- Inorganic nomenclature
- Preparing chemical solutions

The output of this phase were the topics selected as potential topics to be supported with AR applications and an overview of the teaching and learning processes in the VET programme. These outputs will be the input of the next phase.

7.4.2 Identify applications that integrate one or more modules defined in the ARMotiD framework

The purpose of this phase was to identify applications that implement one or more modules of the ARMotiD framework and to ensure that those applications are aligned with the curriculum of the VET programme of Laboratory Operations. In particular we sought to identify applications related to the two topics selected in the previous phase: Inorganic nomenclature and Preparing chemical solutions.

To identify the applications three tasks were carried out in this phase.

- **First task: Identify applications for teaching chemistry topics with AR**: The purpose of this task was to search applications available in Google Store and Google search engine in general to find applications for teaching chemistry in topics aligned with the curriculum of the VET programme of Laboratory Operations. In particular, applications in which the topic can be one of the two topics identified with teachers in the first phase or related topics. The search was conducted by the end of May 2016. After this search the applications were analysed to identify if the applications used the AR technology and if they were aligned with the curriculum.
- **Second Task: Apply criterions to choose the applications that will be used in the validation:** The second task was to analyse the applications with respect to a set of criterions based on the framework and to identify the ones that integrate one or more modules from the ARMotiD framework.
- **Third task: Show a demo to teachers so that they can evaluate the appropriateness of these applications for the curriculum and for the learning process:** The third task was to show a demo of each application to the teachers of the VET programme so that they can evaluate their appropriateness for the learning process.

The three tasks are described as follows:

First task: Identify applications for teaching chemistry topics with AR

As a result of the search in Google and Google Play 21 applications were found. Each application was downloaded and installed in a tablet or smartphone and was tested to identify the purpose of the application, the topic addressed, its cost, the language and to make a decision if the application will be selected for further analysis. Applications were selected for further analysis based on the following criteria:

1. If the topic addressed in the application was aligned with the topics selected by teachers.
2. If the application's language was English, Spanish or Catalan.
3. If the markers recognized by the application were available.
4. If the application can be downloaded for free or can be bought and is not a demo.

The applications that meet all of these four criterions were selected for further analysis.

These 21 applications that were evaluated are detailed in APPENDIX C. Please note that in this appendix, each application is presented in one table and the cell identified with the title "Selected / Discarded" indicates if the application was selected for further analysis taking into account the criterions mentioned earlier.

Thus, the list of 11 applications selected for further analysis (those marked as "selected" in the cell "Selected / Discarded" in APPENDIX C) taking into account the criteria defined earlier is presented as follows (the corresponding ID number of each application corresponds to the cell identified as "#" of each table in APPENDIX C):

- #1. ARLOON Chemistry
- #2. DAQRI – Elements 4D
- #3. Augmenter(Edulus VR Virtual Reality)
- #4. Laborapptorio
- #7. QuimicAR (Augmented Class)
- #8. Química Prebiótica Bioquímica
- #10. Química RA
- #14. Augmented Reality METabolic Pathways (ARMET)
- #15. Molecular Geometry
- #17. Popar Periodic Table
- #21. Augmented Reality Chemistry Review

Second Task: Apply criterions to choose the applications that will be used in the validation

In this task a set of criterions derived from the ARMotiD framework were used to choose the applications that can be used in the validation process. These criterions were defined based on the theoretical specification of the ARMotiD framework. The applications selected for further analysis in the previous task were analyzed according to the criterions defined with the aim of choosing the applications that will be used in the validation process. These criterions are described as follows and are organized according to the four layers of the section about Augmented Reality applications of the ARMotiD framework. Each criterion has one or more associated recommendation from the ARMotiD framework. The associated recommendations from the framework are identified by following the convention of codes for identifying the recommendations from the framework:

R-D-XXX-YY: Where R stands for "recommendation", D stands for "development", XX corresponds to the letters that identify the module of the framework and YY is a consecutive number for numbering the recommendation. This code represents the recommendations provided in the ARMotiD framework for developing a specific module.

H-UDL-XXX-YY: Where H stands for "How?", UDL stands for Universal Design for learning, XX corresponds to the letters that identify the module of the framework and YY is a consecutive number for numbering the items. This code links the reasons provided in the framework on how the specific module of the framework supports the UDL.

H-Mot-XXX-YY: Where H stands for "How?", Mot stands for Motivational Design, XX corresponds to the letters that identify the module of the framework and YY is a consecutive number for numbering the items. This code links the reasons on how the module of the framework supports the motivational design theory and therefore the design of motivational AR learning experiences.

These criterions were applied to each one of the applications selected for further analysis.

UI (User Interface) and Interaction layer

According to the framework specification this layer consists of the Authentication Module and the UI Management & Interaction module.

Criterions for this layer:

- **Authentication module:**
    - The application should provide a mechanism for identifying each student that is using the application in order to track the activities done by students (from R-D-AUT-03).
    - The module should be able to inactivate the application if the teacher decides to block the access to the application (from R-D-AUT-01).
    - The module should be able to synchronize the information about the student with the server (from R-D-AUT-01).
- **UI Management & Interaction module:**
    - Immersive interfaces are preferred. Egocentric and exocentric perspectives of the phenomena are better than plain explanations of a topic (from H-UDL-UII-01, H-Mot-UII-01).
    - The application should facilitate exploration and experimentation through the interaction with real and virtual objects (from H-UDL-UII-03).
    - The navigation in the application should be procedure-guided (from H-UDL-UII-04).
    - Interaction with UI elements and AR objects should be natural (from R-D-UII-01, H-Mot-UI-05, R-D-UII-07).
    - It is desirable that the user interface content should be adaptive and personalized to student needs (from H-UDL-UII-05, H-Mot-UII-04).
    - The UI should be easy to understand (from H-Mot-UII-03, R-D-UII-03).

Augmented Reality Activities/Experiences Layer

According to the specification of the framework this layer consists of the following mechanisms: The Scaffolding module, Augmented Information and the Real-time Feedback module.

Criterions for this layer:

- **Scaffolding module:**
    - The scaffolding module should provide graduate scaffolds to assist students in the completion of the learning activity. This includes a guiding mechanism to find the appropriate information to complete the learning activity or the information they need at a specific time during the learning activity. Besides that, the scaffolding module should provide key pieces of knowledge at the appropriate time during the learning activity (from H-UDL-SCA-01, R-D-SCA-02, H-Mot-SCA-04).
    - The scaffolding module should release the information progressively and remove distracting information during the learning activity (from H-UDL-SCA-05, H-Mot-SCA-05).
    - The scaffolding module should highlight important information and remark critical features to help students to complete the learning activity (from H-UDL-SCA-02, H-UDL-SCA-06).
    - The scaffolding module should create success opportunities to help students to increase their degree of success (from H-Mot-SCA-02 and H-Mot-SCA-03).

- The scaffolding module should be active at any time so that students can use it at any time during the learning activity. Besides that, it should be easy for students to find it and use it during the learning activity (from R-D-SCA-01).

- **Augmented Information module:**
  - The Augmented Information module should be presented in a way that can be able to capture students' attention, create curiosity and help students to stay focused on the task (from H-UDL-AIN-01).
  - The Augmented Information module is used as an alternative form of presentation. For example to show information that is conveyed by using text but as an alternative to textual information (from H-UDL-AIN-02, H-UDL-AIN-03).
  - Connected with the previous criterion, the AR can be used to clarify vocabulary, symbols, equations, complex expressions among others (from H-UDL-AIN-04).
  - There should be an appropriate balance between the Augmented Information and the real-world objects so that students pay attention to both types of information (digital and real) (R-D-AIN-02).
  - The application should use the appropriate type of Augmented Information to convey the appropriate type of content (from H-UDL-AIN-06, H-Mot-AIN-02, R-D-AIN-03).
  - The Augmented Information module is used as a support to convey or show phenomena that cannot be seen without specialized equipment (from H-Mot-AIN-01, R-D-AIN-03).

- **Real-time Feedback:**
  - The Real-time Feedback needs to be mastery-oriented which means that it helps students to be engaged in the task rather than simply confirm their success or errors in the learning activity (from H-UDL-RFE-01 and H-UDL-RFE-02).
  - The Real-time Feedback should be constructive and should help students to complete the task (from R-D-RFE-02, H-UDL-RFE-02 and H-UDL-RFE-04).
  - The Real-time Feedback should be provided in the appropriate moment as a response to the interaction of the student and should not be delayed (from H-UDL-RFE-03, H-Mot-RFE-06, H-Mot-RFE-04).
  - The Real-time Feedback should be informative rather than competitive or comparative (from H-UDL-RFE-03 and R-D-RFE-03).
  - The Real-time Feedback needs to be balanced with the level of challenge proposed to students (from H-Mot-RFE-07).
  - Real-time Feedback should be positive and attributional (from H-Mot-RFE-05).
  - Real-time Feedback should provide some kind of rewards to increase students' intrinsic motivation (from H-Mot-RFE-06).
  - Real-time Feedback should not increase students' cognitive load (from R-D-RFE-01).

Students Support Layer

According to the specification of the ARMotiD framework this layer contains the following modules: Module of Videos, Ask Your Teacher, Frequently Asked Questions (F.A.Q) and Progress Monitor. The criterions for this layer are described by module as follows:

Criterions for this layer:

- **Module of videos:**
  - The module of videos should play videos online from the internet or play videos from the device (from R-D-VID-01 and R-D-VID-02).
  - The module of videos should be provided as a support tool for students and as an alternative form of presentation of information (from H-UDL-VID-01 and H-Mot-VID-02).
  - The module of videos should be closely related to the topic (from H-Mot-VID-01).

- **Module "Ask Your Teacher":**
  - The module "Ask Your Teacher" should allow students to send questions to teachers from any user interface in the application (from H-UDL-AYT-01).
  - The module "Ask Your Teacher" should notify teachers of new questions sent by students (using push notifications or mail notifications) (from R-D-AYT-03, H-Mot-AYT-01).
  - Teachers should be able to answer students' questions or post the answers in a shared space in which all students can be able to see the answers (from R-D-AYT-04).

- **Frequently Asked Questions (FAQ) module:**
  - The FAQ module should be available so that students can have access to the information at any time during the use of the application (from R-D-FAQ-02 and R-D-FAQ-04).
  - The FAQ module should be organized in a way that facilitates the access to the information relevant for students at any time in the application. This mechanism should be a support for reduced memory capacity so it should not increase cognitive load (from R-D-FAQ-04 and H-UDL-FAQ-01).
  - The FAQ module should provide support for students with a lack of background knowledge (from H-UDL-FAQ-02 and H-Mot-FAQ-01).
  - The FAQ module should help learners to locate specific information according to their needs (from R-D-FAQ-02 and H-UDL-FAQ-03).
  - The FAQ module should notify students of new questions posted in the module by the teacher (from R-D-FAQ-01).
  - The FAQ module should be synchronized with the server to have the information updated (from R-D-FAQ-03).

- **Progress Monitor:**
  - The Progress Monitor should highlight the aspects of the learning process in which students are making progress and those aspects in which they have difficulties so that they can reflect and improve their self-regulation activities (from H-UDL-PMO-01 and H-Mot-PMO-01).

  - Students should be able to see the reports and information from the Progress Monitor at any time during the use of the application and all the information need to be updated in real-time. For that aim the module needs to synchronize the information with the server (from H-UDL-PMO-02, H-Mot-PMO-01, R-D-PMO-04 and R-D-PMO-03, R-D-PMO-05).
  - Whenever possible students and teachers should be able to customize the reports so that they can focus on the information that they are mostly interested in (from R-D-PMO-01).
  - With the information of the Monitoring module the Progress Monitor should show the progress of each student in form of reports that can be easy interpreted by students and teachers (from H-UDL-PMO-04).

- **Monitoring module**
  - The Monitoring module should register all or almost all the interaction of students with the UI (from R-D-PMO-03 and R-D-PMO-05).
  - The Monitoring module should send the information about students' interaction to the server. If no internet connection is available, the module should store the information in the device and should synchronize the information when the internet connection becomes available (from R-D-PMO-04).

Assessment Layer

The Assessment layer contains the Assessment module which is the module that manage all the assessment activities in the AR application.

Criterions for this layer:

- **Assessment module:**
  - The Assessment module should be easy to use (usability) (from R-D-ASE-01).
  - The Assessment module should support the synchronization of questions from the server so that teachers can update the questions or add new questions. Thus, students can see the changes in real-time (from R-D-ASE-02).
  - The Assessment module should provide feedback on the questions that are correct and the ones that are not correct. The feedback can be defined by teachers using the web application or using a mobile application for teachers (from H-UDL-ASE-01).
  - The Assessment module can be included in AR activities only at the digital level without the use of augmented information or the assessment can be part of the AR learning experience by taking advantage of AR features (from H-UDL-ASE-02).
  - The Assessment module should store the information about the number of trials done by students for each test and for each question (from R-D-ASE-07).
  - The Assessment module should include other means of presentations of information for each question such as images, videos or other resources to address students' variability or to complement the information provided in each question (from H-UDL-ASE-02 and R-D-ASE-03).

All of these criterions were analyzed for each one of the 11 applications identified during the first task. Table 7-1 shows the result of this analysis and shows the modules of the ARMotiD framework that are considered by the applications. For each module of the ARMotiD framework (presented in columns) the total number of criterions is specified. The list of applications analyzed is listed in the first column of the table. For each cell in the table, the number of criterions that each application meets is specified together with the overall conclusion (YES/NO) that indicate if the application integrates that module (YES) or not (NO). Besides that, for each cell the percentage of criterions that each application meets is also shown next to the number of criterions.

It is important to note that if the application complies with 50% or more of the criterions, then the overall conclusion will be “YES” otherwise the conclusion will be “NO”. Cells that are highlighted with a gray background correspond to the modules that are integrated by each application (module with the YES).

Table 7-1. Modules of the ARMotiD framework implemented in the applications selected.

Application name	Authentication (3 criterions)	UI Management & Interaction (6 criterions)	Scaffolding (5 criterions)	Augmented Information (6 criterions)	Real-time Feedback (8 criterions)	Videos (3 criterions)	Ask Your Teacher (3 criterions)	F.A.Q (6 criterions)	Progress Monitor (4 criterions)	Monitoring (2 criterions)	Assessment (6 criterions)
ARLOON Chemistry	NO (0) (0%)	YES (4) (67%)	YES (4) (80%)	YES (5) (83%)	YES (6) (75%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	YES (4) (67%)
DAQRI – Elements 4D	NO (0) (0%)	YES (4) (67%)	YES (3) (60%)	YES (4) (67%)	NO (2) (25%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Augmenter(Edulus VR)	NO (0) (0%)	YES (3) (50%)	NO (2) (40%)	YES (3) (50%)	YES (4) (50%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Laborapptor io	NO (0) (0%)	YES (3) (50%)	YES (3) (60%)	YES (4) (67%)	NO (0) (0%)	YES* (3) (100%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
QuimicAR (Augmented Class)	NO (0) (0%)	YES (3) (50%)	NO (0) (0%)	YES (5) (83%)	YES (4) (50%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Química Prebiótica Bioquímica	NO (0) (0%)	YES (3) (50%)	NO (0) (0%)	YES (5) (83%)	NO (0) (0%)	YES* (3) (100%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Química RA	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Augmented Reality METabolic Pathways (ARMET)	YES* (3) (100%)	YES* (6) (100%)	YES* (5) (100%)	YES (5) (83%)	YES (6) (75%)	NO (0) (0%)	NO (0) (0%)	NO (0)	YES (3) (75%)	YES* (2) (100%)	YES (3) (50%)
Molecular Geometry	NO (0) (0%)	YES (4) (67%)	NO (0) (0%)	YES (5) (83%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
Popar Periodic Table	NO (0) (0%)	YES* (6) (100%)	YES (4) (80%)	YES (5) (83%)	YES (5) (63%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)
AR Chemistry Review	NO (0) (0%)	YES* (6) (100%)	NO (0) (0%)	YES (4) (67%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)	NO (0) (0%)

***** Module that is in compliance with a 100% of criteria defined.

Third task: Show a demo to teachers so that they can evaluate the appropriateness of these applications for the curriculum and for the learning process

With the analysis conducted in Task 2 from which we obtained Table 7-1, we identified the modules of the framework that were integrated in the 11 applications that were selected for further analysis. At this point we could have selected some applications to conduct the validation process. However, only teachers know which applications are the best for addressing the learning needs of their students and they only know which applications may have a stronger impact on students. In this task we gathered the opinion of teachers to select the applications and the information provided in Table 7-1 defines the components of the framework that are addressed by each application.

In this task, a demo with the 11 applications selected as a result of the analysis in the previous tasks (Table 7-1) was prepared and showed to teachers. Each application was carefully analysed by the teachers. We showed how the application works, its main functionalities, advantages and possible drawbacks. Teachers analysed and discussed the opportunities for using each application in class and they analysed if the application was appropriate for the learning objectives in the VET programme of Laboratory operations.

After the analysis and discussion, the applications chosen by teachers were:

- ARLOON Chemistry
- Popar Interactive Periodic Table

At this point and after reviewing the applications, teachers decided to focus only on the topic of inorganic nomenclature and not in the topic of preparing solutions due to the opportunities identified by teachers in terms of using AR for supporting the learning process in the topic of inorganic nomenclature. Moreover, due to the restrictions of time for conducting the validation, the topic of inorganic nomenclature was the one that best fits the time available.

Moreover, a demo with the Paint-cAR application was prepared and showed to teachers. The purpose was to identify if some of the functionalities in the Paint-cAR application may be useful for supporting the learning process in the topic or inorganic nomenclature. As a result, teachers concluded that the Module of Videos and the Assessment module may be appropriate to support the learning process. Consequently, it was decided to use these modules as an independent application but adapted to the topic of inorganic nomenclature. These two modules depend on the following modules: the Authentication Module, the UI Management & Interaction module and the Monitoring module. Together these modules were integrated in a mobile application called "Chemistry videos and Assessment". Besides, the "Chemistry videos and Assessment" application was developed with an additional module that was defined in the framework: the Progress Monitor.

To design and develop the "Chemistry videos and Assessment" application, we followed the methodology that we defined for the co-creation of AR applications. A description of the activities carried out for each phase in the methodology is presented as follows:

- **Phase 1 - Identify the educational need:** This phase was conducted from the beginning of this validation because we had different meetings with teachers to identify the possibilities of using AR in the VET programme of Laboratory Operations. After we identified the applications that can be used for the validation process and the topic was defined (inorganic nomenclature), teachers described the main challenges they face in this topic.
- **Phase 2 - Understanding the learning domain:** To understand the learning domain some meetings with teachers were needed. Teachers described how they explained the

topic and together with the teachers we identified the possibilities for using the applications to support the students' learning process.

- **Phase 3 - Designing the AR application:** In this phase we had two applications previously selected with teachers (ARLOON Chemistry and Popar Interactive Periodic Table). To design the Chemistry videos and Assessment application we adapted the Module of Videos and the Assessment module so that they can work independently and they were adapted to the topic. To do that, we search on the internet for the videos in this topic and teachers watched the videos and selected the ones that better meet students' learning needs. In total 56 videos were selected by the teachers and it was decided to link this videos in the application. Moreover, with respect to the Assessment module, the teachers created the multiple-choice questions using the teachers' web application (which was adapted from the Paint-cAR web application). Teachers created 250 questions in total for this topic. The Assessment module works in the same way as in the Paint-cAR application: the questions are randomly selected so that students have different test each time.

  After some meetings with teachers, teachers suggested to divide the topic in the following sub-topics:

  a. Symbols and formulas
  b. Oxidation numbers
  c. Cations and anions
  d. Hydrids
  e. Oxides
  f. Non-metals
  g. Hydroxides
  h. Acids hydracids
  i. Acids oxyacid

  Teachers suggested that the application should be designed with a menu with these topics so that students can see the videos in the Module of Videos or answer multiple-choice tests in the Assessment Module for each sub-topic. It is important to note that the two modules had been designed taking into account the recommendations of the UDL.

  Besides the two modules, we designed with teachers a new module by taking into account the recommendations defined in the framework. The new module was de Progress Monitor and this module showed the number of tests passed by students in a ranking order. Thus, students can see how many tests they have passed using the application and they can also see their position in the ranking with respect to their classmates. This design decision addressed the UDL checkpoint # 6.4 – "Enhance capacity for monitoring progress" (Meyer et al., 2014) in which it is recommended to provide representations of students' progress in the learning activities.

  According to our experience in the first and second exploratory studies (described in CHAPTER 3 and CHAPTER 4) we identified that it is important to provide a mechanism to remind students to use the application at home. Moreover, in the framework we identified that the use of notifications can be a good strategy for providing personalized feedback. For this reason, a module for sending notifications to students at any time in the mobile application was suggested. This system was inspired in the UDL checkpoint # 9.3 "Develop self-assessment and reflection" (Meyer et al., 2014). This idea was analyzed together with teachers and they agree with their implementation in the application. The notifications system was designed so that students can receive notifications sent from a web application. The purpose of the notification was that teachers can send messages to encourage students to use the application at home for practicing or to send other types of notifications like reminders, informative messages or feedback. We decided to use push notifications so that students can receive the notifications at any time even if the application is not in foreground. To do so, the Firebase Cloud Messaging (FCM) service from Google was chosen because it was a reliable platform for sending push notification to devices. Moreover, the service was free of charge. Teachers agreed with the suggestion of a system for sending notifications and they stated that it can be very useful.

The Chemistry Videos and Assessment application has four modules: The Module of Videos, The Assessment module, the Progress Monitor and the Notifications module. It is important to note that the Module of Videos and the Assessment module also depend on the following modules that were also integrated in the application: Authentication Module, the UI Management & Interaction module and the Monitoring module.

- ***Phase 4 - First prototype of the Chemistry videos and assessment:*** The Chemistry Videos and Assessment application was completely developed in Android Studio. The application can be downloaded from the following web site that was designed for the application: https://goo.gl/sg7At8. Figure 7-1 shows a screenshot of the main menu of the application. In this interface students can choose from 3 options: Watch videos about inorganic nomenclature, answer questions about the topic and review the general statistics of tests passed in the application for all students.

Figure 7-1. Screenshot of the main menu of the "Chemistry Videos and Assessment" application.

When students select the option for watching videos or the option for answering tests (questions about inorganic nomenclature), a menu with the sub-topics is displayed and students can select the topic in which they would like to practice. As mentioned earlier, the sub-topics were defined together with teachers. Figure 7-2 shows the menu of sub-topics in the chemistry videos and assessment application.

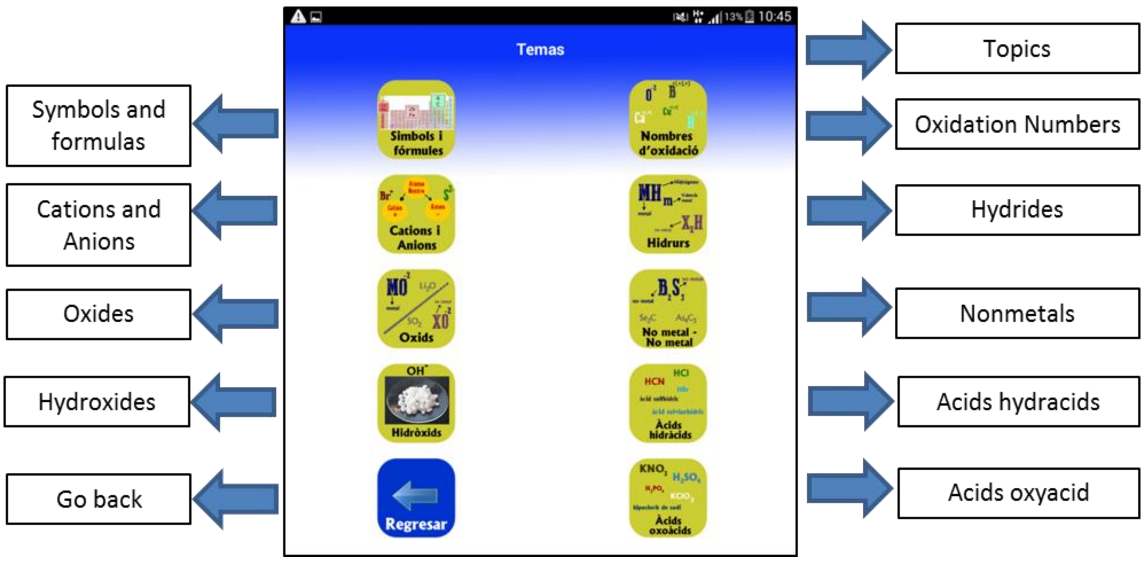

Figure 7-2. Menu of sub-topics in the Chemitry Videos and Assessment application.

Figure 7-3 shows the user interface of the ranking of test passed by students in the application. This screenshot has been edited to remove students' names to protect their identity and instead of each student name we added the word student. This user interface shows all students and next to the name of the students, the number of tests approved is also shown. This user interface is part of the Progress Monitor module. This module receives information from the server and shows the results in the user interface.

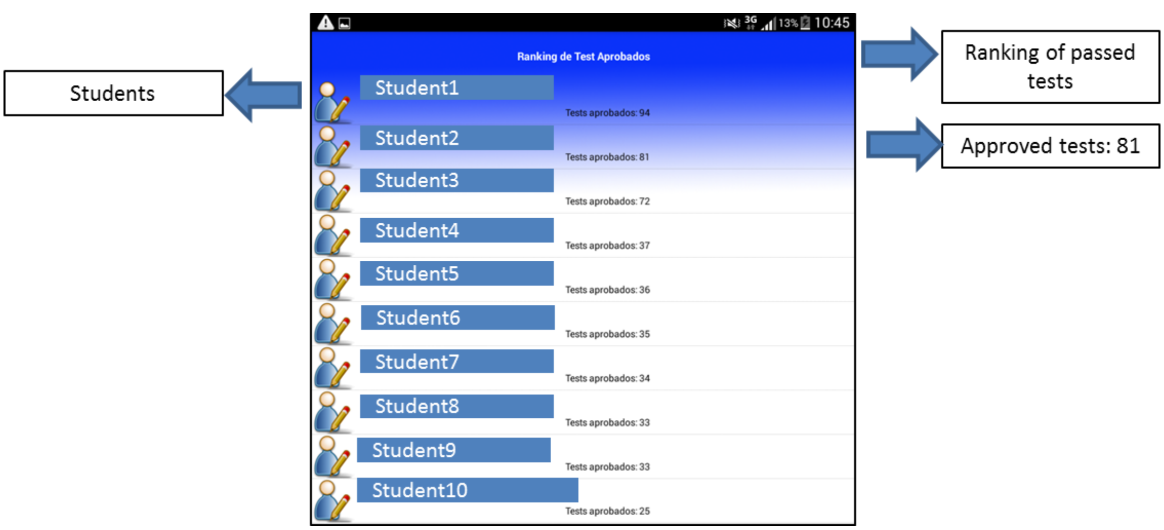

Figure 7-3. User interface of the Progress Monitor module.

Finally, Figure 7-4 shows the user interface that displays an example of the notifications that can be sent by teachers. The notifications can be used for sending reminders, feedback or general information.

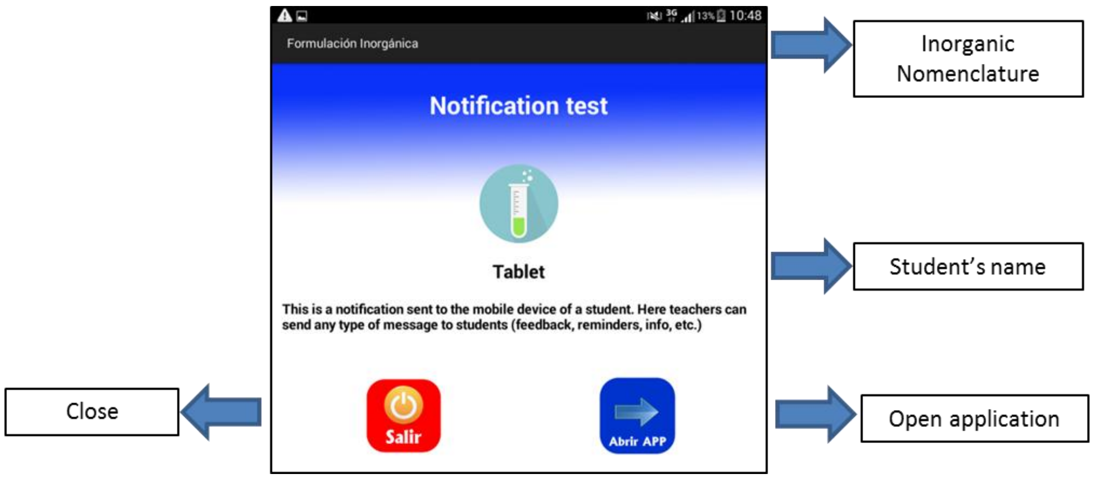

Figure 7-4. Example of a notification that teachers can send in the Chemistry Videos and Assessment.

- **Phase 5 - First testing with students:** The Chemistry Videos and Assessment application was tested with students as part of the validation process. The results of this testing are described in detail in section 0.
- **Phase 6 – Evaluation:** The results of evaluating this application are also provided in section 7.4.4 as part of the validation process.

Table 7-2 shows, in the first column, the two applications selected together with the application "Chemistry Videos and Assessment". The modules of the framework are shown in the first row of the table. In the table, cells with a light-gray background highlight the modules that can be validated with each application and in the last row cells with a dark-gray background highlight the modules of the framework that can be validated in general with the three applications.

As shown in Table 7-2 (see last row), 9 out of 11 modules (82%) of the ARMotiD framework can be validated with the applications chosen by the teachers jointly with the application developed "Chemistry Videos and Assessment". Thus, the validation with these three applications covers most of the components of the ARMotiD framework.

Table 7-2. Applications chosen by teachers and in the last row an indication if the module can be validated with that application is defined.

Application name	**Authentication**	**UI Management & Interaction**	**Scaffolding**	**Augmented Information**	**Real-time Feedback**	**Videos**	**Ask Your Teacher**	**F.A.Q**	**Progress Monitor**	**Monitoring**	**Assessment**
ARLOON Chemistry	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO	YES
Popar Interactive Periodic Table	NO	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO
Chemistry Videos and Assessment	YES	YES	NO	NO	NO	YES	NO	NO	YES	YES	YES
Can the module be validated with the applications?	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**NO**	**NO**	**YES**	**YES**	**YES**

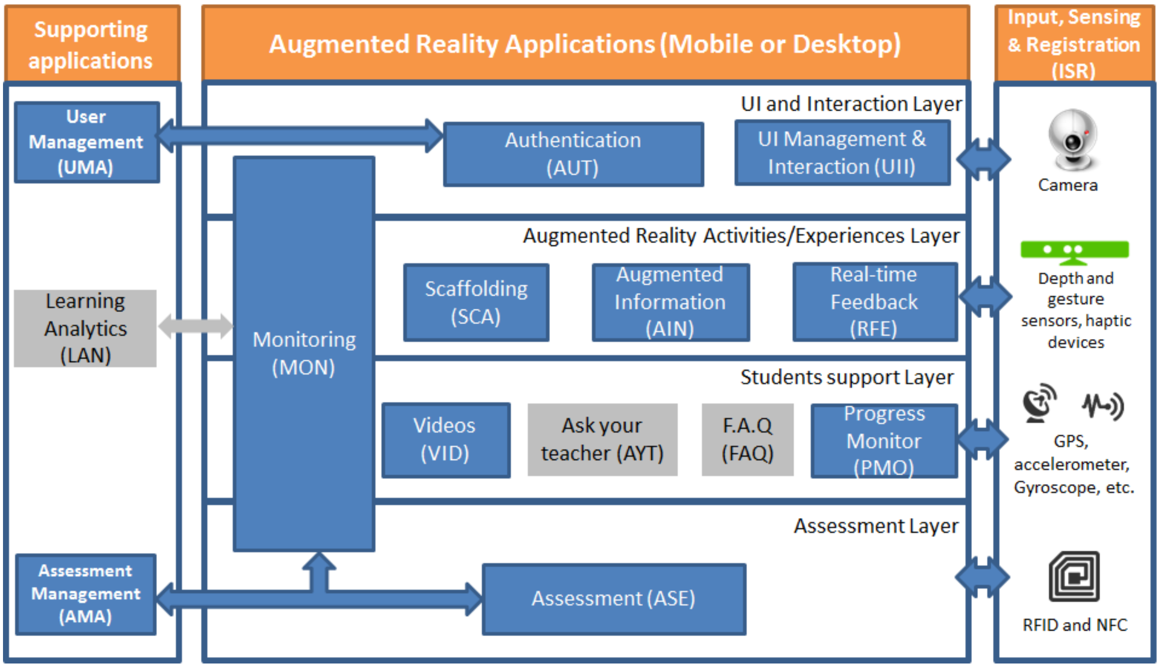

Figure 7-5. Components that were validated (highlighted in color).

Moreover, Figure 7-5 shows (in color) the modules of the framework that can be validated with the three applications. It is important to note that the number of modules in the framework seems to be more than 9 but this is because the Progress Monitor (PMO) and the Monitoring module (MON) work as only one module and the Authentication module (AUT) works with the User Management (UMA) and finally the Assessment (ASE) works with the Assessment Management (AMA). The modules in gray scale are the modules that were not validated in this validation process (LAN, AYT, FAQ).

7.4.3 Conduct the validation in the VET programme with the applications identified in the previous phase

As mentioned before, the aim of validating the ARMotiD framework is to identify if the modules defined in the framework increase students' motivation in AR learning experiences. Aligned with this purpose, in the phase 2 of this validation process we identified two AR applications and we developed one additional mobile application. In total, the three applications cover 9 out of 11 components of the framework (82% of the framework). This phase describes how the three applications are integrated within the curriculum of the VET programme in Laboratory Operations and in particular for the topic of inorganic nomenclature. This section also describes the experimental procedure followed as well as details of the statistical analysis conducted and the results obtained.

How the three applications were integrated within the curriculum

In total 20 hours are available for this topic in the curriculum and during that time the applications were used for the following purposes:

- Popar Interactive Periodic Table: This application was used so that students can recognize the chemical elements from the periodic table. The application was used at the beginning of the course so that students become familiar with the periodic table and the chemical elements. This application shows the periodic table augmented over a poster of the periodic table and students can interact with the periodic table by selecting and combining the chemical elements from the table. Besides that, three activities were arranged so that students can use the application at home for practicing. The main pedagogical intention of these three activities was that students can identify the main characteristics of each specific compound such as the industrial applications and interesting facts with respect to the nature of each compound. The activities were:

- First Activity: Finding the major quantity of compounds that can be obtained by combining some chemical elements from the periodic table and writing the main characteristics of the compound provided by the application to share them in class.
- Second Activity: Find five specific hydrides in the application and take notes of its main characteristics as well as the oxidation state of each element in the compound.
- Third Activity: Find nine specific oxides in the application and take notes of its main characteristics as well as the oxidation state of each element in the compound.

These activities were develivered by students and were revised by the teacher and researchers.

- ARLOON Chemistry: This application will be used so that students can identify and practice about:
    - The oxidation number of the chemical elements of a compound: The application asks students to create a particular compound and they need to select the appropriate oxidation number to create an existing compound.
    - The name of a particular compound: The application provides an explanation on how to give the name of a compound according to the standardized rules. Then in the exercises students are asked to provide the name of some compounds.
    - The compound associated to the standardized name: The application provides an explanation on how to identify the name of a compound from its chemical formula. Then in the exercises students are required to provide the name of a compound for different chemical formulas.
    - The type of compounds that students will be studying are:
        - Cations and anions
        - Binary compounds (Hydrides)
        - Binary compounds with oxygen (Oxides)
        - Binary compounds with nonmetals
        - Hydroxides
        - Acids

  Students used the application as recommended by the teacher to do some exercises proposed in a worksheet and to validate their thoughts about the name of a compound or the oxidation number as well as the number of atoms of each element in a compound. Moreover, the application also provides a mode in which students can do exercises to test their knowledge. The exercises need to be completed under a predefined time limit. With this mode some activities were developed in class to make a competition as long as students have reached mastery in the topic. Teacher recommended using the application at home for practicing and for correcting the exercises in the book that were part of the homework after each class.
- Chemistry Videos and Assessment: With this application students watched videos about the topic of inorganic nomenclature. These videos were collected by the researchers and the teachers chosen the videos that better meet students' learning needs. In total 56 videos were linked to the application. Besides that, students had the possibility of solving tests for each one of the sub-topics in the topic of inorganic nomenclature. The

tests were classified according to each sub-topic and the questions were created by the teacher using a web application. In total 250 questions were created by the teachers for all of sub-topics. The purpose of this application is that students can see the videos with additional explanations and examples for each topic and that they can practice with some exercises provided in the application in the form of test. These activities are designed for being developed at home. As mentioned earlier, students also have a module for checking their progress (when they solve the test) and compare their progress with respect to the rest of the students.

As a result the applications were used in class in a way that provides a wide variety of activities for the AR learning experience to validate the components of the ARMotiD framework.

The three applications were integrated in the curriculum during the seven weeks that the validation lasted as shown in Table 7-3.

Table 7-3. Integrating the three applications in the curriculum for the seven weeks.

Week #	Sub-topic	Materials	Activities
1	Cations and Anions	Popar periodic table application with the poster of the periodic table, students' notebook.	This sub-topic includes the introduction to the periodic table of elements and the explanation of the concepts of anion, cation and oxidation number. The teacher explained the sub-topic in the classroom and at the end of the class students were guided through the installation of the Popar interactive periodic table. An explanation on how to use the application with a poster of the periodic table was given. For homework, students were asked to use the Popar application to find the major quantity of chemical compounds that they can obtain by combining chemical elements from the periodic table. For each chemical compound students had to write a summary of the information given by the application (main characteristics and industrial applications of each compound). The result had to be delivered the next class. Moreover, students had to do some exercises in the students' book.
2	Binary compounds (Hydrides)	Popar periodic table application with the poster of the periodic table, Chemistry Videos and Assessment application, students' book and students' notebook.	The activity for homework was collected and revised by the teacher after the class to give feedback to students. In class, the sub-topic was explained by the teacher. Students did some exercises in the students' book as required by the teacher. For homework students received a worksheet. In this worksheet students were required to use the Popar application with the poster to find some hydrides and they had to identify the oxidation number of each chemical element in the compound and write a summary of the industrial applications for that compound and its main characteristics. Moreover, students were guided through the process of installing the "Chemistry Videos and Assessment" application. Then, for homework students were asked to revise the videos about

Week #	Sub-topic	Materials	Activities
			the first and second sub-topics and to answer the multiple-choice questions. Some notifications were sent to students using the web application to remind them to use the application, to do the homework and to motivate them.
3	Binary compounds with oxygen (Oxides)	Popar periodic table application with the poster of the periodic table, Chemistry Videos and Assessment application, ARLOON Chemistry application, students' book and students' notebook.	The worksheet for homework was collected and revised by the teacher after the class to give feedback to students. In class, the sub-topic was explained by the teacher and students did some exercises in the students' book as required by the teacher. For homework students received a worksheet. In this worksheet students were required to use the Popar application to find some oxides and they had to identify the oxidation number of each chemical element in the compound and write a summary of the main industrial applications and characteristics of that compound. At the end of the class, students were guided through the process of installing the ARLOON Chemistry application. An explanation about how to use the ARLOON chemistry application was given and for homework students had to correct the exercises they did in the book to check if they were correct or not. During that week some notifications were sent to students using the Chemistry videos and Assessment application to remind students to use the application and to do the homework and to motivate them.
4	Binary compounds with nonmetals	Chemistry Videos and Assessment application, ARLOON Chemistry application, students' book and students' notebook.	The worksheet for homework was collected and revised by the teacher after the class to give feedback to students. In class, the sub-topic was explained by the teacher and students did some exercises in the students' book as required by the teacher. Part of the class was dedicated to do some exercises with the ARLOON chemistry application about the topics explained so far. Some questions were asked by students as they used the application for doing the exercises and the teacher answered the questions. For homework students were required to do some exercises in the students' book. After that, students had to check if the exercises were correct or not by using the ARLOON chemistry application. For example, if students had to give the name of a compound, first they did the exercise in the book as usual and then they used the application to check if the name of the compound was correct or not. This helped them to reflect on their errors and helped them to correct the exercises. Moreover, students were asked to do more exercises about binary compounds with nonmetals in the Chemistry Videos and Assessment application and using the ARLOON chemistry application. During this week, using the web application, the teacher was able to

Week #	Sub-topic	Materials	Activities
			see students progress and the teacher sent some notifications to students to enourage them to use the applications and motivate them.
5	Hydroxides	Chemistry Videos and Assessment application, ARLOON Chemistry application, students' book and students' notebook.	The exercises for homework were revised in class and some unsolved doubts were clarified. Then the sub-topic was explained by the teacher and students did some exercises in the students' book as required by the teacher. Students were asked to use the ARLOON chemistry application to check the exercises and the doubts were clarified. A short competition was carried out in class with the ARLOON chemistry application in which students had to solve a predefined number of exercises in class. For homework, students were required to do some exercises in the students' book and to use the ARLOON chemistry application to check the exercises and to use the Chemistry Videos and Assessment application to see the videos about Hydroxides and to do more exercises. During that week the teacher used the web application to check students progress and to sent notification to students according to their progress.
6 and 7	Acids	Chemistry Videos and Assessment application, ARLOON Chemistry application, students' book and students' notebook.	The exercises for homework were revised in class and some unsolved doubts were clarified. Then the sub-topic was explained by the teacher and students did some exercises in the students' book as required by the teacher. Since this sub-topic includes two parts: Hydracids and oxoacids, this sub-topic required two weeks. Students were required to do the exercises in class and to check them with the ARLOON chemistry application. Then, the doubts were clarified by the teacher. For homework students were asked to do some exercises in the students' book and they had to check them using the application. Moreover, they need to do the exercises using the Chemistry Videos and Assessment application. During these two weeks the teacher followed students' progress using the web application and the teacher sent some notifications to students to encourage them to use the application and motivate them. After finishing the seventh week the experimental procedure continued with the post-test and the IMMS instrument as described later in this section.

<u>Instruments used in the validation</u>

The instruments that will be used in the validation are:

- **Survey:** This is a survey about the use of mobile devices and other technologies. The purpose is to gather information about the types of devices that students are using and the frequency of use as well as some demographic information.

- **Pre-test:** This instrument is a questionnaire to identify previous knowledge of students before the intervention. The purpose of this test is to compare the results of each student before the intervention with the results of the post-test that is obtained after the intervention. The pre-test was validated with (N=57 students). The test consisted of 20 multiple-choice questions with only one correct answer. The reliability of the questionnaire was analyzed with the KR-20 (Kuder-Richardson) in one phase. The Cronbach's alfa was 0,711. This test is scored in a scale from 0 to 10, where 10 represents the best score in terms of learning outcomes. Please refer to APPENDIX F to see the complete questionnaire.
- **Post-test:** This instrument is a questionnaire to identify gains of knowledge after the intervention. The results gathered with this test will be compared with those of the pre-test to identify gains. The post-test is equivalent in terms of content with respect to the pre-test (see APPENDIX F). This test is scored in a scale from 0 to 10, where 10 represents the best score in terms of learning outcomes.
- **IMMS:** The Instructional Materials Motivation Survey (IMMS) measure the levels of motivation according to the *Attention*, *Relevance*, *Confidence* and *Satisfaction* (ARCS) model. This instrument was applied before in the context of this thesis in CHAPTER 3 and CHAPTER 4. The IMMS instrument was adapted for the purposes of this study to gather data about student motivation when using the Paint-cAR application for learning. The adapation of the IMMS instrument is presented in APPENDIX D. It is important to note that that all the 36 questions of the instrument were maintained (to avoid affecting reliability of the instrument) but the questions were slightly adapted to ask about the experience using the AR applications.

Research Design and Participants

A quasi-experiment research design was adopted for this validation because it was not possible to randomly allocate participants to the control and experimental conditions. Since this situation violates one of the conditions of a true experiment (Coolican, 2014), the quasi-experiment research design was selected in this scenario and in particular, a pre-experimental approach was selected.

To evaluate student motivation the post-test only pre-experimental research design (Cohen, Manion, & Morrison, 2007) was selected. This research design implies the use of one control group and one experimental group but there is no pre-test for the control and experimental groups and only the post-test is administered to both groups at the end of the intervention. In our validation, this research design was applied because it was not possible to measure the "initial levels of motivation" of students before the intervention with the AR learning experience. In other words, it was not possible to obtain a reliable measure of student motivation as a pre-test that can be compared to a post-test. This is mainly because we cannot collect data about "initial" levels of motivation of students because it is difficult to ask students to report their levels of motivation about previous experiences with other learning materials.

Other studies in the literature have adopted a similar approach and they have not measured initial levels of motivation such as the studies by Y. Chen (2013), Chiang et al. (2014), Ibanez, Di-Serio, et al., (2015) and C.-H. Chen et al. (2016). Moreover, in the study by Di Serio et al. (2013) the researchers applied a one group pre-test-post-test research design (Cohen et al., 2007) in which only one group is used and is the group that receives the intervention. This means that they did not use a control group.

To evaluate students' learning outcomes a pre-test-post-test non-equivalent group design (Cohen et al., 2007) was selected. This pre-experimental research design implies the use of one control group and one experimental group. The experimental group receives the intervention while the control group does not receive the intervention. Moreover, a pre-test is administered to both groups before the intervention in the experimental group and a post-test is administered to both groups after the intervention in the experimental group. In the context of this validation it was not possible to administer the pre-test to the control group so we only collected data for the post-test in the control group. For the experimental group we collected data for the pre-test and post-test.

The intervention for the experimental group in the pre-experimental research design consist of the use of the three applications selected previously as part of this validation in an AR learning experience for learning the topic of inorganic nomenclature in the VET programme of Laboratory Operations. On the other hand, the control group followed a traditional learning experience. Further details are presented later in the procedure for this validation.

Participants

In this study students from a VET institute in Catalonia (Spain) participated as the experimental group (N=26). Since there was only one group of students in the VET institute in Catalonia the control group for this study had to be another VET institute. The VET institute of the control group was an Institute of Vocational Education and Training in Colombia. In total (N=32) students from Colombia participated in this study as the control group. The content equivalence was ensured for both groups because the subject matter was similar in both institutions and teachers of both institutes stated that the learning content was equivalent.

The survey was applied at the beginning of the intervention in the **experimental group only**. The purpose was to collect some demographic data and information about the type of smartphones of each student and some information regarding the use of mobile devices. The results of this survey showed that 16 out of the 26 participants in this study were female and 10 were male. Moreover, 16 out of the 26 students are in the age range between 17 to 19 years old, 5 are in the age range between 15 to 16 years old and only one of them is in the range between 23 to 25 years old and finally 4 of them are older than 25 years old. All of the students reported to have a mobile device (tablet or smartphone) with internet connection (3G, 4G or Wi-Fi). One of the questions in the survey asked students about their willingness to use mobile devices for learning at the institute and 76% of them answered that they would like to use mobile devices for learning and 24% answered that they would not.

Another category analysed was the "uses of mobile devices". In this category students were able to choose multiple options, so each option may appear more than once. Students used the mobile devices for: Chatting (92.3%), making calls (92.3%), Social networking (80.7%), Searching on the internet (69.2,4%), using maps - GPS (57.9%), sending emails (46.1%) and playing games (46.1%).

Most of the participants used mobile devices with the Android operative system (88.5%) and IOS operative system (11.5%). In terms of the use of mobile applications for education 80.5% of the students recognized to have used an educational app. However, students stated that they hardly ever (38.4%) and almost never (38.4%) install new applications in their mobile phones. Only 19.2% of the students usually install new applications on their mobile phones. Finally only one out of the 26 students stated to have ever heard the term Augmented Reality and use one application with this technology. The rest of the students have never heard about AR.

With data collected from the first survey we were able to identify that only one student knew what AR was. The rest of the students have not heard about AR before. Moreover, we identified that most of the students are not used to installing new applications on their mobile devices. So based on this information we prepared the introductory session for the intervention so that all students were informed about the type of technology that they were going to use and we also helped them to install the applications that we were planning to use. Moreover, we identified that most of the students (76%) stated that they were willing to use mobile devices for learning. Besides that, most of the students reported to have used educational applications before (80,5%). These results may suggest that students can be receptive with the intervention.

Experimental Procedure

The procedure for the **experimental group** (VET institute in Catalonia) in the quasi-experiment is described as follows:

1. **Survey:** In this phase a survey about the use of mobile devices was administered to obtain some demographic information and to gather information about the type of mobile devices that students have to make sure that the applications work well in each device. This phase lasted for 15 minutes.
2. **Installation of applications:** In this phase, students were guided in the process of downloading and installing the applications. Students were introduced on how to use the applications and basic concepts about AR were explained. The main objectives of the activity were explained. A booklet that contains the markers that the applications recognize was given to each student. This phase lasted 60 minutes.
3. **Pre-test:** In this phase, the pre-test was administered to students. The purpose of the pre-test was to gather information about students' knowledge about the topic so that we can compare the results of the pre-test with the post-test and identify learning gains after the intervention. This phase lasted 1 hour and 15 minutes.
4. **Learning experience with AR:** During the intervention students used the applications in class with the guide of the teacher or at home to do the activities as part of their homework. In this phase the applications were used according to the integration within the curriculum as described before in this section. The researchers observed how students used the applications and solved any technical difficulty. This phase lasted for seven weeks.
5. **Post-test and IMMS motivation questionnaire:** In this phase the post-test was administered. The purpose of the post-test was to identify gains in learning outcomes. Besides that, the final motivation questionnaire was administered. The final motivation questionnaire was the IMMS instrument adapted to gather information about students' levels of motivation after the intervention with the AR applications. This phase lasted for 50 minutes.

The procedure followed by the **control group** (VET institute in Colombia) in the quasi-experiment is described as follows:

1. **Traditional learning experience:** Students followed a traditional class with the materials that teachers usually use and with no changes in the instruction. As mentioned before the content equivalence was ensured for the control group because the subject matter has the same topics as in the experimental group. This phase lasted for 6 weeks. It is important to note that, due to logistic reasons, it was not possible to apply the pre-test and the survey in the control group. For this reason the pre-test and the survey were not part of the experimental procedure followed by the control group.
2. **Post-test and IMMS motivation questionnaire:** The post-test was administered in this phase to identify gains in learning outcomes after the traditional class. Moreover, the IMMS motivation questionnaire was adapted to gather information about students' levels of motivation after a learning process with traditional learning materials such as books, paper copies among others. This phase lasted 50 minutes.

Figure 7-6 shows the experimental procedure for the control and experimental groups.

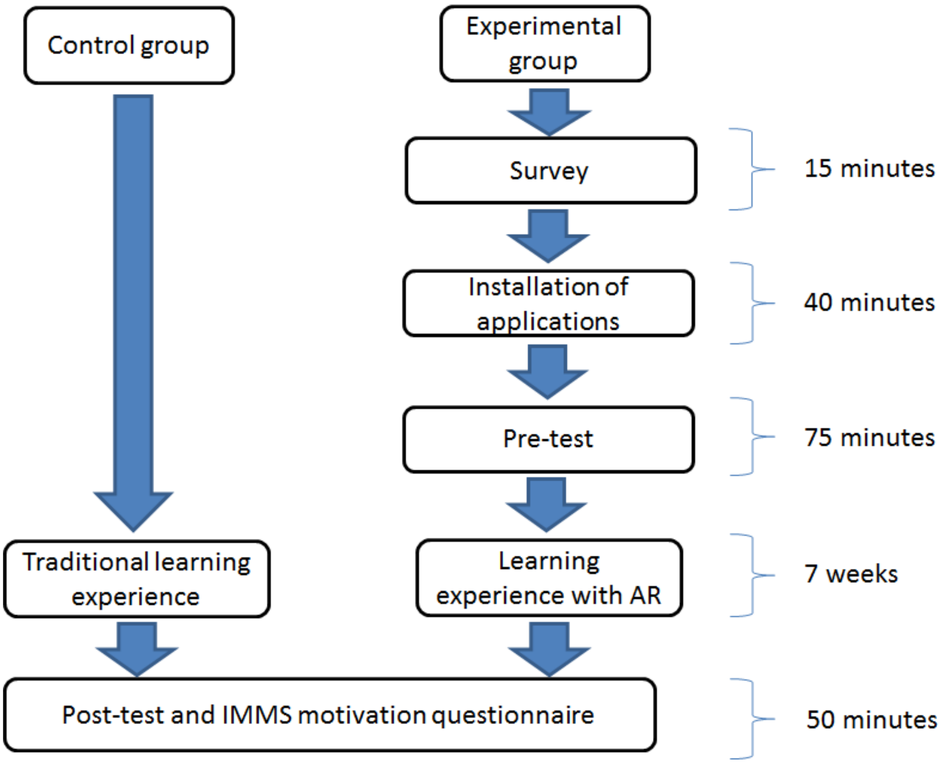

Figure 7-6. Diagram of the experimental procedure for the quasi-experiment.

<u>Statistical Analysis and results</u>

This section presents the statistical analysis and the results obtained from the data collected in the quasi-experiment. The statistical analysis and results are divided into two main subsections:

- **Motivation:** We describe the statistical analysis and results of the data collected from the IMMS instrument regarding student motivation in the experimental and control groups
- **Learning outcomes:** We describe the statistical analysis and results of data collected from the pre-test and post-test in the experimental and control groups.

The discussion of these results is presented later in section 7.4.4.

Results of Student Motivation

The results of student motivation came from the data collected from the IMMS instrument administered to the control and experimental groups.

First, we analyzed if data followed a normal distribution or not to select accordingly the statistical test. Thus, the Kolmogorov-Smirnov and the Shapiro-Wilk tests for normality were used in SPSS to determine if data collected from the IMMS instrument followed a normal distribution or not. The results of the analysis for data gathered from the IMMS instrument are presented in Table 7-4.

Table 7-4. Tests for normality of data gathered from the IMMS instrument

	Kolmogorov-Smirnov			Shapiro-Wilk		
Dimension	**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 it can be seen in Table 7-4, data collected for the *relevance* dimension and *confidence* dimension do not follow a normal distribution (according to the Shapiro-Wilk test for normality) and therefore for the analysis of this data we used the Mann-Whitney U test which is a non-parametric test. For the *attention* and *satisfaction* dimensions we used the standard parametric t-test.

The Mann-Whitney U test was applied to the *relevance* dimension and *confidence* dimension to identify if there was any difference in these dimensions in the control group compared to the experimental group. For the *relevance* dimension, the results showed that participants in the control group (M=3.57; SD=0.5) reported higher levels of motivation than participants in the experimental group (M=3.44; SD=0.55). However, this difference was not significant (*U=354.5, p>0.05, Sig=0.33*).

For the *confidence* dimension, the results showed that participants in the experimental group reported higher levels of *confidence* (M=3.64; SD=0.51) than participants in the control group (M=3.18; SD=0.5). This difference was significant (*U=638, p<0.05, Sig.=0.001*), effect size was large (*d=0.907*) and Power was 0.90.

The standard parametric t-test was applied to the *attention* dimension and *satisfaction* dimension to identify if there was any difference between the levels of motivation in these dimensions in the control group compared to the experimental group. For the *attention* dimension the results of the t-test showed that participants in the experimental group reported higher levels of *attention* (M=3.56; SD=0.44) than participants in the control group (M=3.2; SD=0.44). The difference between the means was significant: *t(37.149)=2.070, p<0.05*, *Sig.=0.045*. Effect size was medium: Cohen's d= 0.56 and Power was also calculated: 0.55.

For the *satisfaction* dimension, the results of the t-test showed that participants in the control group reported higher leves of satisfaction (M=3.7; SD=0.7) than participants 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: Cohen's d= 0.67 and Power was also calculated: 0.71.

To sum up, Table 7-5 shows a summary of the results for each dimension of motivation in the control and experimental group and shows if the statistical difference was significant or not and specifies the group in which the difference was significantly higher.

Table 7-5. 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.

The results in the Table 7-5 are summarized as follows:

- The *attention* dimension and *confidence* dimension rated high in the experimental group than in the control group and there was a significant statistical difference in favour of the experimental group.
- In the *relevance* dimension of motivation there was not a significant diference between the control and experimental groups.
- The *satisfaction* dimension showed higher levels in the control group than in the experimental group and the statistical difference was significant.

Results of Student's Learning Outcomes

As showed in the experimental procedure, the analysis of student learning outcomes was divided into two parts: first, the comparison of the results from the post-test between the control and experimental groups and second, the comparison of the results from the pre-test and the post-test in the experimental group only. This subsection presents both results.

As for the first comparison, we analyzed if data collected with the post-tests applied to the control and experimental groups followed a normal distribution. Thus, the Kolmogorov-Smirnov and the Shapiro-Wilk tests for normality were used in SPSS. The results of the analysis for data gathered from the post-test instrument are presented in Table 7-6.

Table 7-6. Tests for normality of data gathered from the post-test.

	Kolmogorov-Smirnov			Shapiro-Wilk		
Sample	**Statistic**	**Degrees of Freedom**	**Sig.**	**Statistic**	**Degrees of Freedom**	**Sig.**
Control Group	0.214	32	0.001	0.796	32	0.000
Experimental Group	0.106	26	0.200*	0.960	26	0.389*

** p > 0,05*

As it can be seen in Table 7-6 the sample of the control group does not follow a normal distribution and therefore for the analysis of this data we used the Mann-Whitney U test. This test was applied to identify if there was any difference in terms of learning outcomes between the control group and the experimental group in the results of the post-test. The results showed that there was not a significant difference in terms of learning outcomes between the control group (M=8.0; SD=1.5) and experimental (M=7.0; SD=1.5) group ($U=321.5, p>0.05, Sig.=0.136$). For facilitating the interpretation of these results, please remember that the score of this test range from 0 to 10.

We also analyzed the learning gains by comparing the pre-test and the post-test in the experimental group only to identify the effect of the AR learning experience on students' learning outcomes. However, first we analyzed if data collected from the pre-test and post-test followed a normal distribution.

Table 7-7. Tests for normality of data gathered from the pre-test and post-test in the experimental group.

	Kolmogorov-Smirnov			Shapiro-Wilk		
Sample	**Statistic**	**Degrees of Freedom**	**Sig.**	**Statistic**	**Degrees of Freedom**	**Sig.**
Pre-test	0.149	26	0.140*	0.967	26	0.558*
Post-test	0.106	26	0.200*	0.960	26	0.389*

** p > 0,05*

As it can be seen in Table 7-7, data collected for the pre-test and post-test follow a normal distribution and therefore a parametric test can be applied. Thus, a paired samples t-test was applied. The results show that students' learning outcomes in the post-test (M=7.03; SD=1.59) are higher than students' learning outcomes in the pre-test (M=4.6; SD=1.59) resulting in a increase in the post-test which was statistically significant, $t(25)=7.522$, $p<0.001$, two-tailed. Effect size was large (*Cohen's d*=1.47 and Power was calculated: 1).

7.4.4 Discussion of results

Discussion of Results of Student Motivation

In terms of motivation, in general the results show a positive impact in the four dimensions of motivation for the control and experimental groups. This means that students reported positive levels of motivation after learning with both the AR applications and the traditional materials such as text books, print copies and written exercises. However, it its worth noting that higher levels of motivation were reported by students in the *attention* and *confidence* dimensions of motivation when learning with the AR applications (experimental group) compared to the learning process with the traditional materials (control group).

These results demonstrate that the learning experience designed according to the ARMotiD framework was not only useful for supporting the *attention*, *relevance*, *confidence* and *satisfaction* dimensions of motivation but it was also particularly useful for supporting the *attention* and *confidence* dimensions of motivation.. As for the *attention* dimension, students reported higher levels of *attention* in the experimental group than in the control group. This means that the learning experience created by following the framework allowed to capture students' interest and helped students to focus on the most important information of the learning content. This result is also in line with the results obtained by other researchers with respect to the positive impact of AR applications on the *attention* dimension (Chiang et al., 2014; Y. Chen, 2013; Ibanez, Villaran, et al., 2015; Chin et al., 2015; C.-H. Chen et al., 2016; Ibanez, Di-Serio, et al., 2015). Moreover, our results are in line with the results obtained by Di Serio et al. (2013) with respect to the positive impact that AR has on the *attention* and *confidence* dimensions of motivation.

As for the *confidence* dimension, students reported higher levels of *confidence* when using the AR application than using the traditional learning materials. These results show that students perceived that they can success in the learning activities and they perceived more control in their learning process by using the AR applications defined according to the ARMotiD framework. This result might be explained by the fact that 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 the traditional learning materials. This result demonstrates that the components defined in the framework are useful for supporting the *confidence* dimension of motivation in a higher level than the use of traditional learning materials.

Our results are in line with other studies that have demonstrated that AR applications are useful for supporting the *confidence* dimension of motivation (Chiang et al., 2014; Chin et al., 2015; C.-H. Chen et al., 2016).

In contrast, the results showed that in terms of the *relevance* dimension of motivation, there was not a statistical significant difference between the control group and the experimental group. The difference between the control group (M=3.57; SD=0.5) and the experimental group (M=3.44; SD=0.55) was small but the level is slightly higher in favor of the control group. In general it seems that students perceive both the AR learning experience and the traditional learning experience as relevant for their learning process almost at the same level with a slight preference over the traditional learning experience. On the one hand, this result is positive since it indicates that learning experience created by following the ARMotiD framework also supports the *relevance* dimension of motivation. This means that the AR learning experience created with the ARMotiD framework was equally relevant for students than the traditional learning experience and therefore this may demonstrate that the AR learning experiences was not negatively affecting the *relevance* dimension of motivation. On the other hand, this result may be affected by the learning domain or by the applications selected for the validation. In this sense, further research may be needed to identify the causes of the differences in terms of the *relevance* dimension of motivation.

Finally, in terms of the *satisfaction* dimension of motivation, the results showed a statistical significant difference between the control group and the experimental group in which the participants in the control group (M=3.7; SD=0.76) reported higher levels of *satisfaction* than participants in the experimental group (M=3.1; SD=1.0). In this case the difference is significant. The result in the control group may be explained by the fact that students are used to learning with traditional learning materials as they have been learning with them for most of the time in the school. As a result, students rated high the learning experience with the traditional learning materials as they have not had any other type of learning experience. However, students in the experimental group reported a lower level of *satisfaction* in the AR learning experience. This result may be explained by the fact that the AR applications available for creating the AR learning experience vary in terms of its design and therefore these applications might not be adjusted at a 100% with certain needs of the learning domain. These slight differences between the design of third-party applications and the requirements of the learning domain might have a negative impact on student motivation. This is a risk that teachers always face when using applications that have not designed for their specific requirements. However, it is worth noting that this impact might not be huge if the application is selected by teachers according to clear requirements and with clear and defined learning objectives. This is exactly what a teacher may experience when using existing materials for teaching and in this case when choosing existing AR applications for creating a motivational AR learning experience. For instance, the scaffolding mechanism in the applications selected for this validation was not adaptive and had very basic functionalities. As a reult, the use of this component during the learning experience may not have a big impact on students' satisfaction and therefore the *satisfaction* may decrease. Another component that may affect the levels of *satisfaction* (as described in CHAPTER 5) is the real-time feedback which needs to be also improved in the applications selected for the validation. Notwithstanding these issues, the level of *satisfaction* is still positive in the experimental group which indicates a positive impact of the AR learning experience designed based on the ARMotiD framework. In other words, although the levels of satisfaction are not higher than the experience in the control group, the levels of satisfaction reported are not negative.

Another interpretation of the results obtained in the *satisfaction* dimension in the experimental group comes from the observation of the intervention. During the intervention, we observed that some students had negative perceptions towards the topic of inorganic nomenclature because of its high amount of theoretical content that makes this topic difficult for learning. This situation might have diminished the levels of motivation in all the four dimensions but this might have particularly affected the *satisfaction* dimension of motivation. A possible explanation might be that students did not receive enough feedback from the teacher, reinforcement or other types of extrinsic rewards as recommended by Keller (2010) to support the *satisfaction* dimension of motivation. The extrinsic rewards need to come from the teacher and cannot be controlled by the AR learning experience. As a result, we identified that the successful implementation of the AR learning experience needs to be carried out with a high level of support by the teacher. It is also important to note that although the levels of motivation are measured with respect to the AR learning experience, there are many factors that influence students' perceptions and therefore that affect the levels of motivation unconsciously.

Discussion of Results of Students' Learning Outcomes

In terms of learning outcomes, by comparing the control group (M=8.0; SD=1.5) and experimental group (M=7.0; SD=1.5) we found that there was not a statistical significant diference between both groups. However, students from the control group obtained slightly better scores than students from the experimental group. In general, we can conclude that the AR learnig experience supported learning outcomes in a positive way but further research is needed to identify if any aspect of the AR may be affecting learning outcomes.

Moreover, we analyzed students' learning outcomes in the pre-test and the post-test of the experimental group and we identified that there was a significant difference between the pre-test and the post-test with better scores in the post-test. This is an evidence of the learning gains obtained by students in the learning experience supported by AR. However, since it was not possible to collect data for a pre-test in the control group it is not possible to identify if the learning gains in the experimental group are the result of the interaction of students with the AR application. In this sense further research is needed to explore the impact of AR on students' learning outcomes. We can, nevertheless confirm that at least the students' learning outcomes were not dramatically affected by the AR learning experience.

During the time that lasted the intervention (seven weeks), we were observing the interaction of students from the experimental group with the application by using the Monitoring Module and the Progress Monitor. We observed that some students were really engaged with the use of the application because they used the applications frequently (almost every day) for practing. In total the Monitoring Module registered 10,737 interactions in the Chemistry Videos and Assessment application. Moreover, 5,139 questions were answered by the students in a total of 1,508 tests generated by the application. The student who approved more tests in the first attempt reached 94 tests, followed by another student with 81 and the third one with 72.

We also observed that some of the students were engaged in a competition to see who approved more tests in the application. So we had to limit the number of test approved to 20 for each one of the topics in the application to avoid that students reach an unliminted number of tests approved because this may cause disengagement in other students. However, this type of competition engaged some of the students to keep working in the application and this was a positive behavior observed.

As for the notifications sent to each student, we concluded that this strategy helped to encourage students to use the application and it was a strategy for recommending the topics in which students should practice more. Although this strategy seems to be a pervasive approach, we found it to be very effective for helping students to keep engaged in the use of the applications. It is important to note that each student received personalized notifications that were sent by the teacher or by us. The content of the notification was a message of positive and rewarding feedback or recommendations on which topics they would need to practice more. During the intervention 970 notifications were sent to students.

However, we also identified that some other students did not used the application frequently. These students pointed out that they did not have time at home or they did not have internet connection. We observed that in class these students preferred to use the book instead of the AR applications for learning. We also observed that some students were more engaged by one of the applications rather than the other two applications. By talking with the teacher we concluded that not all students are motivated by the same things and that they are not motivated at the same level. In this sense we confirmed the need of an inclusive design approach such as the UDL to address the needs and preferences of all students.

Finally, we also observed the Hawthorne effect (Looi et al., 2009) or novelty effect in this validation because at the beginning of the intervention all of the students did the first learning activity at home with the AR application. But as the time passed, fewer students completed the second and third learning activities at home and the level of motivation and engagement with the applications seemed to decrease. However, we cannot conclude what was the real impact of the novelty effect because we did not take different observations during the intervention. Nothwithstanding the novelty effect, we identified that the levels of motivation were high at the end of the intervention. Thus, we confirmed that an AR learning experience created according to the framework can be used for a longer period of time and the levels of motivation will remain positive.

7.5 CONCLUSIONS

Overall, we found that the framework allowed to create an AR learning experiences for the VET level of motivation that positively impacted the four dimensions of the ARCS model of motivation with an outstanding result in the *attention* and confidence *dimensions*.

The validation allowed to demonstrate the advantages of a decoupling framework. This means that the modules of the framework can be found independently in existing third-party applications or the modules can also be developed together in one application from scratch. In that regard, existing third-party application that implement modules of the framework can be used to create AR learning experiences for the VET level of education without the need of tailor-made software. This advantage opens up possibilities for teachers so that they can create motivational AR learning experiences with a combination of existing applications that implement components of the ARMotiD framework. However, we found that a latent disadvantage of this approach might be that some existing AR applications do not implement the modules as defined in the framework and this may reduce the impact that the use of the application may have on student motivation.

In the context of this validation we developed the "Chemistry Videos and Assessment" mobile application that implemented some modules of the framework. This application was developed by following the co-creation methodology that we defined in this thesis and we showed that teachers can also participate in the development of applications that implement modules of the framework and these co-created applications can be used together with other existing third-party applications to create motivational AR learning experiences in the VET level of education. This approach may help to increase the impact of motivational AR learning experiences created with existing third-party applications that may not implement some of the modules defined in the framework.

In general we found that an AR learning experience defined according to the framework can positively impact the four dimensions of the ARCS model of motivation. In particular with the validation that we conducted we identified that the AR learning experience defined for this validation supported the *attention* and *confidence* dimensions in a better way than a learning experience with traditional materials like textbooks, written exercises or paper copies.

In terms of students' learning outcomes we concluded that there was not a statistical significant difference between the students that followed the motivational AR learning experience and the students that followed the learning experience witht the traditional learning materials. One interpretation of these results is that it seems that the motivational AR learning experience is also effective in terms of supporting learning outcomes but further research is needed to determine if the motivational AR learning experience may provide a better support for learning outcomes.

One of the most relevant aspects that we identified in this validation was that not all students are motivated by the same things and not all students are motivated at the same level. Every student has different motivations and every student is motivated at different levels. In this regard, personalization and adaptive processes may be useful for providing a personalized learning experience that takes into account individual needs and preferences of each student to adapt the AR learning experience.

We concluded that the use of personalized notifications with rewarding feedback and recommendations on the topics that each student need to practice even more was effective for keeping students engaged in the use of the AR applications for learning.

The results of this validation allowed us to answer the second research question of this thesis: "**RQ2:** Can the design and development of motivational AR learning experiences based on the framework positively impact student motivation?". Moreover, by conducting this validation we addressed the fifth specific objective of this thesis: "**SO5:** To validate the framework for the design and development of motivational AR learning experiences".

7.6 RECOMMENDATIONS FOR STAKEHOLDERS

The results and contributions of this thesis may be of special interest for different actors in the educational system. In this section we present some recommendations on how the different actors in the educational field can benefit from the contributions and results of this thesis:

7.6.1 Recommendations for teachers

- The most important recommendation is that the framework defined in the context of this thesis (presented in CHAPTER 6) is not only addressed to software developers but it can be used by teachers to create motivational AR learning experiences. Teachers of the VET level of education as well as teachers from other educational levels may use the framework for the design of motivational AR learning experiences (presented in CHAPTER 6) to create AR learning experiences that really support student motivation. The description of the framework can be used as a guide for identifiying which are the main characteristics that an AR learning experience should have to increase motivation and considering at the same time the needs and preferences of students by following the UDL as an inclusive learning approach. Teachers can focus on the recommendations provided in the framework on how each component addresses the UDL guidelines and how each component in the framework supports the motivational design.
- Teachers do not need to develop any software component because they can use existing AR applications that incorporate the components defined in the framework to create a motivational AR learning experience. An example on how a teacher can do this can be found in CHAPTER 7 in which existing applications are used to create an AR learning experience.
- Teachers may use the methodology that we defined for the co-creation of AR learning experiences to work together with other actors for the collaborative creation of AR learning experiences. Examples on how to apply the method corresponds to CHAPTER 3 and CHAPTER 4.
- Teachers may use the descriptions of the experiences in the development of the Paint-cAR application and the development of the Chemistry Videos and Assessment application as a source of ideas on how to propose AR applications for learning at different levels of education and in different learning domains.

7.6.2 Recommendations for software developers

- Software developers may use the framework defined in this thesis (see CHAPTER 6) for designing and developing motivational AR learning experiences. The framework defines the modules that an AR application should have to successfully support the dimensions of the ARCS model of motivation. Software developers may focus on the recommendations for the development of each module provided in the framework to get ideas on how each module can be designed and developed.
- Software developers may be able to develop new modules or forms of interaction in AR that can be tested in real environments and that can be integrated in the framework to improve it.
- Software developers can follow the co-creation methodology that we proposed to work together with other actors in the design and development of AR applications. Some examples on how the method can be applied can be found in CHAPTER 3, CHAPTER 4 and CHAPTER 7.
- From the AR applications developed in the context of this thesis (named Paint-cAR application and the Chemistry Videos and Assessment), software developers may get some ideas on how to design and develop AR applications for other educational levels and for other learning domains.

7.6.3 Recommendations for researchers

- Researchers may focus on the open issues identified as part of the literature review presented in CHAPTER 2 to conduct further research on AR in education. In particular researchers may focus on the possibilities that AR may offer for addressing special educational needs and conduct studies in different learning domains and educational levels to be able to have a better landscape of this research field.
- Researchers may conduct further research on the predictors of student motivation by taking the predictors that we identified in this thesis and test them in other educational levels or learning domains and contrast the results obtained to adjust the predictors that we identified. Moreover researchers may use the variables that we identified as common variables associated to an AR learning experiences (see CHAPTER 5) to identify predictors of students' learning outcomes.
- From the exhaustive analysis of how AR can support the guidelines of the UDL (presented in APPENDIX B), researches may explore and empirically confirm these claims by building AR prototypes and test them in real environments to uncover the benefits of AR in this sense. This analysis is an important source of ideas for further research in terms of the support that AR may provide for implementing the UDL guidelines.
- Researchers may conduct longitudinal studies with multiple observations to identify the impact of the novelty effect on student motivation. In CHAPTER 4 we identified some insights of the novelty effect on student motivation but further research is needed.
- Researchers may use the framework that we defined in this thesis to test it by creating motivational AR learning experiences in other learning domains or for other levels to validate its applicability to other fields and to improve the framework.

7.6.4 Recommendations for educational technology experts

- Educational technology experts may use the framework defined in this thesis (see CHAPTER 6) for designing educational interventions to support student motivation and to evaluate its effectiveness.
- Educational technology experts may also use the co-creation methodology that we defined to guide co-creation projects of AR applications.
- Educational technology experts may use the results of the analysis of how AR supports the UDL guidelines to define future educational interventions with AR.
- Educational technology experts may use the information provided in CHAPTER 3 and CHAPTER 4 as a source of ideas for designing interventions with AR applications in different educational levels and learning domains.
- The identification of the predictors of student motivation in AR learning experiences can be used by educational technology experts as a source of information for future interventions with AR applications applications.

7.6.5 Recommendations for students

- Students from different educational levels and learning domains may use the AR applications Paint-cAR and Chemistry Videos and Assessment for learning these specific topics and they can use these applications as an example or source of inspiration for thinking of new applications for other specific learning domains. Then, by following a co-creation process together with teachers, software developers and educational technology experts, these ideas might be converted into real prototypes.

7.6.6 Recommendations for educational institutions

- Educational institutions may use the results of this thesis when they make a decision with respect to the integration of AR technology as a support for the learning process. In this thesis we present two AR applications that were designed in a co-creation process for the learning domain of repairining paint on a car and the learning domain of inorganic nomenclature. These examples can be used to propose the development of AR applications in other educational levels and learning domains. Moreover, educational institutions may take into account the predictors of student motivation and the results presented in this thesis when they plan the inclusion of AR technologies as a support for the learning process.

PART 4
CONCLUDING

CHAPTER 8
CONCLUSIONS, CONTRIBUTIONS AND FUTURE WORK

This CHAPTER firstly presents a general overview of this thesis in section 8.1 in which a summary of the main milestones of the research in this thesis are presented together with the limitations of this research. Section 8.2 presents the main conclusions of this thesis followed by section 8.3 that summarizes the main contributions. Finally section 8.4 presents some future research directions of this thesis.

8.1 GENERAL OVERVIEW OF THIS THESIS

The two research questions and the main objective in this thesis were:

RQ1: Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?

RQ2: Can the design and development of motivational AR learning experiences based on the framework positively impact student motivation?

MO: To define a framework for the design and development of motivational AR learning experiences.

These research questions were answered and the main objective was reached with the process that is summarized as follows for each milestone of the research process:

8.1.1 Literature Review

Firstly we conducted a systematic literature review in which we identified some open issues that required further analysis to have a more concrete landscape of the state of research on AR in education. This literature review was presented in CHAPTER 2 and it addressed the first specific objective defined in this thesis: "**SO1:** To conduct a systematic literature review to identify the current state of AR in education". Moreover, the literature review corresponds to the first and second activities in the Exploratory Phase (**AEP1** and **AEP2**) of the research methodology followed in this thesis. The main open issues identified were:

- **OI1:** Research studies on AR in education do not clearly define how and why AR increases student motivation.
- **OI2:** There is a lack of research on how to address special educational needs of students in AR learning experiences.
- **OI3:** Very little has been done in terms of the definition of AR frameworks in education.
- **OI4:** There is a lack of research on the possibilities that AR can offer for supporting learning processes in the VET level of education.

These open issues were further analyzed with more specific reviews of literature (that were not systematic) but that provided a better comprehension of the current state of research on these topics. As a result of the extended reviews in these open issues, we concluded that:

1. As for **OI1**, Current research on AR in education does not clearly report which are the aspects or features (that we call predictors) that increase student motivation in AR learning experiences.
2. As for **OI2**, there are some AR applications developed for addressing some particular students' educational needs but none of them have adopted a more generic inclusive perspective such as the UDL or other approaches of the Universal Design to create inclusive AR learning experiences.
3. As for **OI3**, there are very few frameworks that define guidelines to inform the design and development of motivational AR learning experiences.
4. As for **OI4**, although AR has been extensively used in contexts of maintenance, there is a lack of research on the possibilities for using AR as a support for the learning process at the VET level of education.

Since the literature review (presented in CHAPTER 2) was conducted only in five journals selected from the SSCI index and four journals selected from the SCI index, the literature review did not include studies published in other journals and this is one of its limitations. Although we chose the most important journals in the field by following our method, there are many other journals that publish research on AR in education. Consequently, some studies in the field of AR in education might not have been considered and therefore some information might be missing in this literature review.

Another limitation of this literature review is that the results of the systematic literature review come from the studies published in the timeframe from 2003 to 2013 (until February of 2014). Thus, the results summarize the research for that timeframe. The specific reviews (conducted until 2016) do not cover all the aspects that the systematic literature review originally covered but it focused on very specific topics. Thus, the aspects that covered the systematic literature review are not fully covered by the specific reviews.

8.1.2 First exploratory study

Based on the conclusions with respect to the open issues, we decided to focus on the topic of student motivation in AR learning experiences at the VET level of education. So we conducted a first exploratory study (described in CHAPTER 3) to identify if the mobile AR application Paint-cAR had a positive impact on student motivation. The Paint-cAR application was designed by following a methodology (that we defined) for the co-creation of AR applications. The application was designed together with expert teachers and taking into consideration the UDL guidelines with the aim of reducing barriers in the learning process and taking into account an analysis of the possibilities that AR may offer to support the UDL guidelines. The application was designed to support the learning process of repairing paint on a car which is in fact a very complex process in which teachers have identified that students often face many difficulties.

From the first exploratory study (see CHAPTER 3) in which 13 students participated, we concluded that the Paint-cAR application had a positive impact on student motivation. In particular the results in the four dimensions of the ARCS model of motivation were promising. With this result we confirmed the results of other researchers that have claimed that AR increases motivation. Nevertheless, in our case we confirmed a positive impact of student motivation in the VET programme of Car's Maintenance. Moreover, we identified some design issues that needed to be improved in the application and we identified the need of an intervention that lasted for a longer period of time with the application to evaluate the effect on student motivation when the novelty effect wears off. This first exploratory study provided insights for answering the first research question "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?"**.** This exploratory study also addressed part of the second specific objective in this thesis: "**SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education". This exploratory study corresponds to the first activity in the Exploratory Phase (**AEP3**) of the research methodology followed in this thesis.

Although the purpose of the first exploratory study (see CHAPTER 3) was to measure the impact of an AR application on student motivation from an exploratory perspective, the research sample of the first exploratory study is small (N=13). This is a limitation of this study and this might have impact on the generalization of the results. Moreover, this study did not follow a comparative approach so as to determine the difference between a traditional class and the use of the Paint-cAR application for learning.

Furthermore, the intervention in the first exploratory study was short and therefore as in other interventions with AR applications reported in the literature, the students levels of motivation might be affected by the novelty effect. For that reason, in the second exploratory study the intervention was longer.

8.1.3 Second Exploratory study

Then, the Paint-cAR application was improved as a result of a second iteration of the co-creation methodology (as described in CHAPTER 4) and the application was tested with 73 students from 4 different VET institutes in Spain. Student motivation and learning outcomes were evaluated and the testing lasted for around 20 days. From this exploratory study we concluded that the Paint-cAR application positively affect the four dimensions of the ARCS model even after the 20 days of intervention. Moreover, this study provided an overview of the complexity of the educational processes at the VET level of education. In terms of learning outcomes we identified that students that used the Paint-cAR application had a tendency to have better results compared to students who did not use the application. However due to the complexities in the learning process further research was needed in this topic. We also identified that, notwithstanding the fact that AR increase student motivation, we did not know how and why AR affect motivation.

The second exploratory study provided insights for answering the research question "**RQ1:** Which are the components that should be considered in a framework to inform the design and development of motivational AR learning experiences in the VET level of education?"**.** This exploratory study also addressed part of the second specific objective in this thesis: "**SO2:** To conduct two exploratory studies to identify the impact of an AR application on students' motivation in the VET level of education". This exploratory study corresponds to the first activity in the Exploratory Phase (**AEP3**) of the research methodology followed in this thesis.

One of the limitations of this study was that, due to logistic reasons, in the second exploratory study (see CHAPTER 4), motivation was not measured in the control group so as to compare with the results of the experimental group. Thus, it was not possible to compare the effect of the Paint-cAR application on student motivation in the experimental group compared to a traditional class. Altough this was not the main purpose of this study, further studies might be conducted with the same application and measuring student motivation in the control group in order to compare students' levels of motivation in both scenarios.

8.1.4 Predictors of student motivation

Based on the results of the first and second exploratory studies, we conducted a study to identify the predictors of student motivation (as described in CHAPTER 5). This study was the core study to answer the research question **RQ1** and it was a seminal study to answer the research question **RQ2.** In this study we defined a set of hypotheses from the literature to define a research model that was empirically validated with data gathered from the interaction of 35 students during the second exploratory study. In total we registered 32,641 interactions of students with the application. From this study, we identified that the predictors of student motivation are: *Use of scaffolding, Degree of success, Real-time feedback, Time on-task, Learning outcomes* and *Watching videos*. Moreover, we presented the implications of these predictors in the design and development of motivational AR learning experiences. The predictors of student motivation were one of the inputs for the definition of the framework for the design of motivational AR learning experiences. This study, addressed the third specific objective of this thesis: "**SO3**: To identify the predictors of student motivation in AR learning experiences" and this study corresponds to the first activity in the Hypothetico-deductive and Explanatory Phase (**AHEP1**) of the methodology followed in this thesis.

The main limitation associated to this study is the fact that the study was conducted in only one VET programme, in particular in the VET programme of Car's Maintenance. This might limit the scope of some of the findings to that VET programme. Moreover, the Paint-cAR application is a marker-based AR application and therefore the results obtained in this study might not apply to other types of AR reality such as marker-less or location-based AR. In addition, the research sample was small and this might limit the generalization of the results. Consequently, the results need to be interpreted with some caution.

Another limitation is that the IMMS instrument is a self-report measure and according to (Barker et al., 2002) one of the limitation of self-report measures is that sometimes there are certain experiences that are unconscius and therefore cannot be effectively measured with a questionnaire. Despite of the fact that the IMMS instrument is a validated instrument with high reliability, the students' levels of motivation might not be fully reflected in the results.

Moreover, the Time on-task variable is based on information gathered automatically from the Monitoring module of the Paint-cAR application and the module is able to detect when students send the application to background, when the application is brought to foreground and when students close the application. However, it was difficult to detect when students were engaged in off-task activities with the application in foreground.

Another potential limitation of our study is that we only considered a group of variables represented in the 6-VARLE. These variables emerged from the modules designed under the co-creation process of the Paint-cAR application. Other variables might be included in similar studies to uncover new relationships between these variables and to determine how these variables affect student motivation.

Finally, other statistical methods such as Structural Equation Modelling that consider mediating variables and other statistics might be applied to uncover new relationships between the variables.

8.1.5 Definition of the framework for the design and development of motivational AR learning experiences

With the validated research model of predictors of student motivation, we defined the framework for the design and development of motivational AR learning experiences for the VET level of education. The framework was completely described in CHAPTER 6 and the definition of the framework allowed us to answer **RQ1**. The framework was defined based on three main theoretical underpinnings: the motivational design, the UDL and Co-creation. Moreover, the framework was supported also by the literature on how each one of the modules of the framework has been considered in AR applications. Some of the modules of the framework came from the predictors of student motivation (from the study described in CHAPTER 5). This means that the predictors were materialized in modules within the framework. The framework is divided into sections, layers and modules. For each module a group of recommendations are provided on how the module addresses the motivational design, how the module addresses the UDL guidelines and how to develop each module. The definition of the framework contributed to reach the fourth specific objective of this thesis: "**SO4:** To define the framework for the design and development of motivational AR learning experiences". Moreover, the definition of the framework corresponds to the second activity in the Hypothetico-deductive and Explanatory Phase (**AHEP2**).

The main limitation of the definition of the framework is that some of the recommendations rely only on the literature and therefore these recommendations need to be tested in other VET programmes different from the ones in which the validation was conducted to make sure that the recommendations are effective for the development of motivational AR learning experiences for other VET programmes. Moreover, the recommendations that rely on our experience in the co-creation of the Paint-cAR application come from the experience in the development of only one AR application and may require further validation to make sure they are applicable to any other VET programme.

8.1.6 Validation of the framework

To validate the framework, we defined a methodology for a validation based on components and not based on a holistic approach. The purpose of this approach was to also demonstrate that it is not needed to create a tailor-made application that instantiate the framework but existing applications can be used to instantiate the framework and therefore create motivational AR learning experiences. Based on this methodology, we selected two applications that implemented most of the components of the framework. Besides that, we developed the "Chemistry Videos and Assessment" application by following the co-creation methodology. This application implemented the Module of videos and the Assessment module from the framework. With these applications, we validated 82% of the framework. These three applications were used in a learning scenario as a support of the learning process in the VET programme of Laboratory Operations. The results of the validation showed that an AR learning experience created with the framework can support student motivation. The validation of the framework was completely described in CHAPTER 7 and it allowed us to answer the research question **RQ2**. Moreover, this validation addressed the fifth specific objective of this thesis: "**SO5:** To validate the framework for the design and development of motivational AR learning experiences" and the validation corresponds to the first and second activities (**AVP1** and **AVP2**) of the Validation Phase of the research methodology followed in this thesis.

Through this process the two research questions **RQ1** and **RQ2** were answered and the specific objectives were reached which led to reach the main objective of this thesis.

The main limitation with the validation of the framework is that it was validated in only one VET programme (Laboratory Operations). Thus, the results of the validation might be affected by many aspects that are inherent to that programme such as the type of students that choose to study that programme, the topics and in general the students' background. Student motivation in that programme might be very different from the student motivation in other VET programmes.

Moreover, the research sample in the validation is medium-sized (N=58), so the validation with a bigger research sample and including other VET programes might be conducted to be able to generalize the results.

8.2 CONCLUSIONS

The research conducted in this thesis allowed us to reach to the following conclusions:

From the literature review (presented in CHAPTER 2) we concluded that AR has spread to almost every educational level from early childhood to higher education with few applications in the VET level of education. Nowadays, there are many AR applications for teaching in different learning domains in particular in the fields of Science and Humanities & Arts. Moreover, a growing body of literature has shown that two of the most important advantages of this technology in education are that it increases motivation and it increases learning outcomes. Notwithstanding these advantages, the main limitations of AR reported in the literature are: difficulties maintaining superimposed information, paying too much attention to virtual information (related to the novelty of the technology) and AR as an intrusive technology. We also concluded that the most common type of AR reported in research studies is marker-based

AR, followed by location-based AR and marker-less AR. In general AR seems to have a promising future in education and it will be gaining more and more attention as its limitations are tackled.

Also from the literature review, it is worth noticing that very few studies have addressed students' special educational needs in AR learning experiences. The AR applications that address special educational needs have been designed to address specific special educational needs and this is equivalent to the provision of curricular adaptations to address the needs of few students. In that regard, we concluded that the design of AR learning experiences requires the adoption of a more generic inclusive approach such as the Universal Design for Learning (UDL) or other approaches to Universal Design. These approaches may provide the flexibility needed to address students' educational needs and therefore create inclusive AR learning experiences.

In this thesis we designed and developed the Paint-cAR application (as described in CHAPTER 3 and CHAPTER 4) following a co-creation methodology that we also created and we adopted some recommendations from the Universal Design for Learning as a pedagogical inclusive learning approach with the aim of reducing as many barriers as possible in the learning process. From this co-creation process we concluded that the collaboration between expert teachers, software developers and educational technology experts in the design and development of AR applications is of crucial importance to effectively address the educational need and to address students' needs, preferences, motivations and interests. Moreover, we concluded that an iterative process based on prototypes is effective for improving the design and therefore the application so that it can be better adjusted to the educational needs.

In this thesis we also provided some insights on how AR can be used to support the three main guidelines of the UDL: a) provide multiple means of engagement b) provide multiple means of representation and c) provide multiple means of action and expression. Therefore, AR applications can be designed to address special educational needs of students in VET institutions by adopting an inclusive learning approach like the UDL. As a result, not only students with special educational needs will benefit from the inclusive learning design of the AR application, but all students can also take advantage of a good design. It means that AR could help to overcome some barriers of the one-size-fits-all curricula and support expert learning.

In terms of using the AR technology in the VET programme of Car's maintenance, it is worth noting that the AR-based applications are aimed to provide support for the learning process and may help students to practice certain processes at home, using virtual products cost-effectively and save resources especially in VET institutes where the resources are limited.

In this thesis, we conducted two exploratory studies with the Paint-cAR application. As a result of the two exploratory studies we concluded that the application positively affects student motivation in the four dimensions of the ARCS model of motivation. In particular after the second exploratory study we concluded that the levels of motivation are still high even after 20 days of using the Paint-cAR application for learning. This conclusion has an important implication in research because there are few studies conducted with AR for longer periods of time and therefore our study provides insights with respect to the implications that the Hawthorne effect or novelty effect may have on student motivation in the VET level of education.

Moreover, as a result of the two exploratory studies we recognized the complexity of the learning processes in the VET level of education. One of the aspects of this complexity is given in terms of the wide variety of students' needs, preferences, motivations and interests. We realized that there are many students that come from many different levels of education and therefore they have different needs, preferences, interests, motivations, etc. This situation creates a huge diversity of students in VET education and therefore a big challenge for teachers. We identified the challenges that teachers often face and we strived to understand this issues and together with teachers address them in the design and development of the Paint-cAR application and the "Chemistry videos and Assessment" application.

From the review of literature (described in CHAPTER 2), we identified that current research have not clearly identified the predictors of student motivation in AR learning experiences for the VET level of education. Therefore, in this thesis we identified (as described in CHAPTER 5) the predictors of student motivation. These predictors were identified when the Paint-cAR application was used by students in two different levels of challenge that we called the Guided Mode and the Evaluation Mode. The predictors that we identified are: *Use of scaffolding, Degree of success, Real-time feedback, Time on-task,* and *Watching videos*. We concluded that these predictors positively affect the four dimensions of the ARCS model of motivation and we identified how these predictors are related with the four dimensions of the ARCS model. These relationships are described as follows:

- The *Use of scaffolding* positively affects the *relevance* and *satisfaction* dimensions in the Evaluation Mode. There were no relationships identified for the Guided Mode.
- The *Real-time feedback* positively affects the *satisfaction* dimension in the Evaluation Mode and in the Guided Mode.
- The *Degree of success* positively affects the *satisfaction* dimension in the Evaluation Mode and the *relevance* dimension in the Guided Mode.
- *Learning outcomes* are positively affected by the *confidence* and *relevance* dimensions in the Evaluation Mode. Learning outcomes are positively affected by the *attention* dimension in the Guided Mode.
- The *Time on-task* positively affects the *attention*, *relevance* and *satisfaction* dimensions in the Evaluation Mode. *Time on-task* positively affects the *confidence* dimension in the Guided Mode.
- *Watching videos* positively affects the *confidence* dimension in the Guided Mode.

We also concluded that there is a wide variety of AR frameworks in education but very few of them have considered motivational factors and therefore very few of them provide recommendations on how to design and develop motivational AR learning experiences. Moreover, very few of them have adopted a pedagogical inclusive learning approach to address students' needs in the learning process. To overcome this issue, we defined the framework for the design and development of motivational AR learning experiences for the VET level of education. This framework aims to inform the design and development of motivational AR learning experiences by providing a set of recommendations on which modules should be integrated to AR applications an how these modules should be designed to sustain student motivation. The validation process of this framework allowed us to confirm that the framework was useful to define a motivational AR learning experience for the VET level of education. In particular, we found that the motivational AR learning experience that we created based on the framework was useful for supporting the four dimensions of motivation. This motivational AR learning experience was found to be specially useful for increasing the levels of motivation in the *attention* and *confidence* dimensions at higher levels than a traditional learning experience.

We also confirmed that the framework is decoupled so there is no need to instantiate the framework in a tailor-made application but existing applications can be used to create motivational AR learning experiences if each application is aligned with the recommendations provided in the framework.

In this context, we also conclude that motivation and learning outcomes are complex issues in the context of the VET level of education. Regarding motivation, one of the most relevant conclusions of this thesis is that we recognized that not all students are motivated by the same things and not all students are motivated at the same level. This is something inherent to the educational system because not all students are equal. This means that, as recognized by the UDL, each student is different from the others and students' diversity is the norm not the exception and therefore students' motivations are different. However, in this thesis we defined a framework that provides insights and recommendations on how to create motivational AR learning experiences.

As for the learning outcomes, we concluded from the second exploratory study (described in CHAPTER 4) that statistically there were no significant differences between the students who used the Paint-cAR application and those who did not use it. However, there was a tendency of the students that used the Paint-cAR application to have better learning outcomes. In this sense further research is needed to identify the impact of an AR application on students learning outcomes in the VET level of education.

8.3 CONTRIBUTIONS

The contributions of this thesis are described as follows:

- The most important contribution of this thesis is that we defined the framework for the design and development of motivational AR learning experiences for the VET level of education. The framework is completely defined in CHAPTER 6. The framework aims to inform the design and development of AR learning experiences that increase motivation. The framework defines the modules that an AR should have to support the dimensions of the ARCS model of motivation. In particular, the framework provides a description of each module together with a review of literature on how the module often appears in AR applications and why it is important. Besides, the framework defines how the module addresses the motivational design, how the module addresses the UDL guidelines and recommendations on how to develop the module are also provided.
- The framework is a decoupled framework which means that can be instantiated by any teacher or anyone who want to create an AR learning experience because the modules of the framework can be instantiated by independent and existing applications and together the applications may be used to create a motivational AR learning experience. This means that the framework does not need to be completely instantiated in a tailor-made application. Instead, the modules of the framework can be instantiated by different applications to take advantage of existing applications and develop only certain components that are needed to complete the motivational AR learning experience.
- We identified the variables that are commonly associated to AR learning experiences in the literature and that are related to student motivation from the perspective of the ARCS model of motivation. These variables are: Use of scaffolding, Real-time feedback, Degree of success, and Time on-task.
- We have identified the predictors of student motivation in AR learning experiences in the VET level of education. The predictors identified were: *Use of a scaffolding*, *Degree of success*, *Real-time feedback*, *Time on-task* and *Watching videos*. We have empirically validated the relationships that exist between these variables and the relationships that exist between these variables and the four dimensions of the ARCS model of motivation. Moreover, we have described the implications of these predictors and its relationships with respect to the design and development of motivational AR learning experiences. The identification of these predictors was carried out empirically with data from two sources: The interaction of 35 VET students (32,641 interactions) for the 20 days of the intervention and the IMMS instrument as a self-report measure. The identification of the predictors of student motivation is described in CHAPTER 5. This is a contribution to the knowledge on the impact of AR in student motivation. This is in line with the need expressed by S. Li et al. (2014) with respect to the need of more studies that explore the impact of AR on student motivation.
- We conducted a systematic literature review of 32 journal papers and 18 conference papers that provided an overview of the research on AR in education for the time frame from 2003 to February 2014. Moreover, more specific reviews provided an overview of the research on AR in education until 2016 in the following topics: predictors and acceptance of AR, AR and students' special educational needs, AR frameworks in education, AR in the VET level of education. These reviews contributed to the analysis of

current research on AR in education and allowed us to identify current issues in this field (see CHAPTER 2).

- Since there is a lack of studies that explore the benefits of AR in the VET level of education, we focused on this level of education and we provided insights into the effect that AR has in motivation and learning outcomes in the VET level of education. In short, we confirmed that AR has a positive effect on students' motivation in the VET level of education and we described the complexity of this level of education with respect to motivation and the learning outcomes (see CHAPTER 3 and CHAPTER 4).
- We defined a methodology for the co-creation of AR applications in education. The methodology brings together expert teachers, software developers and educational technology experts to work collaboratively in the design and development of AR applications. The methodology is based on an iterative process and adopted the UDL as a pedagogical inclusive learning framework. In this thesis we showed how to apply the methodology for designing and developing the Paint-cAR application as described in CHAPTER 3 and CHAPTER 4. This methodology can be used and adapted for developing other AR applications.
- We carried out an exhaustive analysis on how the guidelines and recommendations of the UDL framework can be supported by AR. This analysis is reported in APPENDIX B. This analysis might be used for exploring other benefits of AR for addressing special educational needs of students and therefore create inclusive AR learning experiences.
- We designed and developed the Paint-cAR application. The Paint-cAR application is a mobile AR application for supporting the learning process of repairing paint on a car and is addressed to the VET programme of Car's Maintenance. The application was designed and developed in two iterations by following the methodology that we defined and taking into account some recommendations of the UDL framework. The Paint-cAR application was used in the first and second exploratory studies and its design and development is reported in CHAPTER 3 and CHAPTER 4.
- We designed and developed the "Chemistry videos and Assessment" application. "Chemistry videos and Assessment" is a mobile application that instantiates three modules of the framework that we defined in this thesis: Module of videos, Assessment Module and Progress Monitor. The application was used during the validation of the framework. With the development of this application we demonstrated how to instantiate three modules of the framework for using them with other applications to create a motivational AR learning experience for the VET level of education.
- With the Paint-cAR application, in the second exploratory study, we identified that the levels of motivation are still high even after 20 days of using the Paint-cAR application when the novelty effect has disappeared. This is a relevant contribution because there are very few studies that have been conducted in longer periods of time and therefore many researchers have claimed that there is a need of conducting studies for a longer period of time to identify the real effect of AR after the novelty effect disappears (Di Serio, Ibáñez and Kloos, 2013; Chin, Lee and Chen, 2015; Akçayır & Akçayır, 2017). To the best of our knowledge, the second exploratory study is one of the few studies that explore the effect of AR on student motivation for a longer period of time to discard the impact of the novelty effect.
- We defined a methodology for validating the framework. The methodology was designed to validate the framework based on its components (taking into account the decoupling nature of the framework) and not based on a holistic approach. In this validation we selected some existing applications that integrated some components of the framework and we developed the "Chemistry videos and Assessment" application. Together the

applications were used to create a motivational AR learning experience in the VET programme of Laboratory Operations. The methodology allowed us to successfully validate the framework.

8.4 FUTURE WORK

This section describes some future research directions that can be followed to extend the research conducted in this thesis:

8.4.1 Regarding the Paint-cAR and the "Chemistry Videos and Assessment" applications

- With the results of the second exploratory study (described in CHAPTER 4) it would be possible to carry out another iteration of the co-creation process to improve even more the Paint-cAR application. Teachers suggested that students also need to learn how to perform certain movements with some tools like the sand paper or the painting gun. These movements are important to obtain high quality results during the process of repairing. In this regard, it would be possible to use the sensors of the mobile device to detect the movement and correct it so that can practice this until they reach certain basic knowledge and then they can use the real tool to practice even more. Moreover, the application can be improved in the AR experience to allow students to interact with a 3D model of the car's part they are repairing so that they can see the result of using certain products or tools during the process of repairing. For instance, it would be possible to see the result of using certain type of sand paper on the car's part. Besides that, other modules defined in the framework may be included in the Paint-cAR application such as the Progress Monitor, the FAQ module and the Module "Ask Your Teacher".
- It might be possible to explore the use of the emerging data interchange format standard for AR (P1589 - Standard for an Augmented Reality Learning Experience Model) (IEEE, 2016) also known as AR-LEM (Augmented Reality Learning Experience Model) to improve the specification of the learning process of repairing paint on a car by using the XML language. So far, the standard seems to be useful for definining workflows and step-by-step guidance in learning processes at the workplace.
- Connected with the previous point, the teachers' web application can be improved to provide more reports with the information captured by the Progress Monitor module in the Paint-cAR application. For instance it might be possible to provide information about the questions in which students found major difficulties in the Assessment Module, or a more detailed report with respect to the use of the application for each student. The reports and the information needs to be defined together with the teachers as part of the co-creation process so that teachers can have the information that they need and the information that will be useful for making informed decisions for their classes.
- As for the "Chemistry Videos and Assessment" application, it would be possible to include some other modules defined in the framework to improve its effectiveness for increasing student motivation. For instance, we could include the modules "As Your Teacher" and the FAQ Module. Moreover, an AR learning experience can be included in this application for the topic of inorganic nomenclature by including some of the activities that the teacher uses for explaining this topic in class. Students may therefore have an additional support for the learning process of this topic. Including the AR learning experience in the application will imply to include the following modules from

the framework: Scaffolding module, Augmented information module and real-time feedback module.

8.4.2 Regarding the predictors of student motivation and learning outcomes

- In this thesis we focused on the VET programmes of Car's Maintenance (in the topic of repairing paint on a car) and Laboratory Operations (in the learning domain of Chemistry). By incrementing the sample size and instantiating the framework in other VET programmes it would be possible to gain more insights into the effect of AR applications on student motivation in the VET level of education in order to generalize the results to the whole VET level of education. Moreover, this may help to confirm the results with respect to the predictors identified or it may allow identifying new predictors or uncovering other relationships between the variables that were identified. In addition, more studies can be conducted in other levels of education to confirm if the predictors identified are still valid for other levels of education.
- In the analysis of predictors of student motivation, we used Multiple Linear Regression to identify relationships of causality between the variables. However, as a future work we could use a more robust method such as the Structural Equation Modelling (SEM) to identify mediating variables or obtain a better explanation of the relationships between the variables that we identified in CHAPTER 5.
- Although we focused on student motivation and the framework defined aimed to inform the design and development of motivational AR learning experiences for the VET level of education, further research need to be conducted on student learning outcomes in the VET level of education to gain insights into the possibilities that AR may offer in terms of increasing learning outcomes.
- From the literature review on predictors of student motivation, we found that most of the studies have identified predictors of the acceptance of AR in different learning domains using the TAM and extended TAM models. However, none of the studies have focused on the use of the TAM3 which adds new variables and relationships that may provide new insights into the acceptance of AR in education. Therefore, further research may be conducted using the TAM3 model to identify the predictors of the acceptance of AR technology.
- From the literature review we identified that AR increases motivation and increases learning outcomes. We focused on student motivation in this thesis but further research need to be conducted to identify the predictors of student learning outcomes. These predictors will provide insights to inform the design of AR learning experiences that effectively increase student learning outcomes. The framework could be extended to add new layers, sections or modules to support student learning outcomes.

8.4.3 Regarding the framework for the design and development of motivational AR learning experiences

- The framework can be instantiated for creating motivational AR learning experiences in other levels of education apart from the VET level of education to determine the effectiveness of the framework for the creation of motivational AR learning experiences in other educational levels.
- As more research is conducted on AR in education, new variables that affect or impact the AR learning experiences are discovered. Thus, these variables need to be taken into account as possible modules, layers or sections in the framework.

- The framework provides recommendations on how to design a motivational AR applications for the VET level of education. However, the framework does not provide recommendations on how to evaluate a situation in which a teacher might require or not to design an intervention with a motivational AR application. This was not included in the framework because it was not part of the scope of the framework. The inclusion of these recommendations might extend the framework.

8.4.4 Regarding the attention to diversity in the VET level of education and other levels

- Further research need to be conducted on how to effectively address students' diversity in the VET level of education and in other levels of education. In particular, it would be important to identify the benefits that AR may offer to create learning experiences that address students' variability and foster expert learning. The use of an inclusive learning approach such as the UDL in the creation of AR learning experiences may help to overcome some barriers in the learning process and may help to create inclusive AR learning experiences. The analysis reported in the APPENDIX B of this thesis is a seminal work to extend the research in this field.
- In this thesis we concluded that not all students are motivated by the same things and that they are not motivated at the same level. Thus, motivational AR applications would need to identify the aspects that better motivate students and the specific moments in which students should be motivated. In that regard, the use of personalization and adaptive processes may help in this issue so that the application can be adapted to students' needs and can provide a unique experience to each student according to the levels of motivation.
- Connected with the previous aspect, personalization and adaptive processes can also be used to provide a more personalized AR learning experience. For instance, the scaffolding, real-time feedback and assessment can be adapted according to the student's needs. For instance, for students who do not have the required background knowledge, the adaptive mechanism may reduce the challenge and offer more hints and help. The hints and help will be gradually removed until students become expert learners. It is important to note that the adaptive processes may be used to manage the amount of augmented information provided to students according to their cognitive load. All of these possibilities might be useful for addressing students' variability.

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APPENDIX A
LIST OF FRAMEWORKS ANALYZED

The table presented in this appendix is the result of the specific review of literature on AR frameworks in education as detailed in section 2.5 in CHAPTER 2. The table presents 35 frameworks identified in the literature review. Since the frameworks are different one from each other and they do not share many features in common, the aspects that were used to compare the frameworks (columns in this table) came up from the analysis of all the frameworks.

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
(Kavakli, 2015)	Pedagogical Technological	Actors Profiles Metadata Scenario	Location-based AR	History	Student-centred learning	Not reported	No	No	Framework 4Any (Anybody, Anywhere, Anytime, Anyway) is a generic framework for rapid development of Mobile AR systems.
(Jamali et al., 2014)	Motivation	Learning Group Context Internal representation Process of Learning	Not reported	Science	Student-centred learning	Higher education	No	Yes	Theoretical framework for using AR and MAR in higher education. It extends the framework of Piccoli, Ahmad, & Ives, (2001) in the dimension of motivation. Dependent variables are: Perceived Learning Effectiveness, Satisfaction and Self-efficacy.
(Wang et al., 2013)	Augmented Reality Based learning system		Marker-based AR	Computer Science	Learn by doing	Higher education	Yes	No	ARICE Framework: Augmented Reality in Computing Education. It aims to use AR in undergraduate computing education to improve the performance, student retention and learning outcomes.
	Design for learning materials	Texts Videos 2D interactive demo Interactive AR demo Assessment							
	Learning game								
(Behzadan & Kamat, 2013)	AR magic book Real-time video stream from an IP camera in the construction jobsite. HMD and Ultra Wideband Sensors		Marker-less AR and Marker-based AR	Education in construction and civil engineering	Collaborative Learning and discovery based learning.	Higher education	NO	NO	Conceptual framework for delivering visual information from a remote jobsite in the context of education in construction. The system uses UWB (ultra wide band) sensors,

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
	(UWB).								HMD and an AR book.
(W. Chen, 2014)	AR View and Map View SQLite database		Location-based AR	History	Not reported	Informal Learning	NO	NO	The authors introduce a generic framework for location-based AR applications. It shows images and information about points of interest depending on the users' location and orientation. An application was developed for showing information about Oslo.
(Margetis et al., 2015)	Physical (Computer vision techniques for tracking). Communication (interoperability between the components). Decision (Book modeling and context sensitive assistance). Information (Educational Applications).		Marker-less AR	Multiple domains	Smart environments (Ambient intelligence system)	Multiple levels	NO	NO	Framework to enhance educational process by augmenting physical assets like a book, pencil, etc, in an unobtrusive manner. It was designed as an ambient intelligence system. The system recognizes the users' book, the page and the pencil as well as the pointing action with a finger.
(Chao et al., 2014)	Authentication module	Student profiles database in the cloud Login/register Work Authentication Local Data Collection	Location-based AR and marker-based	Visual communication design	Collaborative learning (Peer assessment)	College and higher education	NO	NO	Mobile Augmented Reality Peer Assessment System (MARPAS) aims to enhance peer assessment in which AR is used to enhance the work presentation and the assessment of student's work in a peer
	Context Aware Module	Position Model Device Model Content Model User Model							

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
	AR interaction module	Work Demonstration Assessment Activity Assessment feedback							assessment activity. It consists of 3 main modules: authentication module, context-aware module and AR interactive module.
(Barbadillo, Barrena, Goñi, & Sánchez, 2014)	Creation Module (authoring tool for creating AR activities) Distribution Module (AR processing, manage interaction and store multimedia content) Execution module: Client application		Marker-based AR	Multiple domains	Collaborative learning	Multiple	NO	NO	Framework for creating, distributing and executing sequential AR activities for mobile devices. It defines an authoring tool to create AR activities by defining states. A distribution module is used for synchronizing users in collaborative activities. A plugin for integrating the activities in Moodle was developed.
(Bujak et al., 2013)	Physical Dimension	Intuitive Interactions Physical Action Encoding	Not reported	Mathematics	Learning with manipulatives	Multiple	NO	Yes	A framework for understanding AR learning from 3 dimensions physical, cognitive and contextual taking into account the use of virtual and physical manipulatives in the classroom.
	Cognitive dimension	Spatial and Temporal Contiguity Abstract physical encoding							
	Contextual dimension	Micro-scale interactions Macro-scale interactions Personal relevance							
(Zimmerman & Land, 2014)	Guideline 1: Facilitate participation in disciplinary conversations and practices within personally	- Present a classificatory or organizational scheme for understanding the place - Include references to common sources of prior knowledge	Marker-based AR	Science	Place-based education and informal science learning	Primary education	Partially	No	A design framework that relies on the research on place-based education and location awareness to develop understanding about science concepts in local

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
	relevant places								communities. The framework consists of 3 design principles to bring place-based education to informal science learning
	Guideline 2: Amplify Observations to See the Disciplinary-Relevant Aspects of a Place	- Focus on core elements of a place - Provide contextualized expert guidance to encourage deliberate comparison and explanation							
	Guideline 3: Extend Experiences through Exploring New Perspectives, Representations, and Data	- Capture and annotate artifacts of a place for making thinking visible - Provide visualization of non-visible aspects of a place through technological augmentation - Collect and share data to support the development of an artifact							
(C. C. Yang et al., 2013)	Printed science books		Marker based AR	Science	Meaningful learning	Secondary education	NO	NO	A u-learning system for supporting printed book reading. The system includes a concept map tool to help students to organize their ideas. QR codes are used to augment learning resources. The system was found to be useful for learning achievement and acceptance.
	Mobile devices								
	Learning resources								
(Gupta & Shah Bharadwaj, 2013)	Richness		Not reported	Business education	Experiential Learning	Higher education	No	No	A conceptual model for agile business education and based on three paradigms: Theory of
	Reach								
	Business school education agility								

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
									experiential learning, theory of social networks and the contingency theory.
(Park, Lee, Kwon, & Wang, 2013)	Planning module Education Module Inspection Module		Location-based AR and marker-less AR	Safety management in construction	Not reported	Higher education	No	No	A framework in the context of construction environments for safety management and visualization. The framework combines location-based augmented reality with games and the Building Information Modelling reflects the typical safety management process that consists of three phases: planning, education and inspection.
(Ternier et al., 2012)	APP Engine Core functionality Feature Clusters Transport protocols and data encoding Client side		Location-based AR	Visual arts, History, Hostage taking simulation	Situated learning, Expository learning and Learning through decision taking	Multiple	No	NO	ARLearn Framework aims to define common architecture for developing "location-based and context-aware learning games". The purpose of the authors was to link AR and AV. The framework defines 2 client applications: an android application and a StreetView client.
(Dankov et al., 2011)	Software components		Marker-based AR	Multiple	Not reported	Multiple	No	No	The UIAR (User Interface through AR) software framework for
	System model	AR Markers							

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
		Database							ubiquitous AR and human-computer interaction. Two types of interaction were defined: User-Object interaction and Object-Object Interaction.
	System interaction	User-Object interaction Object-Object Interaction							
(Quint et al., 2015)	The Code BD The CPS (cyber-physical system) Framework The AR engine The CPS system		Marker-less AR	Cyber physical systems	Not reported	College and higher education	No	No	Framework architecture of a mixed reality learning environment in the context of cyber physical systems (CPS). The components are: Code DB, cyber-physical system and AR engine.
(Yin et al., 2013)	Step 1: Initial process Step 2: The concrete experience Step 3: Observation and reflection Step 4: Abstract conceptualization Step 5: Testing in new situations		Not reported	Computer Science	Experiential learning with scaffolding	Higher education	No	No	Scaffolding participatory simulation for mobile learning (SPSML) framework. It draws on the experiential learning model. The steps considered in the framework are: Initial, concrete experience, Observation and reflection, Abstract conceptualization, Testing in new situations.
(Ledermann & Schmalstieg, 2005)	Setup Cast Story Interactions Behaviours		Marker-less and marker-based AR	Multiple	Not reported	Higher education	No	No	APRIL: A High-level Framework for Creating Augmented Reality Presentations. The authors introduce an AR authoring tool for

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
									creating AR-based presentations. An XML based language called APRIL was introduced by the authors.
(Cochrane, Antonczak, Keegan, & Narayan, 2014)	Pedagogy Andragogy Heutagogy		Location-based AR	Multiple	Not reported	Multiple	No	No	The authors introduce a framework for creative pedagogies. the framework is "a continuum of pedagogical approaches that can be scaffolded across the length of a course"(Cochrane et al., 2014).
(Yusoff & Dahlan, 2013)	Mobile Learning	Internal level: Cognitive tool, Learner Inter-medium level: Content and context External level: Technological, social and cultural.	Not Reported	Multiple	Not reported	Multiple	No	No	A framework to successfully integrate mobile learning with an AR environment. It has the following levels: External level, inter-medium level and internal level. AR is considered to be the visualization aspect of the content.
	Mobile learning environment	Process in AR Learning content							
	Knowledge visualization framework								
	Learning engagement								
(Carlson &	Simulation	Low Fidelity – High	Marker-	Health-	Situated	Higher	NO	NO	Augmented Reality

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
Gagnon, 2016)		Fidelity	based	care	learning	education			Integrated Simulation Education (ARISE) is a conceptual model that integrates the concepts of simulation, augmented reality, game-based learning and situated learning theory.
	Game Theory	Critical Thinking application Understanding concepts							
	Augmented Reality	Realistic Engaging							
	Facilitators	Feedback Debriefing							
(K.-H. Cheng & Tsai, 2016)	Dominance		Marker-based	Visual communication and visual arts	Not reported	Primary education	NO	NO	As part of a research on behavioral patterns on child-parent shared reading activities a framework for understanding the interaction between children and parents when reading AR books was proposed. The interaction between the children, parents and AR book defines the AR learning experience.
	Guidance								
	Communication								
(K.-C. Li et al., 2015)	Tutor		Marker-based	English teaching	Flow theory and Situated learning	Multiple domains	NO	NO	AR classroom is a framework for language learning that is based on the flow theory and situated learning. It consists of 5
	Theme								
	Media								
	Agent								
	Operational Area								

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
									components: Tutor, Theme, Media, Agent and operational area.
(Mendoza, Baldiris, & Fabregat, 2015)	Behaviour monitoring behavior database recommendation system delivery system Heritage Learning Resources Collaborative Content management Heritage Manager		Location-based	Heritage Education	Not reported	Informal learning	NO	NO	The framework to Heritage Education is an extension of the Learning Technology System Architecture (LTSA) for heritage education using AR. The framework's components are: Citizen/visitor, Behaviour monitoring, recommendation system, behavior database, delivery system, Heritage Learning resources and Collaborative Content management.
(Rodríguez-Vizzuett, Pérez-Medina, Muñoz-Arteaga, Guerrero-García, & Álvarez-Rodríguez, 2015)	Evaluation Technology Collaborative learning Learning content Context Interaction resources		Marker-based	Language learning	Collaborative learning	Preschool education	NO	NO	A meta-model for a framework that supports the development of interactive collaborative learning applications for preschoolers. It follows a user-centred approach. The application of AR aims to facilitate the interaction among preschoolers by using QR codes
(Syberfeldt	Expert System		Marker-	Multiple	Not reported	Vocational	NO	NO	The ARES (Augmented

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
et al., 2016)	AR System User Interface		based			Education and training			Reality Expert System) framework combines expert systems with augmented reality to provide content adjusted to the individual learning progress of the operator.
(Rogers et al., 2002)	Physical to Physical transform Physical to digital transform Digital to digital transform Digital to physical transform		Marker-less	Multiple	Not reported	Primary education	NO	NO	A conceptual framework to guide the design of mixed reality (MR) systems. MR spaces are conceptualized as “transforms”. Authors defined four types of transforms: Physical action to Physical effect (PPt), Physical action to Digital effect (PDt), Digital Action to Digital effect and Digital Action to Physical effect.
(R. Chen & Wang, 2008)	Tangible AR system Processing continuum Concrete experience Abstract Conceptualization Active Experimentation Response		Marker-based	Multiple	Experiential learning	Multiple	Partially	NO	A framework for conceptualizing, integrating and evaluating tangible AR in design learning. The framework considers learning styles, design development, physicality and embodied cognition.
(Colpani & Homem, 2015)	Marcadores Proyecto Unity Tracker		Marker-based AR	Multiple	Not reported	Primary education	Yes	Partially	An AR framework that integrates gramification to assist the learning

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
	QCAR Behaviour Vuforia Unity								process of children with intellectual disabilities. The purpose of the system is to help children to identify daily life objects and its features. The activities implemented in the framework are grouping fruits, animals, and associating words.
(Covaci et al., 2015)	The stationary system The Mobile System	User interface input Dialog controller Itinerary generator Training module User interface output Data Interpretation Image recognition Geolocalized position	Location-based and marker-less	Everyday tasks / daily routines	Not reported	Informal learning	Yes	No	The authors introduce a framework instantiated on a system based on AR and VR for education and training on everyday task for people with cognitive disabilities. The authors state that the system consist of two components: One for training daily activities and other for providing real-time guidance. The authors chose the skills for navigation in order to show how the system works in people with down syndrome.
(Ibanez, Villaran, et al., 2015)	The tests The tasks	Presentation Response Feedback	Marker-based AR	Science	Not reported	Secondary education	NO	NO	A framework for developing meaningful assessment tasks supported by AR. The authors characterize the elements that should be

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
									considered in assessment activities with AR: real elements, digital elements and events. They also characterize the types of interaction and the types of events of AR in assessment tasks.
(He et al., 2016)	Browser-side Server-side		Marker-based AR	Science	Not reported	Multiple	NO	NO	A framework for the design of a tool for learning about molecular docking. The authors created the ARDock game based on the framework. It uses marker-based AR and is a web-based application.
(Kuo-hung et al., 2016)	Authentication module	Login/register Learner Assesse or Assessor	Marker-based AR	Multiple	Collaborative learning (Peer assessment)	Multiple	NO	NO	A framework for combining AR with performance assessment. The framework provides functionalities to assist users in the process of showing their works for peer assessment and help them to do the assessment.
	AR Context Awareness Module	Recipe recognition tool Learning by doing Dish recognition tool Authoring tool							
	AR interaction module	Work Demonstration Assessment Activity Feedback & Discuss							
(Capece, Agatiello, & Erra, 2016)	Client-side Server-side	Metaio Android Platform Restlet client	Location-based AR	Multiple	Not reported	Multiple	NO	NO	A client-server framework for the design of location-based AR applications. The framework is based on the concept of Points of Interest (POI) and is

Framework	Dimensions/Modules	Layers/Components/variables(sub-components)	Type of AR	Topic/ domain	Pedagogical / didactical Approach	Educational Level	Addresses special educational needs	Motivational aspects	Description / Comments
									build with Metaio, REST web services and JSON format for data interchange. The framework was validated in two case studies: Management of failures in power lines and hydrogeological monitoring.
(Kurilovas, Dvareckienė, & Jevsikova, 2016)	Create a learning profile Create relations in an ontology Create a recommender system		Marker-based AR, Location-based AR and Markerless AR	Multiple	Not reported	Multiple	Partially	Partially	The authors introduce a set of stages for designing personalized learning systems with AR. The stages consist of the definition of a learner model based on standardized psychological and pedagogical taxonomies and the definition of an ontology to represent the equivalences of the learning units and learning styles and finally a recommender system.

APPENDIX B
UDL AND AR ANALYSIS

In this thesis we analyzed how AR can be used to support the UDL guidelines with the aim of identifying opportunities for creating inclusive AR learning experiences and therefore address students' variability in the learning process. We analyzed each specific consideration in the UDL with respect to the advantages and effectiveness of AR in education. The results of the analysis are presented in a Google Spreadsheet (Google Sheets) organized in the following columns:

- **Principles of the UDL:** In this column each one of the three principles of the UDL is presented.
- **Guidelines:** For each principle of the UDL the guideline is presented.
- **Checkpoints:** For each guideline the checkpoints associated to the guideline are presented.
- **Specific Consideration:** For each checkpoint a group of specific considerations is presented.
- **How can AR be used to support the specific considerations:** For each group of specific considerations, we defined how AR can be used to support the specific considerations.
- **Limitations of AR to support the specific considerations:** In this column the limitations of AR to support the specific considerations are described.
- **Level of Support at this moment:** In this column we defined the level of support that AR may provide for the specific considerations at the moment of this analysis.
- **Is it possible to support the specific considerations with other technologies?:** In this column we describe some other possibilities for supporting the specific considerations with other technologies different from AR.

Since the spreadsheet document was very large (more than 30 pages) it was not included together with this thesis but a persistent link is provided here so that anyone interested can have access to the results:

https://goo.gl/4KkHAE

Moreover, the same information was presented in a Google docs online document to provide another format of presentation of the results:

https://goo.gl/Xi9YUp

APPENDIX C
AR APPLICATIONS FOR LEARNING CHEMISTRY

As part of the validation of the framework presented in CHAPTER 7, we found in Google and Google Play 21 AR applications for learning chemistry. In this appendix we present the 21 AR applications found with the characteristics analyzed for each application. Each application is presented in one table and the cell of each table identified as “#” is the ID of the application which is referenced in CHAPTER 7.

#	Application Name	Topic addressed	Language
1	ARLOON Chemistry	Inorganic nomenclature	Spanish
Description and purpose			
Application for learning about inorganic nomenclature. The application allows to choose chemical elements from the periodic table to combine them in a compound. It recognizes more than 3.000 compounds. AR is used to see the molecular structure of each compound.			
Selected / Discarded	**Reasons for which the application was selected/discarded**		**Cost (in €)**
Selected	The application is useful for learning the topics of inorganic nomenclature.		0,6
URL			
https://play.google.com/store/apps/details?id=com.Arloon.Chemistry.AR&hl=en			

#	Application Name	Topic addressed	Language
2	DAQRI – Elements 4D	Chemical compounds (36 chemical elements)	English
Description and purpose			
Application for learning about compounds. It uses 36 chemical elements represented in 6 physical cubes (each side represents one chemical element). When the elements are combined the AR shows the compound obtained inside the cubes using the AR.			
Selected / Discarded	**Reasons for which the application was selected/discarded**		**Cost (in €)**
Selected	The application is useful for learning about compounds formation with an AR experience.		0
URL			
http://elements4d.daqri.com/#intro			

#	Application Name	Topic addressed	Language
3	Augmenter(Edulus VR)	3D models of chemistry, biology, physics, maths.	English
Description and purpose			
This applications is for exploring 3D models of different learning domains such as chemistry, biology, physics and maths. In chemistry the following 3D models can be visualized in AR: Fullerenes, diamond, cyclohexane, benzene, Ethane, graphite, Isobutane and methane.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Selected	The applications allows to interact with 3D models of molecules to understand its properties.		6
URL			
https://play.google.com/store/apps/details?id=com.augmented.android			

#	Application Name	Topic addressed	Language
4	Laborapptorio	Solutions of HCL y NaOH	Spanish
Description and purpose			
Application for learning about preparing HCL and NaOH solutions. In the AR view a video about how to prepare the solutions is shown augmented over the marker.			
Selected/Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Selected	The application seems to be useful for the VET programme of Laboratory Operations.		0
URL			
https://play.google.com/store/apps/details?id=es.itop.laborapptorio			

#	Application Name	Topic addressed	Language
5	Nytra	Multiple topics	English
Description and purpose			
The application allows to get augmented information in form of videos from the images contained in a book printed in India. The application only recognizes the images of those texts.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	The book is not available and the language of the book is not English or Spanish		0
URL			
https://play.google.com/store/apps/details?id=com.mbdgroup.ar.nytra			

#	Application Name	Topic addressed	Language
6	XI Jornada Carbohidratos 2014	Carbohydrates	Spanish
Description and purpose			
Application for the “XI Jornada Carbohidratos 2014”. The application recognizes images from the conference posters and shows a molecule of a carbohydrate. There is no interaction with the molecule.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	Topic out of the curriculum. This app was for a conference about carbohydrates and this topic does not fit in the curriculum of this VET programme.		0
URL			
https://play.google.com/store/apps/details?id=com.CreativiTIC.Carbohidrate			

#	Application Name	Topic addressed	Language
7	QuimicAR (Augmented Class)	Water compound and methane combustion	Spanish
Description and purpose			
Application that simulates how to produce water by combining hydrogen and oxygen. The application also simulates the methane combustion.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	The application shows only two chemical reactions but the reactions are fixed and cannot the modified.		0
URL			
https://play.google.com/store/apps/details?id=com.CreativiTIC.AugmentedClass			

#	Application Name	Topic addressed	Language
8	Química Prebiótica Bioquímica	Multiple topics from origin of matter to organic compounds.	Spanish
Description and purpose			
Application for showing 3D objects in some markers placed in the book with the title: “De la química prebiótica a la bioquímica. The book can be downloaded from: http://www.lte.ib.unicamp.br/qpbq/documentos/QPBQ.pdf			
Selected/Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Selected	There are many resources in different formats that can be seen in the AR markers. It seems appropriate for the learning process in the VET programme.		0
URL			
https://play.google.com/store/apps/details?id=lte.ib.unicamp.br.qpbq			

#	Application Name	Topic addressed	Language
9	AR Quimica	N/A	N/A
Description and purpose			
The application does not provide additional information about the topic. It was not possible to test de application because the markers were not available.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	Markers are not available.		0
URL			
https://play.google.com/store/apps/details?id=cl.datainnova.AR_3D_Quimica			

#	Application Name	Topic addressed	Language
10	Química RA	N/A	Spanish
Description and purpose			
The application does not provide additional information about the topic. The markers for the application are not available. The application was built with Vuforia and Unity. It was not possible to contact with the developer.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	Markers are not available.		0
URL			
https://play.google.com/store/apps/details?id=com.rocket.quimica			

#	Application Name	Topic addressed	Language
11	iScience AR	Physics and Chemistry for children	English
Description and purpose			
AR application to be used with the iScience book (basics of chemistry and physics). The topics seems to tbe for children and not for VET education.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	Topic out of the curriculum		0
URL			
https://play.google.com/store/apps/details?id=com.redfrog.isciencear			

#	Application Name	Topic addressed	Language
12	Navneet	Multiple topics	English
Description and purpose			
Application that works with books adapted to the curriculum in India in chemistry, physics and biology.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	The markers are not available and the topic is out of the curriculum		0
URL			
https://play.google.com/store/apps/details?id=com.visionar.NavneetaTqPUpMw			

#	Application Name	Topic addressed	Language
13	ARMolVis	Molecular Geometry	Spanish
Description and purpose			
Application with AR for visualizing molecules contained in daily life products. The application was made with Vuforia and Unity and recognizes some images as markers. The markers can be downloaded from: https://drive.google.com/folderview?id=0BzHOBnzx9F8iNENUQXBmbUxjWE0&usp=sharing			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Discarded	Topic out of the curriculum.		0
URL			
https://play.google.com/store/apps/details?id=nus.cc.mobile.armolvis			

#	Application Name	Topic addressed	Language
14	Augmented Reality METabolic Pathways (ARMET)	Metabolic pathways	Spanish
Description and purpose			
Application for learning about metabolic pathways and Krebs Cycle. The application provides a learning mode and an evaluation mode. The application has a login system and was developed with Vuforia.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Selected	Topic out of the curriculum.		0
URL			
https://play.google.com/store/apps/details?id=lte.ib.unicamp.br.armet			

#	Application Name	Topic addressed	Language
15	Molecular Geometry	Molecular Geometry	English
Description and purpose			
Application for learning about molecular geometry. The application shows 3D models of the following molecules:			

paracetamol, methane, ammoniac, water, carbon dioxide, methanamine. The application shows the angle between the atoms for some of the molecules. The developed provided a worksheet (in French) for a learning activity with this application.		
Selected/ Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**
Selected	The topic seems to be out of the curriculum.	0
URL		
https://play.google.com/store/apps/details?id=com.miragestudio.geometrie		

#	Application Name	Topic addressed	Language
16	Moléculas	Molecular Geometry	Spanish
Description and purpose			
Application is a demo. Some of the markers show a video of a teacher explaining the purpose of the application and some molecules do not have its name. The web page of this project is : http://realidadaumentada.us.es/index.php?option=com_content&view=article&id=70:mol%C3%A9culas&catid=27:ra&Itemid=123			
Selected /Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**	
Discarded	The application is only a demo.	0	
URL			
https://play.google.com/store/apps/details?id=com.sav.moleculas			

#	Application Name	Topic addressed	Language
17	Popar Periodic Table	Periodic Table	English
Description and purpose			
Application for learning about the periodic table. The marker is a poster of the periodic table and it is possible to explore each chemical element to get information about its main characteristics. It has a mode in which it is possible to combine different elements from the periodic table to form compounds.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**	
Selected	The application seems to be useful for learning about the periodic table.	0 app and (30€ **the poster**)	
URL			
https://play.google.com/store/apps/details?id=com.popartoys.periodictable			

#	Application Name	Topic addressed	Language
18	ShakeMyVirus	HIV virus, DNA, electrostatic fields, proteins and aminoacids.	English
Description and purpose			
Application for visualizing DNA structures and the HIV virus. The application also has other models for explaining concepts of electrostatic field, proteins and aminoacids. The application seems to be a demo. The web page is: http://mgl.scripps.edu/projects/tangible_models/mobile-ar			
Selected / Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**	
Discarded	The application is a demo an it is out of the curriculum.	0	
URL			
https://itunes.apple.com/us/app/shakemyvirus/id616800272?ls=1&mt=8			

#	Application Name	Topic addressed	Language
19	FL-AR-MolecularViewer	Biology and biochemistry	English
Description and purpose			
Application for visualizing the DNA molecule in a interactive form, including some peptides.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**	
Discarded	The application is a single demo and is out of the curriculum.	0	
URL			
http://mgldev.scripps.edu/projects/AR/FLARMg61/src/index.html			

#	Application Name	Topic addressed	Language
20	Chemistry VR - Cardboard	Compounds formation	English

Description and purpose		
This application uses the Google Cardboard, so it is Virtual Reality. The main objective is to form compounds with different chemical elements from a virtual world.		
Selected / Discarded	**Reasons for which the application was selected/discarded:**	**Cost (in €)**
Discarded	The application uses Virtual Reality (with the Google Cardboard) and does not use augmented reality.	0
URL		
https://play.google.com/store/apps/details?id=com.arloopa.chemistryvr		

#	Application Name	Topic addressed	Language
21	Augmented Reality Chemistry Review	Molecular geometry	English
Description and purpose			
This is a web application that shows the molecules of the following compounds: Etilene, propylene, acetylene, Ethane, Acetamide, methylaniline, carbon dioxyde, methane, ammoniac.			
Selected / Discarded	**Reasons for which the application was selected/discarded:**		**Cost (in €)**
Selected	The topic seems to be out of the curriculum.		0
URL			
http://sponholtzproductions.com/3d/			

APPENDIX D

INSTRUCTIONALS MATERIALS MOTIVATION SURVEY

This appendix presents the Instructional Materials Motivation Survey administered to students to collect data about their levels of motivation. This version of the instruments corresponds to the adaptation of the instrument for the first exploratory study (see CHAPTER 3). For the second exploratory study (see CHAPTER 4). The instrument can be downloaded from the following link:

https://goo.gl/KLBBUP

The IMMS instrument was also adapted for the validation of the framework (see CHAPTER 7). Hene, there are two versions of the instrument: one for the control group and one for the experimental group. The instrument is in Spanish language as it was administered to students in this language and can be downloaded from the following link:

https://goo.gl/NuU9K5

APPENDIX E

QUESTIONNAIRE FOR EVALUATING LEARNING OUTCOMES IN CAR'S MAINTENANCE

This appendix presents the questionnaire for evaluating students' learning outcomes in the topic of repairing paint on a car. This questionnaire was used in the second exploratory study (see CHAPTER 4). This questionnaire is in Catalan language and the complete questionnaire can be found in the following link:

https://goo.gl/KLBBUP

APPENDIX F

QUESTIONNAIRE FOR EVALUATING LEARNING OUTCOMES IN INORGANIC NOMENCLATURE

This appendix presents the questionnaire for evaluating students' learning outcomes in the topic of inorganic nomenclature in the VET programme of Laboratory Operations. This questionnaire was applied during the validation of the framework (see CHAPTER 7). The questionnaire is in Catalan language and can be downloaded in the following link.

https://goo.gl/NuU9K5

In this doctoral thesis a framework for the design and development of Augmented Reality learning experiences that increase motivation in the Vocational Education and Training level of education is introduced. The research process started with two exploratory studies that were conducted in the Vocational Education and Training (VET) programme of car's maintenance. As part of these two exploratory studies, a mobile AR application called Paint-cAR was co-created with VET teachers. As a result of these studies we confirmed that the Paint-cAR application increased student motivation.

With the information collected during the two exploratory studies, we conducted a study of predictors of student motivation to identify the components of the Paint-cAR application that positively affect student motivation during a learning experience with AR.

Based on the study of predictors of student motivation and the literature on AR in education, the framework for the design and development of motivational AR learning experiences was defined. The framework was validated in the VET programme of Laboratory Operations in the field of chemistry and we found that the learning experience created by following the framework positively impact student motivation, in particular, the attention and confidence dimensions.

Framework for the Design and Development of Motivational Augmented Reality Learning Experiences in Vocational Education and Training

Universitat de Girona