ENLIVENED LABORATORIES METHODOLOGICAL GUIDELINES (ELMG)

Enlivened Laboratories within STEM Education (EL-STEM)

Motivating EU students to choosing STEM studies & careers and improving their performance in courses related to STEM education

Co-funded by the Erasmus+ Programme of the European Union

This document is issued within the frame and for the purpose of the Enlivened Laboratories within STEM Education project, funded by the European Commission-Erasmus+/ Key action 2, Cooperation for Innovation and the Exchange of Good Practices/ KA201 - Strategic Partnerships for school education (Ref. #: 2017-1-CY01-KA201-026775)

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Executive Summary:	The Enlivened Laboratory Methodological Guidelines - ELMG (IO2) outline the methodology on how to implement an Enlivened Laboratory within EU lower and upper secondary education schools, supported by Augmented Reality technologies. Specifically, the ELMG provide answers to core questions, including: (i) "whom" they are addressed to and to "whom" they can be applied, (ii) "where" they could be implemented within the educational context, (iii) "why" they should be integrated within STEM-related courses, (iv) "what" educational approaches and which digital tools could be used and finally, (v) "how" they could be generated to teach STEM-related disciplines in secondary education using Augmented and/or Mixed Reality technologies.

European Commission

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List of Abbreviations/ Acronyms

Abbreviation / Acronym	Description
AR	Augmented Reality
CY	Cyprus
EE	Estonia
EL	Hellas (Greece)
ELMG	Enlivened Laboratory Methodological Guidelines
EL-STEM	Enlivened Laboratories within Science, Technology, Education and Mathematics
et al.	Latin: et alii (eng: and others)
EU	European Union
FI	Finland
ICT	Information Communication Technology
IO	Intellectual Output
IoT	Internet of Things
LO	Learning Object
LP	Lesson Plan
M#	Month of the project time plan (M1-M30)
MR	Mixed Reality
OECD	Organisation for Economic Co-operation and Development
PISA	Program for International Student Assessment
PT	Portugal
SAM	Successive Approximation Model
STEM	Science, Technology, Education and Mathematics
TIMSS	Trends in International Mathematics and Science Study
VR	Virtual Reality
WP	Work Package

EL-STEM Project Description

EL-STEM is an Erasmus+ Action 2 program, funded by the EU for 30 months. The consortium consists of nine partners from five EU countries including Cyprus (2 Universities, 1 Public High School), Greece (1 University, 1 Private High School), Estonia (1 University, 1 Public High School), Finland (1 Teacher Training School) and Portugal (1 company).

The Project objective is to develop a new approach, which combines Augmented Reality (AR)/Mixed Reality (MR) technologies with Remote and/or Local Laboratories, for encouraging 12-18 year-old students' STEM engagement. In particular, we are targeting students of lower and upper secondary schools and irrespective of the expected varying individual inclination to STEM subjects, we are aiming to:

(a) attract students who currently might not be interested in STEM related studies/careers and enhance the interest of those who have already chosen this field of studies/careers,
(b) improve students' performance in courses related to STEM education.

Inspired by emerging technologies of IoT (Internet of Things) and AR (Augmented Reality), we wish to connect the physical laboratory and/or the remote laboratory to the digital world and turn it into an "Enlivened Laboratory". We aim to explore various digital solutions to "immerse" students within STEM laboratories while implementing experiments. Moreover, we aim to attract more students to STEM related studies/careers through intense hands-on experiences, where they can participate, transform and augment what they are implementing, thus applying digital competences, developing haptic skills, collaborating with peers and ultimately, becoming more engaged in STEM education. This approach will be supported at school as well as at home through the involvement of appropriate platforms offering remote access to laboratories.

Acknowledging the crucial role of teachers in any effort to bring about change and innovation, our project will make available the necessary knowledge, indicative tools, and will introduce underlying dynamics in teaching cultures that will enable STEM education to obtain the full benefits of AR/MR. This will be achieved by providing teachers with high quality professional development opportunities to acquire knowledge and skills to effectively embed AR/MR in teaching and learning. More specifically, we will create a comprehensive framework for providing teachers with innovative digital tools to enrich their laboratory-based courses, in order to not only attract students' attention towards STEM education but also to achieve better performance in STEM related subjects. Project outputs will include AR/MR educational scenarios implemented through Remote and/or Local Laboratories. The technologies used for the implementation of these scenarios explore where applicable, the utilization of (a) AR/MR Remote Laboratories, (b) AR/MR Local Laboratories, (c) Mobile Technologies (e.g. smartphones and/or tablets), and (d) AR hardware technologies (e.g. AR glasses) in the teaching and learning of STEM courses.

1. Introduction

This particular IO is closely related to IO1 (Accounting for diversity and accessibility in European STEM classrooms), which provides the pedagogical framework for developing an inquiry-based STEM learning approach that could be used in designing instructional processes and educational materials for using Augmented Reality (AR) and Mixed Reality (MR). IO2 outlines the methodological guidelines on how to implement an Enlivened Laboratory within EU lower and upper secondary education schools, supported by “AR STEM Teachers” and “AR STEM Students”.

To make the methodological guidelines more clear, this report starts with the description of the methodological framework of the EL-STEM project, namely the SAM model, that indicates the process through which the guidelines are designed and developed. Moreover, the background of the EL-STEM project is defined to highlight the main axes of the situation under research. Then, the Enlivened Laboratory Methodological Guidelines (ELMG) reply to core questions, including (i) *whom* they are addressed to and to whom they can be applied, (ii) *where* they could be implemented, (iii) *why* they should be applied within the context of STEM-related disciplines, (iv) *what* approaches and tools could be used and finally, (v) *how* they could be generated to teach STEM-related disciplines in secondary education using AR/MR technologies. An example of an AR STEM Learning Object and an AR STEM Lesson Plan are described, as best practices of applying ELMG in a real STEM laboratory.

IO2 material is considered to be a “framework” based on practical case studies in Estonia, Cyprus, Finland, Greece, and Portugal, providing step-by-step guidelines on how to integrate AR technology into teaching and learning in the field of STEM. We consider this to be valuable material for teachers to understand the background of the EL-STEM project (including the pedagogical background of IO1) and creating innovative AR/MR Learning Objects (IO5) and Lesson Plans (IO6). In addition, IO2 will be referenced in the EL-STEM Library and Toolkits (IO3). IO2 will also constitute the core of the learning material, in the context of the in-service teachers’ training course (IO4).

2. ELMG Rationale – Target Groups – Recommendations

The approach suggested in the guidelines and their content are in line with the critical need to equip students from an early stage, with the knowledge and skills necessary to upscale their profiles to a well-prepared workforce of the future labor market. STEM is adapted, not simply referring to the individual subjects of the acronym but providing an engaging and interdisciplinary way of teaching and learning. Students need a well-rounded education to acquire 21st century skills, which could be achieved through interdisciplinary approaches to face real-life problems (Beers, 2011; Mishra & Kereluik, 2011). Moreover, there is clearly a need for students to be knowledgeable about a wide variety of purposes for innovative technologies (i.e. Augmented and Mixed Reality) - not only to meet standard-based instructional goals, but also to become ready both for their future studies and careers (Woodward & Hutchison, 2016).

These guidelines are useful for enhancing the teaching and learning processes in the context of STEM-related disciplines by using the innovative technologies of AR and MR. The primary audience and key users these guidelines are addressed to are lower and upper secondary education STEM teachers in EU, aiming to or already teaching students between 12-18 years old. The specific characteristics of these teachers could be summarized as follows:

- Teachers of STEM related courses not using Remote/Local Labs within their courses, in order to change their teaching cultures.
- Teachers of STEM related courses already using Remote/Local Laboratories, applying innovative approaches within their courses and/or willing to include AR/MR technologies to obtain full benefits of them.
- Teachers of STEM related courses aiming to apply innovative methodological approaches and integrate emerging technologies, namely AR/MR, in their teaching practices.
- Teachers serving in schools with a particularly high proportion of students from low socio-economic backgrounds.

Other potential users include third parties such as educational institutions and/or schools, research centers, universities and development partners interested in AR/MR technologies in the field of STEM. Although the guidelines aim to be comprehensive, country contexts vary. The beneficiaries are encouraged to select and adapt the sections relevant to their use cases "à la carte", according to their main education policy issues and specific constraints. Some of these challenges have been identified through a survey implemented in the early stages of the EL-STEM project (IO1) in partner countries (CY, EL, EE, FIN, PT).

3. Methodological Framework of the EL-STEM Project: SAM model

The instructional design literature is clear concerning the need of effective management when referring to educational/training product development projects, including technology enhanced learning (Allen, 2006; McDaniel & Liu, 1996; Williams van Rooij, 2010). An instructional designer requires not only instructional design skills, but also project management skills (Stubbs, 2002; Yang, Moore, & Burton, 1995), such as leadership of a project team, estimation of project requirements and risks, and development of processes and standards for the completion of the project (Li & Shearer, 2005). Similarly to the success criteria of any project, a technology enhanced learning project could be considered as successful if it (a) is delivered on time, (b) does not exceed the initial budget and (c) meets the expectations and requirements of the project stakeholders (Crawford & Pollack, 2007; Stubbs, 2002; Williams van Rooij, 2010).

The ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model, the most popular model used by instructional designers to combine project and instructional management, refers to a systematic development of the teaching/learning method (Molenda, 2003) or more specifically, a systematic and iterative method for creating learning experiences that develop and enhance skills and knowledge (Allen, 2006). Nowadays, despite being a well-established and easy to implement model with foundations that have become very strong over the years, ADDIE is considered to be somewhat outdated and faces criticism due to its hierarchical structure. Allen (2012) refers to four main criteria that lead to the "*leaving ADDIE*" trend: (a) iteration, (b) collaboration, (c) effectiveness and (d) manageability, suggesting agile approximation as a superlative process for the development of any instructional product.

As a solution to the above-mentioned trend, SAM (Successive Approximation Model) was suggested, which refers to an agile development of the teaching method or more specifically, an effective strategy for designing learning events intending to produce greater performance (Allen, 2012). This model is appropriate for innovative e-learning projects, since it provides the options, strategies and tools to be successful. The stages involved in the SAM process include (Figure 1):

- **Preparation** - An initial meeting (locally or online) with representatives from all partners of the consortium to collect basic information about the learning outcomes and necessary actions.
- **Iterative Design** - Designing, prototyping and evaluating loops during the project's implementation.
- **Iterative Development** - Evaluation, development and implementation loops.

Probably one of the most notable features of SAM is the preparation phase, which consists of two main steps: (a) gathering information, and (b) holding a brainstorming and prototyping (savvy start) (Rimmer, 2016). Despite being still new to developing educational/training product projects, SAM seems to be a promising and cost-efficient model, due to its adaptivity and agility (Allen, 2012). Moreover, it promotes collaboration as a critical characteristic during all phases of a project, which is very important when referring to consortiu within EU educational/training product projects.

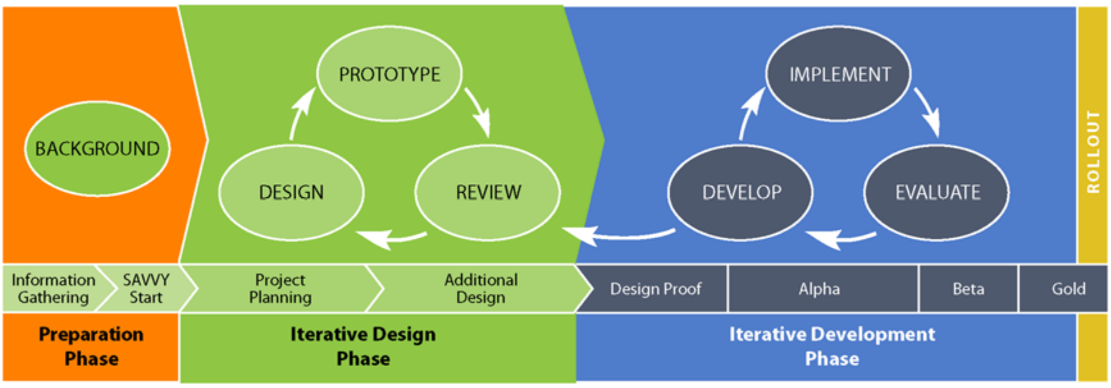
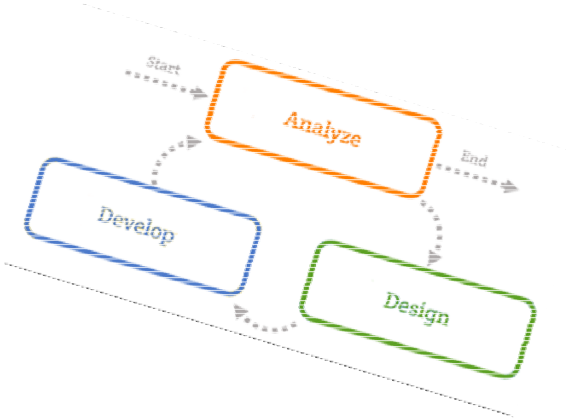


Figure 1: SAM phases (Allen, 2012)

Within EL-STEM, which is obviously an e-learning project, there is a general need of setting a Methodological Framework, to guide the design and implementation of all relevant tangible and intangible outputs and results (Amado et al., 2011). As described above, taking into consideration the EL-STEM project background, SAM is appropriate for this purpose. The general framework of the project's methodology consists of the following plan (*colors based on the phases of Figure 1):*

- Research on applied knowledge, best practices, technical solutions;
- Analysis of existing resources, case studies, pedagogical and didactical methods;
- Design and development of Methodological Framework, related AR/MR Learning Resources and in-service teacher training program;



- Pilot testing/validation of resources, methods and technology.

At the same time, based on the SAM model, all the above-mentioned are accompanied by:

- An iterative work method, remodeling of the resources;
- Evaluation of the quality of the resources and methods produced.

In detail, the EL-STEM project phases, following the methodology described are:

Table 1: EL-STEM Project Phases

PHASE (DURATION)	DESCRIPTION
PHASE 1: **INCEPTION** **(M1-M2)**	Project structures are set up for project governance and day-to-day management through preparation of: (i) Guidelines, internal management plan and reporting tools; (ii) Communication Plan between project partners, Dissemination and Post-Project Exploitation Plan; (iii) Templates/drafts of documents concerning WPs and deliverables.
PHASE 2: **BUILDING OWNERSHIP-INVOLVING TARGET GROUPS** **(M1-M3)**	A pivotal phase for ensuring ownership by project's beneficiaries and alignment of IOs with real needs of secondary school STEM teachers and students. Dialogue with target groups (already started before submission) has been re-launched. Care was taken to involve teachers and students. Groups of teachers have been created in all territories to participate in the design of IOs (IO5 and IO6), while their work continues throughout the project implementation. After involving the main target groups, a survey was conducted to map the current situation concerning the challenges and success stories in applying contemporary inquiry-based STEM learning in innovative learning environments (described in IO1).
PHASE 3:	The innovation contents have been conceived by the project's staff and intellectual outputs have been laid out and made available for dissemination and experimentation. Teachers also created their own LOs. It is a delicate phase in terms of the quality of the project results

CREATION OF RESOURCES AND TOOLS **(M3-M32)**	envisaged, and for this reason, it requires constant communication and exchange among internal staff.
PHASE 4: **CAPACITY BUILDING AND PREPARATION FOR PILOT** **(M13-M16)**	This phase is aimed at ensuring, at the territorial level, an adequate level of knowledge and competences on the side of partners' staff to manage the testing phase with local teachers and students. A 3-day joint staff training event will be first organized in Greece to create a pool of teachers and operators, working in partner organizations, with reinforced abilities to become "teacher trainers" in their respective territories. This trained staff, upon return, will train local teachers that will participate in the pilot experimentation on the methodology of the Enlivened Laboratories. Participating STEM teachers (approx. 60 from CY, EL, EE, FI) will be motivated to effectively integrate AR/MR with core STEM curricular ideas both by (a) using AR/MR Remote/Local Laboratories and AR/MR LOs created and tested during previous months of the current phase, and (b) creating their own AR/MR LOs and LPs with appropriate tools. Teacher training will be offered through combined use of e-learning and physical meetings. A transnational online teacher community will be created for the exchange of experiences, ideas and resources.
PHASE 5: **PILOT EXPERIMENTATION** **(M17-M30)**	Trained teachers will activate "Enlivened" didactical paths in their schools. They will implement their LPs and AR/MR LOs within Remote/Local Labs, each with at least one group of students (approx. 800 students in total). Feedback and information received about students' performance, 21st century skills, motivation and interest through appropriate measurements (IO1) will be integrated in the final project reports.
PHASE 6: **SECTORAL/CROSS-SECTORAL DISSEMINATION** **(M10-M34)**	Involves project partners' commitment to disseminate IOs locally, nationally and across EU. Hands-on dissemination seminars and other national events will be organized in all territories to reach teachers, students, and the wider school education community (sectoral dissemination), but also the wider community even outside the school sector (cross-sectoral). The IOs created will be at the disposal of all actors interested in increasing the motivation to STEM education of youth. Dissemination will also take place through national and transnational workshops, conference presentations, publications, reports to government bodies, social media etc.
PHASE 7: **EVALUATING COOPERATION AND PLANNING FOLLOW-UP** **(M22-M34)**	During the last few months prior to the project's completion, partners will evaluate their cooperation and results achieved. They will also lay out detailed follow-up activities to sustain the project's results over the long term.

4. Overview - Background to the EL-STEM Project

During the last decade, cross-national studies of students' achievement (e.g. TIMSS, PISA) indicate underachievement in basic skills (reading, science and mathematics) and lack of scientific competence for a considerable proportion of students (Grek, 2009; Martin, Mullis, Foy & Stanco, 2012; Tienken, 2013). Since 2009, some EU countries have made significant progress towards improving their students' performance in science skills while others are still behind (Schleicher, Zimmer, Evans & Clements, 2009; Walker, 2011). Recent results specify that about 50% of the EU countries remain lower than the average, while only two (Estonia and Finland) are included in the top ten countries globally ("About TIMSS 2015", 2015; "PISA 2015", 2015). In addition to students' low achievement in sciences, there is well-documented evidence of declining interest in key STEM (Science, Technology, Education and Mathematics) topics and careers for students in the EU and internationally (EU Commission, 2016; Panorama 2016).

The situation calls for urgent action, since skills in STEM[1] such as *statistics*, *problem-solving*, *creativity*, *argumentation*, *intellectual curiosity*, *data-driven decision-making* and *flexibility* (Caralee, 2017) are among key competencies that individuals need in a knowledge-based society for employment, inclusion, subsequent learning, personal fulfillment and development (OECD, 2016; Panorama, 2016). EL-STEM seeks to practically contribute[2] to an extent towards (EU Commission, 2016): (a) meeting the 2020 EU target of reducing the number of underachievers in STEM education to below 13% and (b) motivating a bigger proportion of young Europeans to exhibit interest in STEM and to undertake STEM studies and careers. At EU level, this concern has been expressed by relevant policy makers, in a series of EU summits and reports from the Education Committee (EU Commission, 2016), culminating in the strategic targeting of resources to improve science education and reduce disparities in science and mathematics outcomes between different EU countries.

Technological developments of the 21st century have provided the opportunity to create entirely new learning environments by significantly increasing the range and sophistication of possible classroom activities and introducing new pedagogical models (Meletiou-Mavrotheris & Prodromou, 2016). One promising approach lately explored, is the potential of integrating **Augmented Reality (AR)** and/or **Mixed Reality (MR)** within primary and secondary STEM education, as a means of making the subjects under study more accessible and attractive for students, and particularly, those at special risk of exclusion from scientific studies and/or careers. AR and MR are emerging technologies[3] in the immersive learning landscape and have gained a growing interest among researchers during the last two decades (Cooperstock, 2001; Shelton, 2002; Haller, 2004; Lee, 2012; Bower, Howe, McCredie, Robinson & Grover, 2014; Meletiou-Mavrotheris, 2019). Moreover, **laboratories within STEM** related courses constitute

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[1] IO1 provides a wider overview concerning the generic 21st century skills needed in the future labor market and addressed in the context of EL-STEM project as well.

[2] IO1 provides a set of assessment tools to identify the gaps and measure improvements in students' performance and 21st century skills, using EL-STEM LPs in teaching and learning.

[3] More details about these technologies, their specific characteristics and affordances, are explained within section 5.4.2 Understanding the differences of Virtual, Augmented and Mixed Reality and IO1 (Accounting for diversity and accessibility in European STEM classrooms).

a field in which schools and other educational authorities invest, attempting to make their curricula more innovative, attractive and competitive (Heradio et al., 2016). These two dimensions (Figure 2) have recently been combined under multiple perspectives to promote the advantages of their intersection (Lasica, Katzis, Meletiou-Mavrotheris & Dimopoulos, 2016). Despite the increasing interest within this field, the amount of available research concerning their integration into teaching and learning practices is still relatively small due to the novelty of the technologies and the hesitation of the educational authorities. Nonetheless, the majority of the existing studies highlight a large number of positive attributes that have the potential to enhance both learning and teaching and could introduce education to a new era (Hu, Wu & Shieh, 2016; Martín-Gutiérrez & Contero, 2011).

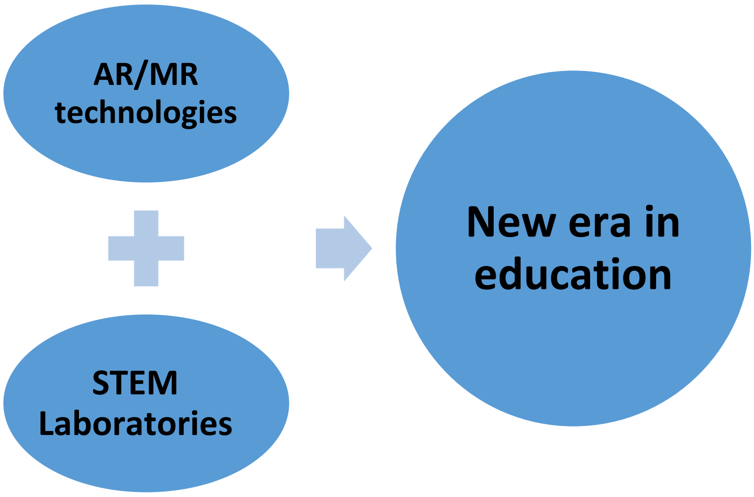

Figure 2: New era in education

There are many researchers arguing that viewing AR/MR as a *concept* rather than a technology is more productive and effective (Wu, Lee, Chang & Liang, 2013). However, many case studies and current learning environments still limit development to silo products and create barriers to the overall adoption of new learning technologies. Adapting AR/MR within STEM laboratories should be accompanied with *innovative pedagogical approaches* and *re-contextualized learning environments* in order to be successful (Kaufmann, 2003; Bower et al., 2014). AR offers new learning opportunities, but also creates new challenges both in teaching and learning (Wu et al., 2013; Heradio et al., 2016). There is a growing need for the uptake of learner-centered forms of pedagogy within STEM education, focused on inquiry and problem-solving, however, changing teaching practices is proving very difficult in practice (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur & Sendurur, 2012). New technologies and associated pedagogies require a very different skillset compared to more conventional teaching, which can put additional pressure on teaching staff (Bower et al., 2014). Among European countries, there is lack of a single policy concerning teachers' education both in Primary and Secondary Education (OECD,2016). Many teachers remain unprepared to effectively employ Information Communication Technology (ICT) tools in their teaching practices (Bower et al., 2014), while a number of studies have asserted that it is much more demanding for teachers to exploit the growing prominence and transformative potential in instructional settings of AR and other digital technologies than was originally anticipated (e.g. Ertmer et al., 2012; McNair & Green, 2016; Meletiou-Mavrotheris et al., 2017).

Thus, the provision of high quality teacher training that will enable education to reap the full benefits of AR/MR technologies is of utmost importance (Delello, 2014). Teachers should be encouraged and motivated to recognize the actual potential and groundbreaking impact that AR/MR laboratories could have on teaching, learning, and assessment within STEM related courses, and should be appropriately informed about best practices in their exploitation as instructional tools (Meletiou-Mavrotheris, 2019). Providing teachers with high quality preservice and in-service training opportunities that will equip them with the knowledge and skills necessary to effectively infuse AR/MR into teaching, needs methodological planning and reflective implementation, based on solid research (Lasica, Meletiou-Mavrotheris, Katzis & Dimopoulos, 2018). Numerous studies highlight the role of teachers' preparation for using AR/MR and other new technologies in their classrooms (Delello, 2014; Dunleavy, Dede & Mitchell, 2009; Mcnair & Green, 2016; Meletiou-Mavrotheris, Paparistodemou, & Christou, 2019), since many teachers reject them for reasons such as lack of time or motivation for learning new technological skills, lack of existing resources, fear and lack of confidence in using technology, and failure of materials to align with the standards (Delello, 2014; Ertmer et al., 2012; McNair & Green, 2016). Moreover, another restriction is the fact that there are many teachers that do not feel comfortable with adapting new styles of learning provided by innovative technologies, especially with those moving away from teacher-centered approaches to learner-centered ones (Bower et al., 2014; Delello, 2014).

Changes in teaching cultures are required that will enhance students' performance and improve their attitudes, as well as reduce disparities in STEM outcomes between different EU countries. Taking this requirement as a point of reference, it could be suggested that teachers are the key persons in beginning to understand the *what, how* and *why* of AR/MR supported laboratories within STEM education, as they are the "links" providing the necessary instructional support to students and maximizing the impact of this technology. For this purpose, a renovated effort in providing continuing professional development in this area is needed, as well as providing teachers with new stimulus to tackle groups at risk.

As a solution to the above-mentioned situation, the EL-STEM project aims to adopt an innovative in-service Teacher Training Program for secondary education STEM teachers within the EU, that will offer them high quality professional development on how to effectively integrate AR/MR technologies within the existing school curricula, especially 12-18 years old students. EL-STEM aims at fostering an "ecosystem" that will facilitate more effective and efficient user-centric design and use of AR/MR resources for personalized STEM learning and teaching. The core of this specific teacher training program is the Enlivened Laboratory Methodological Guidelines (ELMG), which consist of the foundations on which the background of the EL-STEM project was laid. The following section provides the framework for the ELMG, which are developed in detail in the context of the teacher training program in IO4.

5. Enlivened Laboratory Methodological Guidelines (ELMG)

The Enlivened Laboratory Methodological Guidelines (ELMG) are primarily addressed to secondary education teachers across Europe on how to apply the methodology of the Enlivened Laboratories (EL-STEM), in order to create their own Lesson Plans (LP) and AR/MR

Learning Objects (LOs) within their STEM related courses. More specifically, they reply to core questions, including:

(i) **whom** they are addressed to and to whom they can be applied,
(ii) **where** they could be implemented,
(iii) **why** they should be applied within the context of STEM-related disciplines,
(iv) **what** approaches and tools could be used and finally,
(v) **how** they could be generated to teach STEM-related disciplines in secondary education using AR/MR technologies.

The impact of the ELMG is expected to be:

- Provide the necessary methodological framework and recommendations for teachers to understand how to: (i) increase European Youth (students 12-18 years old) skills in STEM related courses and attractiveness to STEM studies and careers, and (ii) make an appropriate use of ICTs and especially AR/MR technologies for this purpose.
- Suggest interactive activities for students in Europe with disadvantaged backgrounds who need additional support to be motivated in STEM, as a vehicle of integration, inclusion and prevention of early school leaving.
- Suggest interactive AR/MR LOs, that will be widely available to European teachers and generally educators during and after the completion of the project.
- Develop a framework and appropriate tools for identifying and assessing the competences of the "Augmented Reality STEM teachers" and "Augmented Reality STEM students”. The framework will make reference to the EU framework of Key Competences for Lifelong Learning, and it will be broken down into different levels, according to the age of students. It will take into account the specificities of each national educational system.
- Offer suggestions for teachers to create Augmented/Mixed self-evaluation activities to be carried out by STEM students themselves.
- Offer inputs (instructions and suggestions) on how to transfer the approach and successfully implement it in a diverse range of non-formal educational sectors, equally interested in increasing young people's motivation to STEM (e.g. organisations within STEM discipline, youth associations, public libraries).

The following sections describe the main axes of the ELMG in detail.

5.1. Who: To whom are the ELMG addressed to and to whom they can be applied

As already mentioned, ELMG are useful to enhance the teaching and learning processes in the context of STEM-related disciplines by applying AR and MR technologies. The primary target group and key users these guidelines are addressed to are lower and upper secondary education STEM teachers in EU, aiming to or already teaching students between 12-18 years old. These teachers could consist of the core of a community expected to be the "Augmented Reality STEM teachers", aiming not only to apply the guidelines in their teaching practices but also, to share them with others and increase the community range. The specific characteristics of these teachers could be summarized (but not limited to) as following:

- Teachers of STEM related courses not using Remote/Local Labs within their courses, in order to change their teaching cultures.
- Teachers of STEM related courses already using Remote/Local Laboratories, applying innovative approaches within their courses and/or willing to include AR/MR technologies to obtain full benefits from them.
- Teachers of STEM related courses aiming to apply innovative methodological approaches and integrate emerging technologies, namely AR/MR, in their teaching practices.

Other potential users include third parties such as the staff of educational institutions and/or schools, research centers, universities and development partners interested in AR/MR technologies in the field of STEM.

Concerning the primary target group these guidelines could be applied, this is students of lower and upper secondary education in EU (aged between 12 and 18 years old). These students could consist of the core of a community expected to be the "Augmented Reality STEM students", aiming to apply AR/MR technologies in their learning and share their experience with students from the other countries of the consortium. The ELMG (when adopted by teachers) are expected to:

- encourage students' STEM engagement,
- attract students who currently might not be interested in STEM related studies/careers and enhance the interest of those who have already chosen this field of studies/careers,
- equip students with 21st century skills through inquiry-based approaches in STEM-related courses, supported by AR/MR technologies (see IO1 for more details),
- improve students' performance in courses related to STEM education.

Other potential target groups of the ELMG are individuals aged between 12 and 18, attending STEM-related activities and/or programs, provided by stakeholders in the field of STEM as events and entertainment.

5.2. Where: Localization of the ELMG in and out of the classroom

The second important question that the ELMG aim to answer is "where can they be applied?", which refers to the location where a teacher can integrate an AR/MR Learning Object and/or implement a total or part of a Lesson Plan concerning a STEM-related discipline. A strong advantage of the AR/MR technologies, as already mentioned, is the fact that their most common usage is a layer on top of the smartphone's and/or tablet's field of view, through the device camera. This makes the AR technology easily accessible without spatial constraints. Taking into consideration the "Instructional Design for using MR/AR in inquiry-based STEM learning" suggested in IO1, Table 2 describes some alternatives of locations where "Enlivened Laboratories" could be implemented.

It is important to declare that these are only some suggestions, but the final decision on where an educational intervention should take place, is based on the teacher and could depend on numerous factors, such as the school directory, the parents, the school location and facilities, the curricula, the country's educational context etc. Also, the different inquiry-based phases could be implemented in more than one location.

Table 2: Where to use AR/MR to Enliven Laboratories in STEM

LOCATION	DESCRIPTION	INQUIRY-BASED LEARNING PHASE
CLASSROOM	Talking about education, of course the most common place where ELMG could be applied is a school's classroom. Teachers could provide their students with "triggers"[4] enabling the AR content through their devices in different points (wall, board, etc.) or in different objects (books, notepads, workbooks, library, desk etc.) in the classroom. The classroom could be considered as a safe location to introduce the students into the AR technology for the first time.	Orientation Conceptualization Conclusion Discussion
LABORATORY	Since the main idea of the ELMG is to enliven STEM laboratories, the different kinds of laboratories (see more in section 5.4.3) could not be omitted from the suggested locations. Teachers could provide students with triggers enabling the AR content through their devices in different objects/ equipment within a STEM laboratory (tubes, thermometers, beakers, flasks, models such as human body, construction materials etc.). Moreover, access could be provided to remote laboratories supported by AR technologies through a computer device (desktop or laptop). Local school laboratories could be considered as an ideal location to implement inquiry-based STEM learning by using AR/MR technologies, since there is usually a satisfactory stable internet connection while the teacher can use numerous triggers to enable AR/MR content.	Orientation Conceptualization Investigation Conclusion Discussion

[4] Trigger is usually the element (QR code, marker, object, image etc.) that includes the AR content which can be accessed through the appropriate application of a smartphone/ tablet.

OUT OF THE CLASS	An additional suggestion is to get students out of the class, using their mobile devices, to investigate real environments and get an authentic learning experience. In this case, it is of critical importance to ensure that internet connection will be available to access the AR/MR content. Teachers could provide students with triggers enabling the AR content through their devices in different locations around the school (e.g. school's garden). Students could play the role of a real traveler or researcher through activities such as searching for the lost treasure or finding the secret of the milk planet through an experiential learning process. Moreover, out of the class learning experiences could be implemented in locations related with science disciplines, such as a science museum, a zoo, a planetarium. In this case, teachers could have prepared their own AR content based on the place to visit or design appropriate activities based on the AR/MR content provided by the location visited (e.g. most planetariums have already integrated AR/MR experiences in their exhibitions). Using location-based AR/MR educational applications could enrich the educational process, providing additional information to the students. Applying ELMG out of the class could be considered as the appropriate location to promote collaboration in learning.	Orientation Conceptualization Investigation
HOME	Using AR/MR at home could also be an option as a location. Teachers could provide students with triggers enabling the AR content through their devices in different objects, such as workbooks, notepads, books. This content could focus on summarizing the inquiry-based process implemented in other locations, providing additional information or guidance on how to complete a project.	Conclusion Discussion

5.3. Why: Reasons to apply the ELMG

Some of the main reasons to apply the ELMG within the educational process based on the existing studies concerning the affordances of this technology are the following (Chen et al., 2017; Wu et al., 2013):

Technical

- ✓ AR overcomes VR limitations, such as lack of realism, since real and virtual elements of the environments can be clearly distinguished by students (Johnson & Levine, 2008; Tall, 2017).

- ✓ AR offers affordances of presence, immediacy and immersion (Bronack, 2011).
- ✓ AR provides rich contextual interactive learning environments, that engage students in the educational process in ways that were not possible in the past (Garzón et al., 2017).

Students

- ✓ Problem-Based and Inquiry-Based Learning are promoted, as students can take control of their own learning and follow their own learning paths (Chiang et al., 2014; Garzón et al., 2017; Klopfer, 2008).
- ✓ Students have been observed to have better learning performance, especially in science courses, when AR technology is implemented during the educational process (Chiang et al., 2014; Squire & Jan, 2007).
- ✓ AR games can be engaging for learning 21st century skills (Schrier, 2006).
- ✓ Students are motivated to learning and realize the relevance of their learning to their everyday lives and real-environment (Di Serio, Ibáñez & Kloos, 2013; Holley et al., 2016).
- ✓ Since AR is a very recent technology, it can make the studying experience fun and students have still positive attitudes as well as curiousness in using it (Wu et al., 2013).

Educational Process

- ✓ Educational activities can be implemented, including dangerous tasks (e.g. explosions), without consequences on the real environment (Garzón et al., 2017).
- ✓ Scientific disciplines including abstract or complex concepts that could not be accessed (such as microworlds) or explained, can be discovered (Akçayır et al., 2016; Garzón et al., 2017).
- ✓ Opportunities for more authentic learning are provided and it is appealing to multiple learning styles (Chiang et al., 2014; Klopfer & Sheldon, 2010).
- ✓ AR has the potential to bridge the gap between formal and informal learning (Wu et al., 2013, p.8).

5.4. What: Focus on STEM and AR/MR through the ELMG

Having personalized and located the ELMG, as well as having convinced the teachers to apply them in their instructional practices, a critical remaining question is "*what should teachers know in order to create their own Lesson Plans (LP) and AR/MR Learning Objects (LOs) within their STEM related courses*". There are two main axes here; the first one refers to STEM as an instructional approach and the second one refers to AR and MR as innovative technologies. These concepts are described in the following units.

5.4.1. STEM related concepts

STEM refers to an approach that overcomes the strict individual borders of Science, Technology, Engineering, and Mathematics and treats them as a "*single whole*" (Morrison, 2006). Sanders (2009, p.21) mentions that "*it will take a lot more than a four-letter word to bring them together*", when referring to STEM education. It has been expressed by EU policy makers (OECD, 2015) that the demand for STEM skills is expected to increase both in the short and medium term. According to Beers (2011), there is a natural match between the basic tenets of STEM and the 21st century skills. More specifically, "*exemplary science education can offer a rich context for developing many 21st-century skills, such as critical thinking, problem-solving, and information literacy*" (NSTA, 2011, p.1). These skills can provide students with life competences, leading them to more in-depth understanding of the subjects under study and allowing them to effectively "combine" the different disciplines in consideration (Binkley et al., 2012).

The research community has been "arguing" about the acronym of STEM (Jolly, 2014; Land, 2013; Robelen, 2011), while changing STEM to STEAM (most common - incorporating "Arts"), STEMM (incorporating "Music") or STREAM (incorporating both "Reading" and "Arts"), has initialized numerous discussions between experts (Miller & Kimmel, 2012; Sanders, 2009). The fact is that students need a well-rounded education to acquire 21st century skills, which could be achieved through interdisciplinary approaches to face real-life problems (Beers, 2011; Mishra & Kereluik, 2011). Real-life problems are composed of many disciplines, so it is not about adding any letter to the acronym, but instead, adding to the relevancy of learning and providing students with skills that will help them apply concepts in a real context (Bertram, 2014).

All these STEM approaches exist under the umbrella of an "integrated" approach, meaning there are no boundaries that prevent shared understanding of complex STEM-related individual topics (Stock & Burton, 2011). In particular, the terms cross-disciplinary, multi-disciplinary, inter-disciplinary and trans-disciplinary are the most commonly used in the literature (Burton, Rønningen & Wedderburn, 2008; Jensenius, 2012) to define the extent of integration and holism in a STEM approach.

- A **cross-disciplinary** approach refers to viewing one discipline from the perspective of another (Jensenius, 2012). The aim is not integration, but highlighting the aspects of one STEM discipline by means of studying the other.
- Within a **multi-disciplinary** approach, students work on a common problem but silo boundaries of the individual fields of STEM exist (Zhe, Doverspike, Zhao, Lam & Menzemer, 2010). Each student contributes to the final solution from a different perspective while there is no attempt to cross the boundaries and generate integrated knowledge.
- An **inter-disciplinary** approach could be considered as a step up from multidisciplinarity (Stock & Burton, 2011). Students work on a common "real-world" problem but in this case, they overlap disciplinary boundaries to create new knowledge, and jointly frame integrated solutions (Huutoniemi, Klein, Bruun & Hukkinen, 2010).

- Finally, **trans-disciplinarity** is an approach where "*a problem is faced through problems*" (Schmidt, 2008) by transcending disciplinary boundaries. This is probably a desirable approach but it is the most "utopian" one compared to the other approaches (Tress, Tress, Décamps & d'Hauteserre, 2001).

Stock and Burton (2011) mention that in practice, the most feasible approach seems to be the multi-disciplinary one, which corresponds to the lowest extent of integration and holism, while a trans-disciplinary approach (highest extent) is doubtful whether it could be achieved at all (Pohl, 2005).

Within the context of the EL-STEM project, STEM is adapted, not simply referring to the individual subjects of the acronym, but providing an engaging and interdisciplinary (or at least multidisciplinary) way of teaching and learning.

5.4.2. Understanding the differences between VR, AR, and MR

Milgram, Takemura, Utsumi and Kishino (1994) have defined the relationship between the different realities, by describing the "Reality-Virtuality Continuum" between the real and the virtual environment. Based on this continuum, Mixed Reality consists of "Augmented Reality - AR" and "Augmented Virtuality - AV", where AR is considered as the "infusion" of digital content within the real environment while AV is considered as the "transplantation" of a real-world into a virtual environment. However, in the literature, Augmented Reality is the prevailing term (Garzón, Pavón & Baldiris, 2017; Wu et al., 2013).

Virtual Reality (VR) was introduced in education about three decades ago in professions mostly related to medicine and industry (Helsel, 1992; Wickens, 1992). It was about ten years later when it became very popular in education, through commonly used software such as "OpenSim" and "Second Life" (Dickey, 2005). Today, AR is a technology receiving increased attention and interest within the educational process, while MR seems to be the future of AR, still not widely exploited within the field of education. Taking into consideration the crucial role of laboratories within STEM related courses, in order to suggest an effective implementation of AR/MR technologies within a school environment, it is important to understand the definitions and main differences of these technologies (Billinghurst, Clark & Lee, 2015) (Figure 3):

- **Virtual Reality (VR)** is a digital world, fully accessible and exploitable through a computer device, where the users are completely isolated from the real world. Nothing is real within this "reality" but everything is virtual (digital).
- **Augmented Reality (AR)** consists of the real world "supplemented" by digital objects, where the users can interact with them, but the objects are obviously not part of the real world (they are on top). It is actually a layer on top of the existing reality, not integrated into it.
- **Mixed Reality (MR)** is the real world with digital objects integrated, where all the users' senses are enabled, and it looks like if the content interacts with the real world as real part of it instead of a layer on top of it. Users have the illusion that real and digital is a unity and they can interact with it.

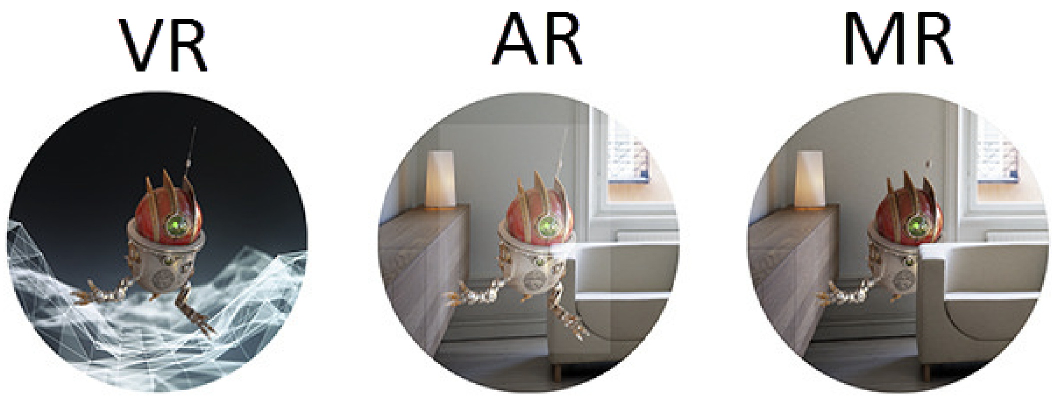

Figure 3: The environment and object representation within VR, AR, MR
(Image Source: Magic Leap)

There is also a main difference when referring to the equipment needed to interact with each of the above-mentioned technologies. VR is accessible through 3D glasses or simply through a computer device. There are some VR headsets which are designed to be used while sitting in front of a monitor and moving through the virtual space with a handheld controller, similarly to a video game (Dachis, 2017). These headsets require both a computer (to be cabled into) and a separate controller to function.

AR equipment varies a lot, including headsets, sensors etc., but "*the most common use is pretty straightforward: the screen of our smartphones*" (Dachis, 2017) and in some cases the screen of a tablet. AR became known to the public through the *Pokemon Go* Game, when users got out of the isolation of a computer's monitor and started chasing Pokemons "*on top of the real world*", using their smartphones to view and catch them (Clark & Clark, 2016). While AR headsets certainly fall into this category, the most common usage of AR is a layer on top of the smartphone's field of view, through the existing camera, while the visualization can't be interacted with as part of the real environment, but only through the smartphone's screen (Dachis, 2017).

MR is the next level, the future of AR. Since MR refers to the ability to mix digitally rendered objects into the real environment, it needs more specific equipment to interact with, including headsets, sensors and in some cases, even whole rooms where the real and virtual content seem to be a single entity (Figure 4; Georgieva, 2016). Unlike AR, when referring to MR the visualization can be interacted with as part of the real environment without any mediating device, just the users' bare hands.

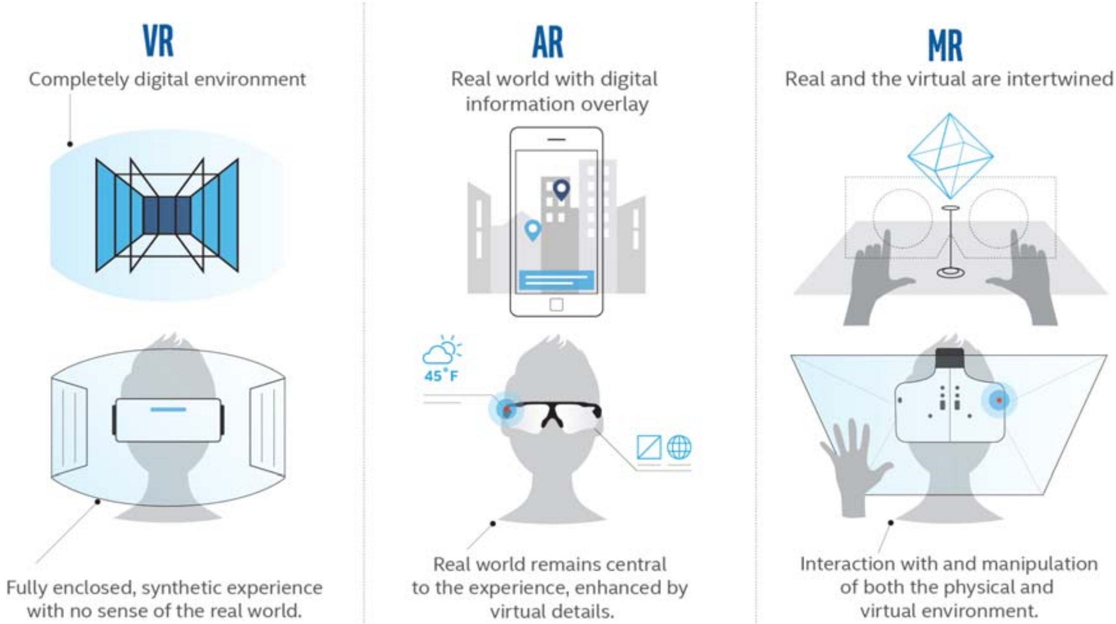

Figure 4: Equipment and interaction within VR, AR, MR
(Image Source: https://jelvix.com/blog/vr-vs-ar-vs-mr)

It is important to mention that these technologies are still not clearly distinguished from each other within the bibliography especially when referring to educational applications. VR in education was initially mentioned in the early '90s while AR timidly appeared in the early 2000s and has recently become more popular. MR is a dynamic field still under research and further construction, thus there are not many showcases of MR integration within schools yet. Reality-altering terminology gets confusing sometimes as they are still fluid concepts and the different technologies and relative equipment definitely overlap (Dachis, 2017). Within IO1 the affordances and features of AR/MR are explained based on existing research in the field of AR/MR within education.

Considering the EL-STEM project, it is important that partners and the target groups involved (teachers, students, stakeholders etc.) realize the main differences between these technologies and are able to recognize them. As mentioned above, these technologies overlap, and this is why AR/MR is mentioned within the project's outputs and results. However, taking into consideration the fact that the current state of MR is still under development and the costs of adapting such technologies are still high, the aim of EL-STEM is to integrate AR within the educational process and set the fundamentals for future research and development, concerning MR within education. To sum up, **VR** could be considered as **the past** that EL-STEM is willing **to go beyond**, **AR the present** that EL-STEM is willing **to reclaim as an innovative solution** and finally, **MR the future** that EL-STEM is willing **to invest in**.

5.4.3. Laboratories within STEM education

Laboratories are being given a central and distinctive role within STEM education while experiments constitute a critical part of STEM related courses and they promote better understanding of the taught theories among students (Clough, 2002). There are several potential benefits to adapting laboratories, including (a) the attraction of students' interest and (b) the provision of multiple opportunities for the acquisition of practical knowledge (Krneta, Restivo, Rojko & Urbano, 2016). Within this field, there is a significant number of studies (Nedic, Machotka & Nafalski, 2003; Odeh, Abu Shanab & Anabtawi, 2015; Heradio et al., 2016; Lasica et al., 2016) concerning the different types of laboratories depending on their location (local and remote) and type of technology (real, virtual, augmented) (Figure 5). These studies point to the need of employing a combination of the different types of laboratories during the different phases of an educational process, such as preparation, live lectures that involve experimentation, repetitive experimentation etc. (Heradio et al., 2016). In addition, there are studies that highlight the potential of remote, virtual and augmented reality labs on the enhancement of the educational process, especially within e-learning and blended learning environments (Radhamani et al., 2014). A worth mentioning federation of online labs is the Go-Lab Sharing Platform (https://www.golabz.eu/), which consists of a huge repository with authoring tools to build learning scenarios (de Jong, Sotiriou, & Gillet, 2014). It is a well-known European initiative which provides a large collection of quality-proven remote and virtual laboratories, shared by renowned research institutions and technology providers from all over the world.

There is also remarkable research that highlights the positive and negative aspects of using each lab category within the educational process (Gomes & Bogosyan, 2009; Radhamani et al., 2014; Chiu, DeJaegher & Chao, 2015; Lasica et al., 2016). Real local laboratories are the most popular type, still traditionally used in schools, preferred mainly for younger ages (e.g. kindergarten, first classes of primary education) (Ma & Nickerson, 2006). However, critical issues such as high maintenance costs, accessibility, availability and safety (Gomes & Bogosyan, 2009) increased the need for remoteness and virtuality. As mentioned by Hofstein & Lunetta (2004) "remoteness" gave a partial solution to the above-mentioned issues. Moreover, it was "virtuality" that gave additional solutions to some STEM sciences (e.g. chemistry, biology) where it was necessary to represent elements and phenomena in non-accessible levels (e.g. atoms, molecules, cells) which were not visible with the basic equipment available in most laboratories (Gabel, 1999).

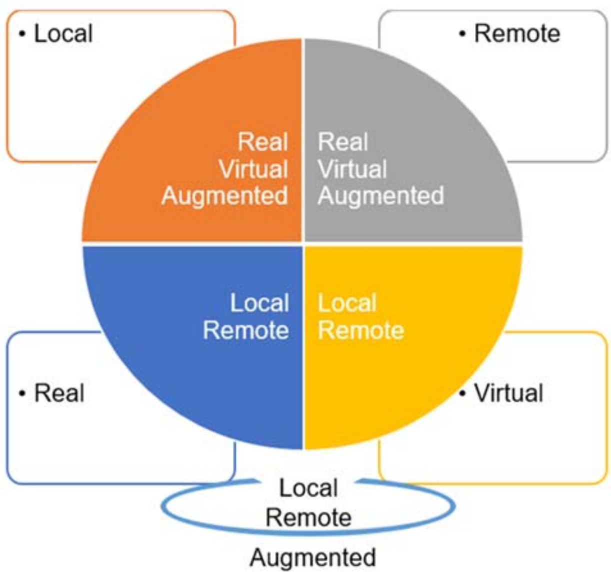

Figure 5: Different types of laboratories presented by Lasica et al. (2016)

Despite the benefits of virtual environments, the fact that they are imitations of reality and visualize experiments and their components graphically, could make it difficult for students to face real work circumstances in the future (Odeh, 2014). Through the virtualization of STEM topics some students could actually have an illusion to some degree of understanding the natural phenomena and focus on superficial elements instead of in-depth study (Chiu, Chen & Linn, 2013). In addition, virtual labs rarely satisfy social skills of students (Jara et al., 2009). AR came as a solution to the weaknesses of virtual laboratories, augmenting the real environment with virtual elements (Odeh, 2014) or vice versa (Chiu, DeJaegher & Chao, 2015). Bringing AR technologies into local and remote labs within STEM education is an efficient way to achieve better learning outcomes (Radhamani et al., 2014), and to attract students to STEM related fields of study and careers (Krneta et al., 2016). AR labs overcome the issue of misunderstanding differences between real and virtual worlds, however, they are still immature, since they have recently entered the educational field (Ma & Choi, 2007). MR labs could enhance AR ones, adding the dimension of interaction both with the objects of the laboratory and the students implementing the experiment.

Within this framework, the EL-STEM project will design, develop, pilot test, and implement local and/or remote "*Enlivened Laboratories*", including Open Educational Resources for teachers and students across Europe and beyond to visit, learn, enjoy and contribute. The aim is to augment the AR/MR experience with rich media content, increasing the engagement within STEM education. The platform will be initially seeded with AR/MR contents produced by the project's partners, but will soon become a dynamic portal integrating new AR/MR contents produced by teachers and students using the relative library. Gamification methods will be applied to stimulate engagement around the AR/MR tools and resources. The Enlivened Laboratories will also be accompanied by social communication tools to foster the creation of EU communities of "*AR STEM Teachers*" and "*AR STEM Students*", while social media style tools will be offered for end-users to interact with each other, allowing them to comment, share, provide feedback, etc. Moreover, content creators will be challenged to create more impactful and higher quality content, with the rating system adding a gamified layer to the Enlivened Laboratories platform.

5.4.4. Case studies of AR/MR in STEM education

Since 2010, when Augmented Reality was integrated as a technology into common mobile devices (smartphones, tablets etc.), there has been an increasing interest in applying AR in the educational process (Akçayir & Akçayir, 2017). This access to AR offers new learning opportunities but, at the same time, creates new challenges for both teaching and learning. There is already a wide range of emerging AR educational applications including skills training, discovery-based learning, AR gaming, modelling objects and AR books (Figure 6). STEM education is a field of high interest when referring to the studies that have already been implemented concerning AR integration within the educational process (Chen, Liu, Cheng & Huang, 2017), while more than 45% of the existing studies have been implemented in the context of STEM-related courses (Bacca, Baldiris, Fabregat, Graf & Kinshuk, 2014).

Figure 6: Augmented Reality in education
(Image Source: https://www.slideshare.net/kehamilt/augmented-reality-in-education)

Since AR is still a technology under development, most AR educational applications are marker-based[5] (Bacca et al., 2014), which is a stable technique. These applications usually include AR interactive books (Dünser, Walker, Horner & Bentall, 2012; Holley, Hobbs & Menown, 2016) and objects modelling emerging from educational objects such as worksheets, notebooks, AR cards (McGrath, Craig, Bock & Rocha, 2011; Wagner & Barakonyi, 2003) and objects in STEM laboratories (Akçayır, Akçayır, Pektaş & Ocak, 2016; Andujar, Mejías & Márquez, 2011; Vargas, Farias, Sanchez, Dormido & Esquembre, 2013). Recently, many science museums and/or exhibitions of educational interest have included AR experiences to bring their exhibits to life and to engage students in discovering and learning additional information about what they see (Yoon, Elinich, Wang, Steinmeier & Tucker, 2012). These kinds of applications advance inquiry-based learning as students can retrieve additional information on the content they are interested in and interact with 3D models through actions such as rotation, customization etc.

Marker-less AR[6] is still lagging behind in educational applications, because of its complexity. It is expected that marker-less AR will be widely exploited within education in the future (Garzón et al., 2017), promoting AR gaming (Klopfer & Sheldon, 2010; Li, van der Spek, Feijs, Wang & Hu, 2017; Lv, Halawani, Feng, Ur Réhman & Li, 2015) and skills training (Chiang, Yang & Hwang, 2014; Thornton & Ernst, 2012). Moreover, explaining abstract and difficult concepts within the context of STEM-related courses, could be enhanced through marker-less AR applications, since the restriction of using images encapsulated within markers could be overcome.

There are also some location-based AR[7] educational applications, enhancing the interaction with the real mobile learning environment of a student (Chang & Tan, 2010; Ebling & Cáceres, 2010; Kamarainen et al., 2013; Squire & Jan, 2007). These AR applications could be used in

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[5] Type of AR based on the use of visual cues that trigger the display of the virtual information (Park & Park, 2004). These visual cues could be labels with coloured or black and white patterns, recognized by AR applications.

[6] Type of AR based on the recognition of the objects' shapes (also known as object-based AR). It allows more complex applications of AR, since it overcomes the interactivity limitations placed on the range of images encapsulated within markers (Beier, Billert, Bruderlin, Stichling & Kleinjohann, 2003).

[7] Type of AR where the information is superimposed based on the geographical location of the user, detected through the GPS sensor of a mobile device (Bacca et al., 2014).

wider contexts, including "learning out of the classroom", providing students with on-the-spot information and additional knowledge.

Within the context of the EL-STEM project, an AR/VR game in the field of STEM will be designed and developed. The aim is to evaluate the feasibility of teachers utilizing advanced development tools like Unity in secondary STEM Education.

5.5. How: Using the ELMG to teach STEM integrating AR/MR

The final critical question to answer is "how could teachers apply the ELMG to create their own AR/MR Learning Objects (LOs) and Lesson Plans (LP) within their STEM related courses". Respectively to the "what" question, there are also two main axes here. The first one refers to the pedagogical theories of implementing a STEM approach as well as integrating AR/MR technologies into the educational process. These could be part of the total guidelines on how to create a lesson plan in this context. The second one refers to the "tools", including applications and software that could be used to design and create an AR/MR LO. These guidelines are described in the following sections.

5.5.1. How to create a Lesson Plan supported by AR/MR

In the context of the EL-STEM project, it is suggested that the ELMG are applied by preparing appropriate Lesson Plans (LP), that could be designed to teach a STEM-related topic in a location defined by the teacher (as described in 5.2). A general template of a LP is provided in APPENDIX A: LESSON PLAN TEMPLATE. The steps to create a Lesson Plan have been defined by the teachers themselves during the teacher trainings as follows (Figure 7):

Figure 7: Steps to create a Lesson Plan supported by AR/MR

Wu et al. (2013) have highlighted some critical pedagogical issues that need to be taken into consideration when AR technology is integrated into a classroom. The educational activities implemented through AR are mainly based on innovative approaches, such as game-based learning, place-based learning, participatory simulations, inquiry-based learning, problem-based learning, role-playing, studio-based pedagogy, and jigsaw method. Based on these approaches, Wu et al. (2013) categorize the instructional designs used to integrate AR in the educational process into three main dimensions: (a) emphasizing the "roles", where students get into a role and collaborate with others to achieve a learning outcome, (b) emphasizing the "locations", where students interact in the physical environment, getting a sense of authenticity, and (c) emphasizing the "tasks", where students need to complete different tasks either on their own or in collaboration with others, through a problem-solving situation. Taking these into consideration, in the "Instructional Strategies" part of the LP, the "Instructional Design for using MR/AR in inquiry-based STEM learning" suggested in IO1 could be applied, combining the inquiry-based learning with the contemporary learning approach, emphasizing the students' "tasks" in a problem-based situation.

Based on the LP template and emphasizing on the students' tasks, in the "Learning Activities" part of the LP, teachers could describe the different tasks of the inquiry-based learning phases, including Orientation, Conceptualization, Investigation, Conclusion and Discussion. These phases could also be enriched with learning objects decided by the teacher (more details in the following section).

5.5.2. How to create an AR/MR Learning Object

Digital learning objects include many interesting and engaging activities that invite the learners to experiment with the educational content. **The key to create a successful learning object is to respond to one learning objective at a time.** An **AR/MR Learning Object** is a digital object created with any AR application/tool selected by the teacher, to implement educational tasks supported by AR/MR technologies.

According to research, a great way to explain the concept of a learning object is to use the analogy of the LEGO™ building blocks: **small units that can be fitted together any number of ways to produce customized learning experiences** (Hodgins & Conner, 2000). The New Media Consortium (NMC) describes learning objects as follows: *"***a learning object is any grouping of materials that is structured in a meaningful way and is tied to an educational objective***"*. The "materials" in a learning object can be documents, pictures, simulations, movies, sounds, and so on. The steps to create an AR/MR Learning Object have been defined by the teachers themselves during the teacher trainings as follows:

STEP 1: Choose the learning objective of your Lesson Plan you want to focus on and think of a scenario for your Learning Object.

STEP 2: Select one of the **Tools for AR/MR** suggested by EL-STEM (or one of your choice) to create your own AR/MR Learning Object OR use an existing AR/MR Learning Object.

STEP 3: Use the relevant manuals to create your own AR/MR Learning Object.

STEP 4: Pilot and receive feedback concerning the AR/MR Learning Object.

STEP 5: Share your AR/MR Learning Object with the EL-STEM online community!

5.6. Useful Tips for applying AR in STEM-courses and promoting the ELMG

The following tips for applying AR in STEM-courses and promoting the ELMG have been developed in collaboration with the EL-STEM consortium and the teachers during the teachers' trainings and the pilots:

- show **additional content** on your students' books (NOT ONLY engagement, curiosity, but also, critical thinking, inquiry, exploration)

(e.g. 3D objects, videos, images, additional information created with an AR tool, interactive material).

- provide **tips** and/or **solutions** for students' worksheets/ classroom exercises/ homework.

(e.g. voice tips provided with AR on specific activities on a worksheet, theory from the school text-books, some formulas to reach a result).

- add **quizzes (or even better AR activities)** at different points of a total lesson plan either as a previous knowledge reminder or current knowledge evaluation.
- organize **competitions/games**

(e.g. hidden treasure, hide AR trigger images in different places in, or even out of the class, and motivate your students to find the hidden knowledge!).

- enhance **STE(A)M**

(e.g. include AR content from different subjects during a course, such as an avatar of Einstein reminding something concerning physics while students are taught mathematics).

- enhance **inquiry-based learning**

(e.g. include AR content at different points of a classroom or book or other objects of a laboratory, allowing students to investigate and reach their own results on a specific topic).

- **posters/ exhibitions** with the summary (revision) of the school year (or shorter time). Let your students have the role of a creator! They will have to understand the topics first and then present them!
- **self presentation**… Let them present their results/conclusions on their own way!

6. Conclusion

This report has presented the Enlivened Laboratory Methodological Guidelines (ELMG). The ELMG, which are primarily addressed to secondary education teachers across Europe, provide educators with guidance on how to apply the methodology of the Enlivened Laboratories (EL-STEM), in order to create their own Lesson Plans and AR/MR LOs within STEM related courses. They respond to core questions, including (i) whom they are addressed to and to whom they can be applied, (ii) where they could be implemented, (iii) why they should be applied within the context of STEM-related disciplines, (iv) what approaches and tools could be used and finally, (v) how they could be generated to teach STEM-related disciplines in secondary education using AR/MR technologies.

The ELMG constitute an innovative inquiry-based approach for teachers on addressing the main target group (students aged 12-18) with respect to diversity and accessibility, by providing attractive STEM education and training programmes, in line with learners' individual needs and expectations.

REFERENCES

About TIMSS 2015. (2015). Retrieved from http://timssandpirls.bc.edu/timss2015/international-results/timss-2015/about-timss-2015/

Akçayir, M., & Akçayir, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1-11.

Akçayır, M., Akçayır, G., Pektaş, H. M., & Ocak, M. A. (2016). Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior*, *57*, 334-342.

Allen, W. C. (2006). Overview and evolution of the ADDIE training system. *Advances in Developing Human Resources*, *8*(4), 430-441.

Allen, M. (2012). *Leaving ADDIE for SAM: An agile model for developing the best learning experiences*. American Society for Training and Development.

Andujar, J. M., Mejías, A., & Márquez, M. A. (2011). Augmented reality for the improvement of remote laboratories: an augmented remote laboratory. *IEEE transactions on education*, *54*(3), 492-500.

Amado, M., Ashton, K., Ashton, S., Bostwick, J., Clements, G., Darnall, R., Drysdale, J., Francis, J., Harrison, B., Nan, V. & Nisse, A. (2011). Project management for instructional designers. *Retreived from http://pm4id. org*.

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology & Society*, *17*(4), 133-149.

Beers, S. (2011). 21st century skills: Preparing students for their future. Retrieved from https://cosee.umaine.edu/files/coseeos/21st_century_skills.pdf.

Beier, D., Billert, R., Bruderlin, B., Stichling, D., & Kleinjohann, B. (2003). Marker-less vision based tracking for mobile augmented reality. In *Proceedings of the Second IEEE and ACM International Symposium on Mixed and Augmented Reality* (pp. 258-259). IEEE Computer Society.

Bertram, V. (2014). STEM or STEAM? We're missing the point. *HuffPost Education*.

Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. *Foundations and Trends® in Human–Computer Interaction*, *8*(2-3), 73-272.

Binkley, M. et al. (2012) Defining Twenty-First Century Skills. In: Griffin P., McGaw B., Care E. (eds) *Assessment and Teaching of 21st Century Skills* (pp. 17-66). Dordrecht, Netherlands: Springer, Cham.

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education–cases, places and potentials. *Educational Media International*, *51*(1), 1-15.

Bronack, S. C. (2011). The role of immersive media in online education. *The Journal of Continuing Higher Education*, *59*(2), 113-117.

Burton, R., Rønningen, K., & Wedderburn, L. (2008). *Conducting integrated research: a critical literature review of interdisciplinary and transdisciplinary research*. Report 12/08. Trondheim: Centre for Rural Research, Norwegian University of Science and Technology.

Caralee, A. (2017, February 23). The 7 Most Important STEM Skills We Should Be Teaching Our Kids. Retrieved from https://www.weareteachers.com/important-stem-skills-teaching-kids/

Chang, W., & Tan, Q. (2010, December). Augmented reality system design and scenario study for location-based adaptive mobile learning. In *Computational Science and Engineering (CSE), 2010 IEEE 13th International Conference on* (pp. 20-27). IEEE.

Chen, P., Liu, X., Cheng, W., & Huang, R. (2017). A review of using Augmented Reality in Education from 2011 to 2016. In *Innovations in Smart Learning* (pp. 13-18). Springer Singapore.

Chiang, T. H., Yang, S. J., & Hwang, G. J. (2014). An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities. *Journal of Educational Technology & Society*, *17*(4), 352.

Chiu, J. L., Chen, J. K., & Linn, M. C. (2013). Overcoming deceptive clarity by encouraging metacognition in the web-based inquiry science environment. In *International handbook of metacognition and learning technologies* (pp. 517-531). Springer New York.

Chiu, J. L., DeJaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. *Computers & Education*, *85*, 59-73.

Clark, A. M., & Clark, M. T. (2016). Pokémon Go and Research: Qualitative, Mixed Methods Research, and the Supercomplexity of Interventions.

Clough, M. P. (2002). Using the laboratory to enhance student learning. *Learning science and the science of learning*, 85-94.

Cooperstock, J. R. (2001). The classroom of the future: enhancing education through augmented reality. In *Proc. HCI Inter. 2001 Conf. on Human-Computer Interaction* (Vol. 1, pp. 688-692).

Crawford, L., & Pollack, J. (2007). How generic are project management knowledge and practice. *ERA-Engineering and Environmental Sciences*, 22.

Dachis, A. (2017). What's the Difference Between AR, VR, and MR?. Retrieved from https://next.reality.news/news/whats-difference-between-ar-vr-and-mr-0171163/.

de Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: the Go-Lab federation of online labs. *Smart Learning Environments*, *1*(1), 3.

Delello, J. A. (2014). Insights from pre-service teachers using science-based augmented reality. *Journal of computers in education*, *1*(4), 295-311.

Di Serio, Á., Ibáñez, M. B., & Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education*, *68*, 586-596.

Dickey, M. D. (2005). Three-dimensional virtual worlds and distance learning: two case studies of Active Worlds as a medium for distance education. *British journal of educational technology*, *36*(3), 439-451.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22.

Dünser, A., Walker, L., Horner, H., & Bentall, D. (2012, November). Creating interactive physics education books with augmented reality. In *Proceedings of the 24th Australian computer-human interaction conference* (pp. 107-114). ACM.

Ebling, M. R., & Cáceres, R. (2010). Gaming and augmented reality come to location-based services. *IEEE Pervasive Computing*, *9*(1), 5-6.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education*, *59*(2), 423-435.

EU Commission. (2016). *Education and Training Monitor*. Directorate-General for Education and Culture.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical education*, *76*(4), 548.

Garzón, J., Pavón, J., & Baldiris, S. (2017, June). Augmented Reality Applications for Education: Five Directions for Future Research. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 402-414). Springer, Cham.

Georgieva, M. (2016). *Off to Educause: VR, Visual Culture and Future Trends in Learning*. Retrieved from https://www.digitalbodies.net/learning/educause-vr-visual-culture-future-trends-learning.

Gomes, L., & Bogosyan, S. (2009). Current trends in remote laboratories. *IEEE Transactions on industrial electronics*, *56*(12), 4744-4756.

Grek, S. (2009). Governing by numbers: The PISA 'effect'in Europe. *Journal of education policy*, *24*(1), 23-37.

Haller, M. (2004). Mixed Reality@ Education. In *Multimedia Applications in Education Conference, MApEC* (Vol. 2004, p. 13).

Helsel, S. (1992). Virtual reality and education. *Educational Technology*, *32*(5), 38-42.

Heradio, R., de la Torre, L., Galan, D., Cabrerizo, F. J., Herrera-Viedma, E., & Dormido, S. (2016). Virtual and remote labs in education: A bibliometric analysis. *Computers & Education*, *98*, 14-38.

Hodgins, W., & Conner, M. (2000). Everything you ever wanted to know about learning standards but were afraid to ask. *Learning in the New Economy e-Magazine (LiNE Zine)*.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science education*, *88*(1), 28-54.

Holley, D., Hobbs, M., & Menown, C. (2016). The Augmented Library: Motivating STEM Students. *Networks*, *19*, 77-84.

Hu, R., Wu, Y. Y., & Shieh, C. J. (2016). Effects of virtual reality integrated creative thinking instruction on students' creative thinking abilities. *Eurasia Journal of Mathematics, Science and Technology Education*, *12*(3), 477-486.

Huutoniemi, K., Klein, J. T., Bruun, H., & Hukkinen, J. (2010). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, *39*(1), 79-88.

Jara, C. A., Candelas, F. A., Torres, F., Dormido, S., Esquembre, F., & Reinoso, O. (2009). Real-time collaboration of virtual laboratories through the Internet. *Computers & Education*, *52*(1), 126-140.

Jensenius, A. R. (2012). Disciplinarities: intra, cross, multi, inter, trans. Retrieved from http://www.arj.no/2012/03/12/disciplinarities-2/.

Johnson, L. F., & Levine, A. H. (2008). Virtual worlds: Inherently immersive, highly social learning spaces. *Theory Into Practice*, *47*(2), 161-170.

Jolly, A. (2014). STEM vs. STEAM: Do the arts belong. Education Week, 18.

Kamarainen, A. M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, *68*, 545-556.

Kaufmann, H. (2003). Collaborative augmented reality in education. *Institute of Software Technology and Interactive Systems, Vienna University of Technology*.

Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. MIT press.

Klopfer, E., & Sheldon, J. (2010). Augmenting your own reality: Student authoring of science-based augmented reality games. *New Directions for Student Leadership*, *2010*(128), 85-94.

Krneta, R., Restivo, M. T., Rojko, A., & Urbano, D. (2016). Evaluation of remote experiments by different target groups: NeReLa project case study. In *Remote Engineering and*

Virtual Instrumentation (REV), 2016 13th International Conference on (pp. 326-331). IEEE.

Land, M. H. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. Procedia Computer Science, 20, 547-552.

Lasica, I. E., Katzis, K., Meletiou-Mavrotheris, M., & Dimopoulos, C. (2016). Research Challenges in future laboratory-based STEM Education. *Bulletin of the IEEE Technical Committee on Learning Technology*, *18*(1), 2.

Lasica, I. E., Meletiou-Mavrotheris, M., Katzis, K., Dimopoulos, C. & Mavrotheris E. (2018). Designing a Teacher Training Program on the integration of Augmented and Mixed Reality technologies within the educational process. In *12th annual International Technology, Education and Development Conference*, Valencia, Spain.

Lee, K. (2012). The Future of Learning and Training in Augmented Reality. *InSight: A Journal of Scholarly Teaching*, *7*, 31-42.

Li, D., & Shearer, R. (2005). Project management for online course development. *Distance Learning*, *2*(4), 19-23.

Li, J., van der Spek, E. D., Feijs, L., Wang, F., & Hu, J. (2017, July). Augmented Reality Games for Learning: A Literature Review. In *International Conference on Distributed, Ambient, and Pervasive Interactions* (pp. 612-626). Springer, Cham.

Lv, Z., Halawani, A., Feng, S., Ur Réhman, S., & Li, H. (2015). Touch-less interactive augmented reality game on vision-based wearable device. *Personal and Ubiquitous Computing*, *19*(3-4), 551-567.

Ma, J. Y., & Choi, J. S. (2007). The Virtuality and Reality of Augmented Reality. *Journal of multimedia*, *2*(1), 32-37.

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. *ACM Computing Surveys (CSUR)*, *38*(3), 7.

Magic Leap. (2017). *Magic Leap's Official Website*. Retrieved from https://www.magicleap.com.

Martin, M. O., Mullis, I. V., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 International Results in Science*. International Association for the Evaluation of Educational Achievement. Herengracht 487, Amsterdam, 1017 BT, The Netherlands.

Martín-Gutiérrez, J., & Contero, M. (2011). Improving academic performance and motivation in engineering education with augmented reality. *HCI International 2011–Posters' Extended Abstracts*, 509-513.

McDaniel, K., & Liu, M. (1996). A study of project management techniques for developing interactive multimedia programs: A practitioner's perspective. *Journal of Research on Computing in Education*, *29*(1), 29-48.

McGrath, R. E., Craig, A. B., Bock, D., & Rocha, R. (2011). *Augmented Reality for an Ethnobotany Workbook*.

McNair, C. L., & Green, M. (2016). Preservice Teachers' Perceptions of Augmented Reality.

Meletiou-Mavrotheris, M. (2019). Augmented Reality in STEAM Education. In M. A. Peters, & R. Heraud (Eds.), *Encyclopedia of Educational Innovation* (pp. 1-6). Springer Nature, Singapore.

Meletiou-Mavrotheris, M., Mavrou, K., Vaz-Rebelo, P., Santos, S., Tenhonen, P., Riska, M., Sundstrom, M. & Pilt, L. (2017) Technology Adoption in Higher Education: A Cross-National Study of University Faculty Perceptions, Attitudes, and Practices. In P. Tripathi, & S. Mukerji (Eds), *Technology-Centric Strategies for Higher Education Administration* (pp. 295-317), Hershey, PA: IGI Global.

Meletiou-Mavrotheris, M., Paparistodemou, E., & Christou, C.M. (2019). Integrating Mobile Devices in the Mathematics Curriculum: A Case Study of a Primary School in Cyprus. *International Journal of Mobile and Blended Learning*, *11*(3), 19-37.

Meletiou-Mavrotheris, M., & Prodromou, T. (2016). Pre-Service Teacher Training on Game-Enhanced Mathematics Teaching and Learning. *Technology, Knowledge and Learning (TKNL)*, *21*(3), 379-399.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994, October). Augmented reality: A class of displays on the reality-virtuality continuum. In *Telemanipulator and telepresence technologies* (Vol. 2351, No. 11, pp. 282-292).

Miller, J. D., & Kimmel, L. G. (2012). Pathways to a STEMM profession. *Peabody Journal of Education*, *87*(1), 26-45.

Mishra, P., & Kereluik, K. (2011). What 21st century learning? A review and a synthesis. In *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 3301-3312).

Molenda, M. (2003). In search of the elusive ADDIE model. *Performance improvement*, *42*(5), 34-37.

Morrison, J. (2006). TIES STEM education monograph series, attributes of STEM education. *Baltimore, MD: TIES*.

Nedic, Z., Machotka, J., & Nafalski, A. (2003). *Remote laboratories versus virtual and real laboratories* (Vol. 1, pp. T3E-T3E). IEEE.

NSTA - National Science Teacher Association. (2011). Quality Science Education and 21st-Century Skills. Retrieved from http://static.nsta.org/pdfs/PositionStatement_21stCentury.pdf.

Odeh, S. (2014). A Web-Based Remote Lab Platform with Reusability for Electronic Experiments in Engineering Education. *International Journal of Online Engineering*, *10*(4).

Odeh, S., Abu Shanab, S., & Anabtawi, M. (2015). Augmented Reality Internet Labs versus its Traditional and Virtual Equivalence. *International Journal of Emerging Technologies in Learning*, *10*(3).

OECD. (2015). EU Skills Panorama 2014 - STEM skills Analytical Highlight. *Organisation for Economic Co-Operation and Development Publications*.

OECD. (2016). *Education at a Glance 2016*. Organization for Economic.

Panorama, E. S. (2016). STEM skills analytical highlight. *ICF and Cedefop for the European Commission*, *19*.

Park, H., & Park, J. I. (2004, November). Invisible marker tracking for AR. In *Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality* (pp. 272-273). IEEE Computer Society.

PISA 2015: Full selection of indicators. (2015). Retrieved from http://gpseducation.oecd.org/IndicatorExplorer

Pohl, C. (2005). Transdisciplinary collaboration in environmental research. *Futures*, *37*(10), 1159-1178.

Radhamani, R., Sasidharakurup, H., Sujatha, G., Nair, B., Achuthan, K., & Diwakar, S. (2014). Virtual labs improve student's performance in a classroom. In *International Conference on E-Learning, E-Education, and Online Training* (pp. 138-146). Springer, Cham.

Rimmer, T. (2016). An Introduction to SAM for Instructional Designers. E-learning Heroes. Retrieved from https://community.articulate.com/articles/an-introduction-to-sam-for-instructional-designers.

Robelen, E. W. (2011). STEAM: Experts make case for adding arts to STEM. *Education week*, *31*(13), 8.

Sanders, M.E. (2009). STEM, STEM education, STEMmania. *The Technology Teacher* (pp. 20-26). Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEMmania.pdf?sequence=1&isAllowed=y.

Schleicher, A., Zimmer, K., Evans, J., & Clements, N. (2009). PISA 2009 Assessment Framework: Key Competencies in Reading, Mathematics and Science. *OECD Publishing (NJ1)*.

Schmidt, J. C. (2008). Towards a philosophy of interdisciplinarity. *Poiesis & Praxis*, *5*(1), 53-69.

Schrier, K. (2006, July). Using augmented reality games to teach 21st century skills. In *ACM SIGGRAPH 2006 Educators program* (p. 15). ACM.

Shelton, B. E. (2002). Augmented reality and education: Current projects and the potential for classroom learning. *New Horizons for Learning*, *9*(1).

Squire, K. D., & Jan, M. (2007). Mad City Mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of science education and technology*, *16*(1), 5-29.

Stock, P., & Burton, R. J. (2011). Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. *Sustainability*, *3*(8), 1090-1113.

Stubbs, S. (2002). How did you manage to do that? An instructional multimedia production management process. *Journal of Interactive Instruction Development*, *14*(4), 25-32.

Tall, T. (2017, October). Augmented Reality vs. Virtual Reality vs. Mixed Reality – An Introductory Guide. Retrieved from https://www.toptal.com/designers/ui/augmented-reality-vs-virtual-reality-vs-mixed-reality.

Thornton, T., & Ernst, J. V. (2012). Augmented reality as a visual and spatial learning tool in technology education. *Technology and Engineering Teacher*, *71*(8), 18.

Tienken, C. H. (2013). Conclusions from PISA and TIMSS testing. *Kappa Delta Pi Record*, *49*(2), 56-58.

Tress, B., Tress, G., Décamps, H., & d'Hauteserre, A. M. (2001). Bridging human and natural sciences in landscape research.

Vargas, H., Farias, G., Sanchez, J., Dormido, S., & Esquembre, F. (2013). Using augmented reality in remote laboratories. *International Journal of Computers Communications & Control*, *8*(4), 622-634.

Walker, M. (2011). PISA 2009 Plus Results: Performance of 15-year-olds in reading, mathematics and science for 10 additional participants.

Wickens, C. D. (1992, October). Virtual reality and education. In *Systems, Man and Cybernetics, 1992., IEEE International Conference on* (pp. 842-847). IEEE.

Williams van Rooij, S. (2010). Instructional Design and Project Management: Which Competencies are Which?. In *33rd Annual Proceedings of the Association for Educational Communications and Technology (AECT)* (vol 1, pp. 249-258).

Woodward, L., & Hutchison, A. C. (2016). *A Look at the Technology Integration Planning Cycle*. Iowa Reading Research Center. Retrieved from https://iowareadingresearch.org/a-look-at-the-technology-integration-planning-cycle.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41-49.

Yang, C. S., Moore, D. M., & Burton, J. K. (1995). Managing courseware production: An instructional design model with a software engineering approach. *Educational Technology Research and Development*, *43*(4), 60-70.

Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Tucker, S. (2012). Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. *International Journal of Computer-Supported Collaborative Learning*, *7*(4), 519-541.

Zhe, J., Doverspike, D., Zhao, J., Lam, P., & Menzemer, C. (2010). High school bridge program: A multidisciplinary STEM research program. *Journal of STEM Education: Innovations and Research*, *11*(1/2), 61.

APPENDIX A: LESSON PLAN TEMPLATE

<table>
<tr><th colspan="3">Lesson Plan Information</th></tr>
<tr><td colspan="2">STEM Disciplines:</td><td>Curriculum alignment:</td></tr>
<tr><td colspan="2">Topic:</td><td>Duration:</td></tr>
<tr><td>Teachers:</td><td>Age Range:</td><td>Language:</td></tr>
<tr><td colspan="3">Prior Knowledge and Skills Needed
(Prior knowledge is the knowledge the learner already has before they meet new information)</td></tr>
<tr><td colspan="3">What prior experiences, knowledge and skills do the learners bring with them to this learning experience?
e.g.
ICT skills,
specific knowledge on a topic
previous experience on using mobile devices</td></tr>
<tr><td colspan="3">Learning Outcomes
(Learning outcomes are what students are expected to learn after completing the lesson plan)</td></tr>
<tr><td colspan="3">Use Action Verbs for Student Learning Outcomes
e.g.
Knowledge (list, state, define, relate, recognize etc.)
Comprehension (explain, describe, express, summarize, classify, compare, discuss, review etc.)
Application (apply, perform, use, solve, role-play, demonstrate etc.)
Analysis (analyze, inspect, distinguish, critique, diagnose, measure, experiment, debate etc.)
Synthesis (develop, revise, compose, plan, collect, establish, prepare, design, modify etc.)
Evaluation (review, justify, argue, conclude, evaluate, measure, support etc.)</td></tr>
<tr><td colspan="3">Pedagogical Approaches (Instructional Strategies ?)
(Teacher approach to helping students achieve the learning objectives and meet their needs)</td></tr>
<tr><td colspan="3">Which pedagogical approach(es) could be applied to implement the suggested lesson plan?
e.g.
game-based learning, place-based learning, participatory simulations, inquiry-based learning, problem-based learning, role-playing, studio-based pedagogy, and jigsaw method</td></tr>
<tr><td colspan="3">Learning Activities
(Tasks provided for students to develop knowledge and skills of the learning objectives based on the selected instructional strategies)</td></tr>
<tr><td colspan="3">Describe the different tasks of the inquiry-based learning phases
e.g.
Orientation, Conceptualization, Investigation, Conclusion and Discussion.
These phases could also be enriched with components of other pedagogical approaches defined above</td></tr>
</table>

Assessment and Evaluation *(Assessment(s) before, during, and after the lesson)*
If applicable. Summative, formative
Resources *(Educational material / equipment/ services/ facilities)*
What do I need in order to complete this lesson? e.g. internet connection at least 8Mbps Android smartphones iOs smartphones
Additional Information/ Comments
What else could be of additional value for the implementation of the Lesson Plan?