Electronic, didactic, and innovative platform for learning based on multimedia assets

e-DIPLOMA

Funded by the European Union

D.5.2 Definition of appropriate metrics for the assessment of learning competencies

Version No.V1.3

01.07.2024

HISTORY OF CHANGES			
Version*	**Publication date**	**Beneficiaries**	**Changes**
V1.0	15.05.2024	PREV	▪ Initial version of Deliverable Owner
V1.1	25.06.2024	UPV	▪ The pre-final version was reviewed by Internal Reviewers
V1.2	27.06.2024	UPV	▪ The pre-final version was sent to the Project Coordinator.
V1.3	01.07.2024	UPV	▪ The final version was sent to the Project Coordinator.

(*) According to the section "Review and Submission of Deliverables" of the Project Handbook

1. Technical References

Project Number	101061424
Project Acronym	e-DIPLOMA
Project Title	Electronic, Didactic, and Innovative Platform for Learning Based on Multimedia Assets
Granting Authority	European Research Executive Agency (REA)
Call	HORIZON-CL2-2021-TRANSFORMATIONS-01
Topic	HORIZON-CL2-2021-TRANSFORMATIONS-01-05
Type of the Action	HORIZON Research and Innovation Actions
Duration	1 September 2022 – 31 August 2025 (36 months)
Entry into force of the Grant	1 September 2022
Project Coordinator	Inmaculada Remolar Quintana

Deliverable No.	D5.2: Definition of appropriate metrics for the assessment of learning competencies
Work Package	WP5:
Task	T5.2: Selection of appropriate metric for evaluation of learning competencies
Dissemination level*	PU- Public
Type of license:	CC-BY
Lead beneficiary	Universitat Politécnica de Valencia (UPV)
PIC of the Lead beneficiary	▪ 999421653

Contributing beneficiary/ies	▪ Universitat Jaume I (UJI) ▪ Technische Universiteit Delft (TU Delft) ▪ Budapesti Muszaki es Gazdasagtudomanyi Egyetem (BME) ▪ Universitat Politécnica de Valencia (UPV) ▪ Innogrowth European Association for Innovation and Growth (INN) ▪ Centre for Social Innovation LTD (CSI) ▪ Aris Formazione e Ricerca Societa Cooperativa (ARIS FR) ▪ Brainstorm Multimedia SL (BRAINSTORM)
PIC of the Contributing beneficiary/ies	▪ UJI: 999882985 ▪ TU Delft: 999977366 ▪ BME: 999904228 ▪ UPV: 999864846 ▪ INN: 900529668 ▪ CSI: 913552403 ▪ ARIS FR: 911643734 ▪ BRAINSTORM: 999441732
Due date of deliverable	01. 07. 2024
Actual submission date	01.07.2024

Table of Contents

1. Introduction 5
1.1. Executive Summary 6
1.2 Relation to Other Project Documents 6
1.3 Abbreviation List 6
1.4 Glossary 7
1.5 Reference Documents 7
2. Context: Learning 8
2.1 Theoretical background 9
3. Experimental design 10
3.2 Objectives of the study 10
3.3 Prototypes content 14
3.4. Participants 15
3.5 Conditions of the study 17
3.6. Measures 18
3.6.1 Cognitive and Affective Skill Questionnaires 18
3.6.2 Behavioural and Psychophysiological Measures 19
3.7 Materials 21
3.7.1 HP Reverb G2 Omnicept Edition 21
3.7.2 Microsoft HoloLens 2 21
3.7.3 EmotiBit device 21
4. Experimental protocol 22
4.1 Informed consent 22
4.2 Baseline 22
4.3 Learning Experience 26
4.4 post-evaluation 28
5. Experimental protocol timeline 31
5.1 Baseline measurement timeline 31
5.2 Timeline of the activities before and after each lesson 31
6. Conclusions 32
References 35

1. Introduction

1.1. Executive Summary

This report investigates and proposes a methodology to determine how effective disruptive technologies are in facilitating the acquisition of new concepts. To develop the methodological and experimental design that will quantify the capacity of these disruptive technologies, the guidelines of the evidenced-centred model (ECD) have been followed. Directing our focus toward the learning process, the cognitive and affective model of immersive technologies (CAMIL) (Makransky & Petersen, 2021) presents a framework aimed at comprehending the influence of virtual reality (VR), augmented reality (AR), and other disruptive technologies on the cognitive processes (including perception, attention, memory, and decision-making) as well as the affective response of users (such as emotions, attitudes and behaviours).

For the analysis of the influence of disruptive technologies within the project, three research objectives are proposed: (1) Compare the impact of the use of disruptive technology on learning with non-disruptive methods. (2) To assess the influence of content (logical, social, psychomotor) on learning in environments with disruptive and non-disruptive technologies. (3) To determine the effect on the cognitive and affective skills using disruptive technologies in the learning process. For this purpose, an experimental protocol is established that will allow us to achieve the three proposed objectives.

1.2 Relation to Other Project Documents

This document is related to Deliverable 5.1, in which the different characteristics to be measured to analyse learning, as well as the metrics used, are proposed in a theoretical way.

1.3 Abbreviation List

Among the acronyms more used in the present document are the following:

VR: Virtual Reality

AR: Augmented Reality

AI: Artificial Intelligence

NLP: Natural Language Processing

CAMIL: Cognitive and Affective Model of Immersive Learning

SDT: Self-Determination Theory

ECD: Evidenced-Centred Design

ET: Eye Tracking

EDA: Electrodermal Activity

HR: Heart Rate

1.4 Glossary

Cognitive skills: refer to the mental abilities and processes involved in acquiring, storing and utilising information. These skills enable the individual to understand, reason, problem-solve and make decisions. These skills play a crucial role in the acquisition of new knowledge.

Affective skills: refers to a set of abilities related to emotions, attitudes, and social interactions. These skills encompass the capacity to recognise, understand, express, and regulate emotions.

EDA: refers to the skin's electrical conductance, which varies in response to changes in a person's emotional and psychological state.

HR: refers to the number of times the heart beats per minute, which indicates changes in the physiological conditions, such as stress.

Prototype content: The three prototypes teach different types of learning content. Prototype 1 is dedicated to teaching logical content, prototype 2 to learning social content, and prototype 3 to teaching psychomotor content.

Disruptive technologies: These are innovations that significantly alter or replace existing technologies. They typically introduce new processes, products, or services that eventually transform the way businesses and societies operate, some examples are virtual reality, augmented reality, mixed reality, videoconferencing, artificial intelligence, and machine learning. Notably, we consider the use of AR a disruptive technology even if it is realised using video composition, as opposed to extended reality glasses, as in the case of Edison.

Non-disruptive technologies: refer to the use of technologies such as video presentations or PowerPoint slides, where the user's interaction with the technology is minimal. This includes learning methods that do not use AR, VR, videoconferencing, or AI.

1.5 Reference Documents

See References Section included in this document.

2. Context: Learning

This report investigates and proposes a methodology to determine how effective disruptive technologies are in facilitating the acquisition of new concepts.

This report explores and proposes a methodological analysis to elucidate if disruptive technologies are effective in learning and studying the effect of disruptive technologies on the acquisition of new concepts. To analyse this effect, the presence and absence of these technologies during the presentation of information must be taken into account, as well as the type of information that is presented and how the person or individual processes this information based on how it structures and uses its own cognitive and affective skills. To understand this last part of learning the CAMIL model is employed as a framework.

The proposed methodology contrasts the use of disruptive technologies or the lack thereof, the type of content or the type of information offered to the user, and the mental model or the level of specific cognitive and affective skills.

Here, goals are proposed to determine how effective disruptive technologies are in facilitating the acquisition of new concepts in the three prototypes presented in the project.

The main research question of this report is:

RQ. Are disruptive technologies enhancing learning?

- RQ1: which technology (disruptive or non-disruptive) is the most effective for improving learning?
- RQ2: Which competences (logical, social and psychomotor) are best enhanced using particular technologies?
- RQ3: How do cognitive and affective skills modulate learning using disruptive technologies?

To achieve these objectives, three prototypes have been developed, each with a different learning content and using different technologies. The prototypes are described below:

- Prototype 1: comprises virtual reality (VR), augmented reality (AR), and Edison technologies. This prototype presents programming and sensing tasks through gamification and disruptive technologies. The content presented in this prototype is included in the logical content. Piloting the prototype will involve 150 participants, 90 students, 30 teachers, and 30 developers.
- Prototype 2: comprises virtual reality (VR), augmented reality (AR), chatbots (AI), gaming, videoconferencing, and Edison technologies. This prototype presents social content. Piloting the prototype will involve 150 participants, 90 students, 30 teachers, and 30 social entrepreneurs.
- Prototype 3: comprises virtual reality (VR), this prototype is more practical in that people learn how to move around in virtual reality through gaming systematically. This prototype presents

psychomotor content. Piloting this prototype involves a total of 150 people, which includes 45 students, 75 teachers, and 30 content providers.

2.1 Theoretical background

To answer the research questions, a methodology following the Evidence-centred (ECD) design is proposed. This model represents a methodological framework employed in the conception and construction of assessments, aimed at guaranteeing the systematic incorporation and acquisition of valid evidence starting from the initial phases of test design. The amalgamation of learning and assessment necessitates the seamless integration of pedagogical components with assessment elements, maintaining consistency in the rigour applied to both domains (Mislevy et al., 1999).

The design framework of the ECD, as outlined by Mislevy et al. (1999), establishes a systematic approach to test development aimed at ensuring the meticulous consideration and acquisition of valid evidence commencing from the initial stages of test design. ECD operates under the fundamental premise that the test functions as a measurement instrument linked with specific claims regarding test scores, emphasising the importance of aligning test items with the skills possessed by test takers to achieve optimal test quality.

In order to establish the learning process and analyse whether disruptive technologies enhance learning, the cognitive and affective model for immersive learning, CAMIL (Makransky & Petersen, 2021), is proposed as a framework for understanding how virtual reality (VR), augmented reality (AR), and other disruptive technologies impact both cognitive processes (such as perception, attention, memory, and decision-making) and affective responses (emotions, attitudes, and behaviours) of users.

The model describes how six affective and cognitive skills, including interest, intrinsic motivation, self-efficacy, embodiment, cognitive load, and self-regulation, lead to factual, conceptual, and procedural knowledge acquisition and knowledge transfer. The six cognitive and affective characteristics involved in the learning process are briefly explained here, followed by their measurement both at the initial baseline level and during the learning process with disruptive and non-disruptive technologies. The cognitive and affective skills are:

- Interest: is a psychological construct that represents a relationship between an individual and a specific topic or content area and is characterised by both affective and cognitive factors. A person's interest level has repeatedly been found to be a powerful influence on learning. (Hidi & Ann Renninger, 2006).
- Motivation: refers to the internal processes that energise, direct, and sustain behaviour towards achieving a goal. Therefore, motivation is an attribute that instigates movements, energy, direction, the reason for our behaviour and "what" and "why" we do something (Filgona et al., 2020).

- Cognitive load: refers to the mental effort required to process information or perform a task. It encompasses the number of mental resources, such as attention and working memory, needed to deal with the demands of a particular activity (Paas & Sweller, 2012).
- Embodiment: refers to the concept that cognitive processes, emotions, and experiences are grounded in the physical body and its interactions with the environment. It contains a sense of presence and sense of agency.
- Self-efficacy: refers to an individual's belief in their ability to successfully perform specific tasks or accomplish goals in various domains of life. For example, an individual may have high self-efficacy in solving maths problems but low self-efficacy in giving public speeches (Jackson, 2002).
- Emotional self-regulation is recognising, understanding, and managing emotions effectively to adapt to changing situations and cope with stressors.

3. Experimental design

3.2 Objectives of the study

The general objective of this methodology is to assess the efficacy of employing disruptive technologies in acquiring knowledge.

To achieve this, three specific objectives are proposed, linked to the three main questions of this deliverable:

RQ1: which technology (disruptive or non-disruptive) is the most effective for improving learning?

- Objective 1: Compare the impact of the use of disruptive technology on learning with non-disruptive methods.
- Hypothesis 1: Disruptive technologies will provide a greater likelihood of learning than non-disruptive contexts.

The first of the questions we ask ourselves, which corresponds to the first objective (RQ1), is related to knowing the technologies more effective in learning: Objective 1: Compare the impact of the use of disruptive technology on learning with non-disruptive methods. (see Figure 1).

EXPERIMENTAL DESIGN

- Intra-group comparison (cluster the lessons of each module by the use of disruptive technologies).

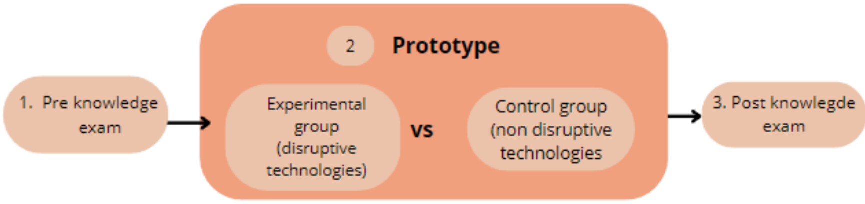

Figure 1: Objective 1 of the e-DIPLOMA Project

To try to answer this first question, an in-depth analysis of the influence of the type of technology on the learning result is proposed; that is, the level of knowledge is evaluated before and after the use of each of the proposed technologies, grouping them using disruptive or non-disruptive technologies.

To carry out this study, an **intra-group and univariate** analysis was proposed, grouping the lessons by type of technology (disruptive vs non-disruptive).

To do this, a grouping of the types of technology (experimental vs control group) is proposed within each of the prototypes, and a comparison of pre- and post-knowledge is made through the knowledge tests proposed in the proposed methodology.

Considering that the literature tells us that disruptive technologies improve the learning outcome, our expected result is directly linear to these conclusions; that is, learning will be better when disruptive technologies mediate it (Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. 2022).

The experimental design is structured as follows: three distinct groups, labelled prototype 1, prototype 2, and prototype 3, each feature unique content profiles. Prototype 1 presents logically oriented content, prototype 2 emphasises social content, and prototype 3 focuses on instructional and psychomotor content. Consequently, comparing people's knowledge before and after the lesson will indicate which technology has been the most beneficial throughout the learning process.

Considering the expected results in this first proposal for comparison between the level of knowledge with disruptive (experimental group) vs. non-disruptive technology (control group), we intend to clarify, analyse how the effect of disruptive technologies depends on the type of content.

RQ2: Which competences (logical, social and psychomotor) are best enhanced using different technologies?

- Objective 2: to assess the influence of content (logical, social, psychomotor) on learning in environments with disruptive and non-disruptive technologies.
- Hypothesis 2: The content and presentation of the content influence learning.

At this point, we must see the influence of the type of content on the learning result (RQ2), but without forgetting that we need to know the effect of disruptive technology; with this, we enter the second level of analysis, where once we have compared the differences in learning mediated by disruptive and non-disruptive technologies, we propose a study to observe whether the content proposed in these technologies influences learning.

Knowing that, objective 2 is to assess the influence of content (logical, social, psychomotor) on learning in environments with disruptive and non-disruptive technologies.

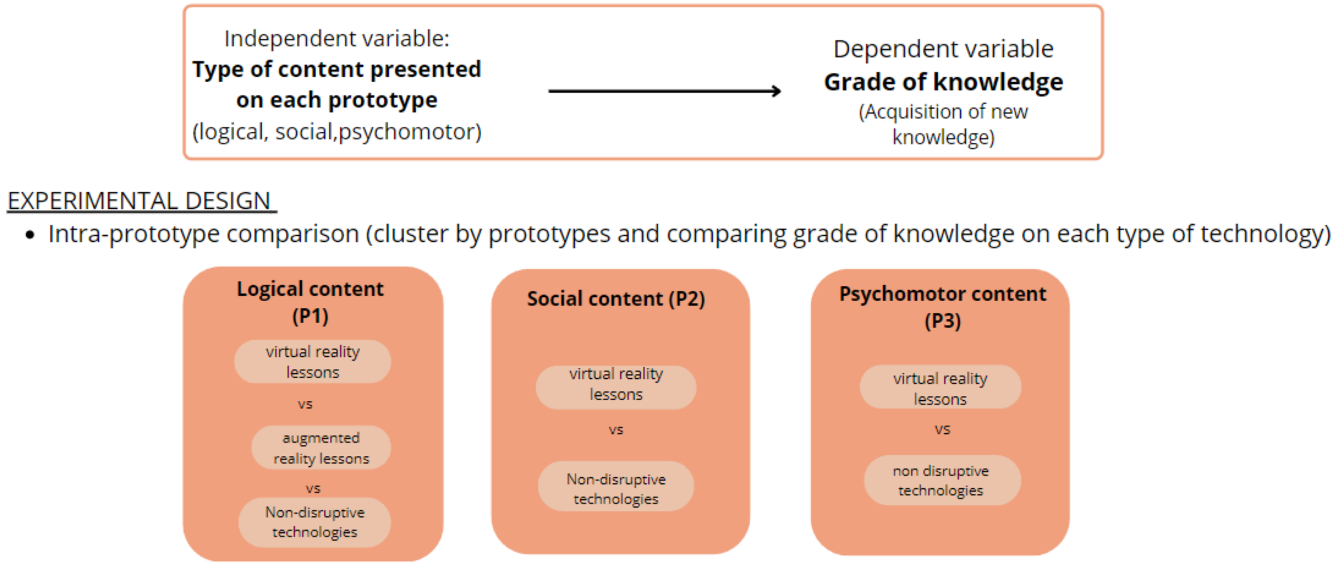

Figure 2: Objective 2 of the e-DIPLOMA Project

To study the effect of the content, an analysis focuses on comparing the level of learning (based on pre- and post-knowledge) within each prototype (see Figure 2). As mentioned above, each prototype presents a different type of content: social prototype 2, logical content in prototype 1 and psychomotor content in prototype 3. The analysis of the extracted data is intended to compare the levels of learning through technology. This level of analysis aims to extract data relevant to the type of content related to the knowledge acquisition, taking into account the technologies used. Once these analyses are done, we know how effective the type of content is within the use of technology on each prototype. A second phase of analysis will be carried out, which will consist of comparing them, that is, between the three prototypes.

Hence, the expected result we seek from this second level is to know the effectiveness of learning (through pre- and post-knowledge metrics) of one content over another mediated by disruptive technologies.

RQ3: How do cognitive and affective skills modulate learning using disruptive technologies?

- Objective 3: To determine the effect on the cognitive and affective skills using disruptive technologies in the learning process.
- Hypothesis 3: The use and level of the learner's cognitive and affective skills will affect learning effectiveness in a disruptive technology context.

Once we know what type of technology is most effective and what type of content works best when mediated by disruptive technologies, the third and final research objective appears (RQ3), which is linked to knowing what aspects or "mental model" (set or levels of cognitive and emotional competencies) are the most appropriate for learning mediated by disruptive technologies and according to the content. In other words, what level of competencies (cognitive and emotional) should a specific student present concerning a specific type of content in learning mediated by disruptive technologies.

To do this, an analysis is proposed based on the baseline of these cognitive and emotional characteristics; in this way, within the sample, an intra-subject analysis will be carried out with users that complete each one of the prototypes, and a comparison will be made on the effectiveness of learning (see Figure 3).

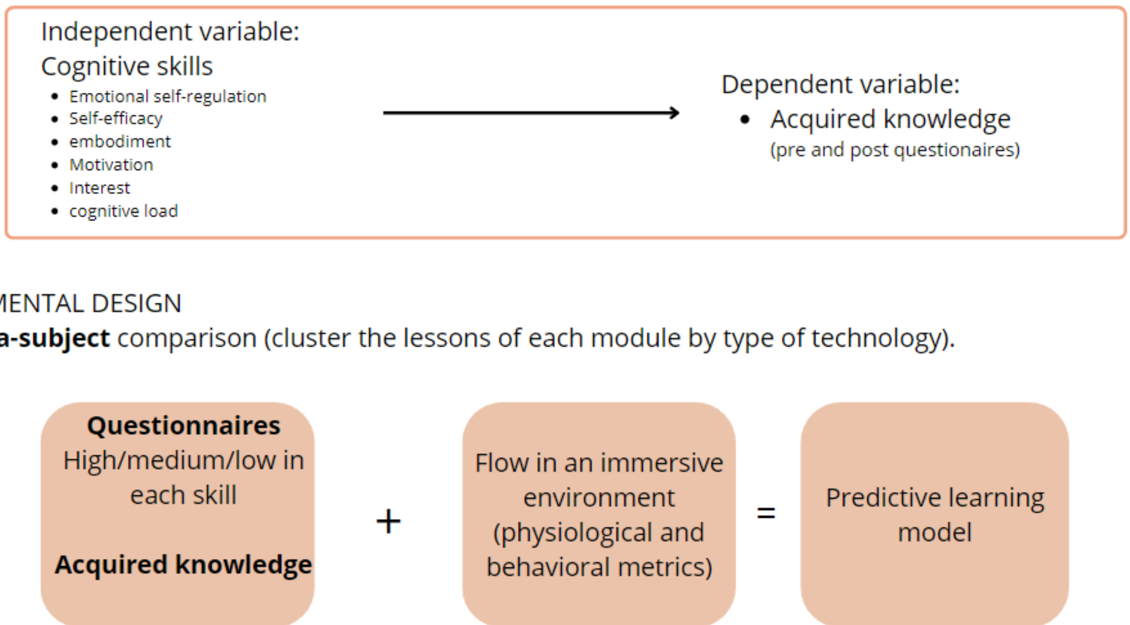

Figure 3: Objective 3 of the e-DIPLOMA Project

As these are somewhat more complex measures related to effectiveness during learning, it is necessary to present the baseline in the subjects and analyse the influence of these characteristics during the learning experience, so they must be considered. . Aspects related to task performance and decision-making during the experience (behavioural), but also to emotional activation and its influence (psychophysiological) will be collected for analysis.

The expected results in this third objective are in line with knowing the optimal levels of each skill to obtain optimal results in learning, in other words, what capabilities we can monitor and improve so that for a specific type of disruptive technology and a specific type of content, learning is enhanced.

After formulating the central problem (Are disruptive technologies effective in acquiring new knowledge?) and announcing our hypotheses to solve this problem. The content of each of the prototypes is explained in detail below, as well as the sample used and its division according to the proposed methodology.

3.3 Prototypes content

Prototype 1 contains four lessons where the content focuses on learning programming concepts by technologies such as VR, AR or Edison. This prototype is divided into four lessons

- First concepts (1): where a video is shown using Edison technology, in which the general concepts necessary to carry out the activities proposed in prototype 1 are explained.
- Instructions, loops and variables (2): in this second lesson we will proceed to solve basic programming problems with the proposed tool of block programming in VR.
- Let's start with the sensor (3): here we will study the sensor using augmented reality, participants should be able to analyse the architecture of the different components.
- Numbers all around (4): using collaborative VR the participants will have to solve a programming problem.

Prototype 2 contains five lessons where knowledge about social interaction in enterprises is taught

- Lodestars (1): here the concepts taught are related to basic knowledge about enterprises and specifically social enterprises, so the procedure for this will be the exploration of a virtual city where participants will be able to interact with AI characters to find examples of social enterprises. The technology to be used in this lesson will be VR, and AI chat. This lesson is done through an individual exploration of the VR environment and then a group discussion of it.
- Heroes (2): here, knowledge related to the social system is learnt. The aim is that the participant learns how to manage the complex social system, for which a virtual city is simulated through the use of cooperative VR. Here the procedure is cooperative so that all participants together have to reach a common result.

- Painters (3): here you learn business-related knowledge, and to learn this knowledge, a chatbot is presented with different characters the participants have to interact with. Here the technology to be used is AR and Edison videoconferencing. The methodology of this lesson is based on group co-creation of a canvas.
- Allies (4): Here knowledge related to human resources is taught, this lesson allows the participant to create the most effective work team by talking to AI characters and analysing the characteristics they present to them. The methodology of this lesson is based on an individual game.
- Angels (5): here students learn about business management, including financing, product management, market research, and marketing, using a multiplayer round-based competitive computer game.

Prototype 3 contains three lessons using VR, in which the main objective is the learning of concepts so that the participant can get by with VR technology.

- (1) VR Interaction: whereby means of a guided game, with different levels, the participant learns how to handle the VR controls and how to perform actions such as picking up, climbing or moving objects.
- (2) VR Navigation: where, through a game, you learn to move in the virtual environment through different types of movements.
- (3) VR Visualization: where the participant plays in a VR environment, In this environment the participant will need all the knowledge acquired from the lessons presented before.

3.4. Participants

In this project, different participants will pilot each of the prototypes. These three prototypes will also be tested in various locations within the European community.

Five profiles are going to get involved in the pilots of the prototypes:

- Students are individuals who are over 16 years old and are enrolled in various academic stages.
- Trainers: people responsible for imparting knowledge, facilitating learning and guiding students in educational settings. They could work in different institutions such as schools, institutes or universities.
- Developers: These professionals specialise in creating software applications, websites, or other technological solutions. They possess programming skills and knowledge of various programming languages, tools, and frameworks to design, build, and maintain software systems.

- Social companies: Social companies, referred to as social enterprises or social businesses, are organisations that aim to address social, environmental, or community issues while also generating revenue. Unlike traditional for-profit companies, social companies' primary goal is to maximise profits for shareholders and create a positive social impact.
- Content provider: A content provider is an individual, organisation, or company that creates and supplies content for consumption by an audience. This content can be in various forms, including articles, videos, audio recordings, images, and immersive media. Content providers can operate across different platforms, such as websites, social media, streaming services, and traditional media outlets.

Three of these participants will take part in the piloting sessions depending on the prototype being evaluated:

- Prototype 1 is piloted by students, trainers and developers
- Prototype 2 is piloted by students, trainers and social companies
- Prototype 3 is piloted by students, trainers and content providers

Inclusion and exclusion criteria

People over 16 years old are included in one of the different groups (students, trainers, social companies, developers or content providers), taking into account which prototype will be tested.

Additionally, the exclusion criteria are the following:

- People who do not understand or read English or the national language of the piloting country.
- People who have had a seizure, loss of consciousness or any other symptom related to epileptic seizure disorder.

The prototypes are going to be piloted in different countries.

Country	***prototypes***
Netherlands	Prototypes 1 and 3
Hungary	Prototypes 1, 2 and 3
Spain	Prototypes 1 and 3
Italy	Prototype 2
Estonia	Prototype 2

Table 1: Summary of the prototypes piloting

3.5 Conditions of the study

The primary objective of the comparison is to evaluate the effectiveness of the three prototypes that utilise disruptive technologies in learning. The methodology will be done by comparing a control group which does not use these disruptive technologies with an experimental group that does. The aim is to determine whether disruptive technologies lead to a significant improvement in learning outcomes.

Hence, a methodology of comparison between groups is proposed, in which the sample is divided into an experimental group (use of disruptive technologies) and a control group (use of non-disruptive technologies).

On the one hand, the contents of the prototypes will be carried out using disruptive technologies, such as new technologies such as VR, AR, and Edison. This will be the experimental group. On the other hand, there is the group which will learn the same learning contents proposed for the experimental prototypes; the difference is in the presentation of the contents. In the control group, the presentation of these same contents will be given by the not use of disruptive technologies,, which include paper texts, presentations, traditional games or non-interactive explanatory videos. Thus, this learning method is proposed to be compared with disruptive technology (experimental group).

- The control group consists of participants who will not use the disruptive technologies incorporated into the three learning prototypes. Instead, they will follow traditional learning methods or use standard educational tools commonly employed in the current educational setting.
- The experimental group consists of participants who will use the three prototypes to incorporate disruptive technologies for learning. This group is designed to test the effectiveness of these technologies in enhancing learning outcomes.

Additionally, each prototype presents distinct learning content, and thus, the three prototypes are categorised based on the content they deliver. Prototype 1 presents content that teaches basic programming concepts, thereby offering logical content. Prototype 2 provides content related to understanding how a society functions and needs, thus delivering social content. Finally, Prototype 3 involves learning about interaction and navigation in virtual reality, which constitutes psychomotor content.

After understanding how the sample will be distributed across each of the three prototypes, the questionnaires used as a baseline of the cognitive and affective skills are going to be explained in detail.

Following the explanation of the questionnaires, a brief explanation of the metrics used to measure these cognitive and affective characteristics during learning will be given.

3.6. Measures

3.6.1 Cognitive and Affective Skill Questionnaires

The questionnaires administered are the following:

- D2: The d2 is a time-limited test that assesses selective attention through a cancellation task. It measures processing speed, attention and adherence to instructions.
- Digit Span: is a measure of working memory that can be used in two formats, forward Digit Span and Reverse Digit Span. This is a verbal task, with stimuli presented auditorily and responses spoken by the participant.
- The self-assessment manikin (SAM): Is a nonverbal pictorial questionnaire that directly measures a person's affect and feeling in response to exposure to an object or an event.
- Locus of control questionnaire: is a 29-item questionnaire that measures an individual's internal or external control level.
- ERQ: This self-report questionnaire evaluates the tendency to regulate emotions, considering two possible strategies: cognitive reappraisal or expressive suppression. Allows the analysis of the strategies of emotion regulation.
- Curiosity and exploration inventory-II (CEI-II): It measures two dimensions of curiosity—stretching, which assesses the individual's desire to seek out new knowledge and experiences. Embracing evaluates the individual's willingness to embrace uncertain, unpredictable experiences.
- General self-efficacy scale (GSE): This is a 10-item psychometric scale designed to assess optimistic self-beliefs to cope with various complex demands in life.
- Knowledge questionnaire: This is an itemised questionnaire that collects everything the participant should learn on each prototype.
- Usability questionnaire: This tool assesses the ease of use, effectiveness, and satisfaction with which participants can interact. It typically gathers subjective feedback from participants to identify usability issues and areas for improvement.
- Nasa task: A multidimensional and subjective assessment tool that perceives workload to evaluate the effectiveness of a task.

	Use for	*Time (in minutes)*	*format*	*punctuations*	*Administration time*
D2	attention	10	paper	Hit and misses	One time before XR
Digit span	Working memory	5	paper	Items correct	One time before XR
SAM	Emotional state	3	Computer	Likert scale (no wrong answers)	Before and after each lesson
Locus of control	motivation	10	Computer	Likert scale (no wrong answer)	One time before XR
ERQ	self-regulation	7	Computer	Likert scale	One time before XR
CEI-II	curiosity	4	Computer	Likert scale	One time before XR
GSE	self-efficacy	3	Computer	Likert scale	One time before XR
Nasa task	Cognitive load	3	Computer	Likert scale	After each lesson
Knowledge questionnaire	learning	5/10	Computer	Likert scale	Before and after each lesson
usability	Usability, presence	5/10	Computer	Likert scale	After each lesson

Table 2: Summary of the questionnaires

3.6.2 Behavioural and Psychophysiological Measures

Here, to measure learning, behavioural and physiological measures are collected:

Behavioural: This measure provides information about the interaction and learning process that a person is doing inside the experience, which allows us to understand how the person is learning and which cognitive skills are helping to improve this knowledge acquisition.

- Eye-tracking:

Eye-tracking is a psychophysiological measure that involves recording and analysing the movements of a person's eyes as they interact with stimuli such as images, videos, or written text. It provides valuable insights into cognitive processes, attention, perception, and decision-making. Hence, a sensor technology is needed to measure and record the eye position and movement to collect ET.

An eye tracker is a device for assessing where or what one is looking at, also known as *the point of gaze*.

To collect this behavioural measure, two different Head-mounted displays (HMD) will be used; on the one hand, for the virtual reality lessons, the HP reverb G2 Omnicept Edition¸ which has integrated sensors that record muscle movements, gaze, pupil size, and pulse, and transfer the data seamlessly to the HP Omnicept platform. Capturing user responses in real time can generate relevant information and adapt it to each user's experience.

On the other hand, the HoloLens are used for lessons that contain augmented reality; these glasses are designed to be used in mixed-reality environments and combine VR and AR technologies to create an extended and immersive experience.

The ET measure is used to measure interest and cognitive load in those lessons which contain virtual reality activity.

- Actions and time done in the extended reality (events)

The user experience will collect the actions the participant does during the learning process; every action the user does will be collected with an event table. Like this, all the hits, trials, and action times will be registered and collected by the application.

Psychophysiological measures:

- Electrodermal activity

EDA is a psychophysiological indicator of emotional arousal. EDA measurement helps overcome three limitations inherent to self-reports of emotions: (1) the difficulty of obtaining a continuous measurement, (2) respondents' inability and unwillingness to report their emotions accurately, and (3) the impossibility of capturing unconscious emotions.

This measure collects information about emotional arousal, cognitive load, and interest.

- Heart rate variability

HRV is defined as changes in the time intervals between consecutive heartbeats. These changes are expected to occur and reflect autonomic nervous system (ANS) activity.

The experience is divided into lessons; one person should complete all the prototype lessons.

All of this is collected from the experience to understand how these cognitive skills are linked with the acquisition of the learning process and how these cognitive skills are inculcated with the acquisition of new knowledge.

3.7 Materials

The following devices will be used for the collection of psychophysiological data:

3.7.1 HP Reverb G2 Omnicept Edition

The HP Reverb G2 (see figure 4) Omnicept Edition glasses represent a cutting-edge advancement in VR technology, specifically designed to enhance user immersion and interaction through integrated biometric tracking capabilities, these glasses incorporate sensors for real-time monitoring of physiological signals such as heart rate, pupil dilation, and facial expressions. This biometric data is utilised to adjust the VR experience dynamically, providing insights into users' emotional and physical states.

Figure 4: Glasses VR (Hp)

Supported by specialised software, the device enables comprehensive data capture and analysis, catering to applications in research and advanced educational environments. Integrating biometric feedback enhances the adaptive nature of VR interactions, facilitating personalised and responsive user experiences within virtual environments.

3.7.2 Microsoft HoloLens 2

The Microsoft HoloLens 2 (see Figure 5) represents a state-of-the-art augmented reality device tailored for immersive and interactive experiences across various environments, including educational applications and research projects focused on learning. With advanced holographic visualisation capabilities, enhanced resolution, and an expanded field of view, these glasses enable users to interact with three-dimensional holograms seamlessly integrated into their real-world surroundings.

Figure 5: HoloLens Glasses

3.7.3 EmotiBit device

EmotiBit (see Figure 6) is a wearable sensor module for capturing high-quality emotional, physiological, and movement data. Easy-to-use and scientifically validated sensing lets you enjoy wireless data streaming to any platform or direct data recording to the built-in SD card. Customise the Arduino-compatible hardware and fully open-source software (Php, s.)

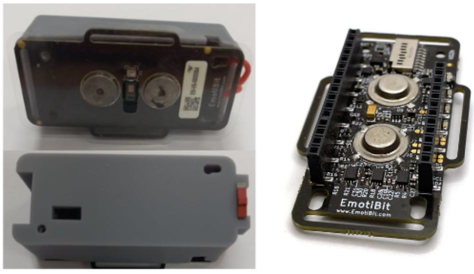

Figure 6: EmotiBit device

4. Experimental protocol

In this section the experimental protocol is explained in detail, considering the division of the sample into a control group and an experimental group. A complete protocol is established. This complete protocol is the same for both conditions (experimental and control), understanding that the changes are in the presentation of the learning content (prototypes).

Specifically, the sample will be divided into control and experimental groups, the protocol being the same, only the content will vary. This approach helps to control for order effects and ensures a more reliable comparison of the two conditions.

The experimental protocol (procedure) contains different phases (see Figure 8):

1. Informed consent
2. Establishment of the baseline
    a. Cognitive skill questionnaires
    b. Psychophysiological baseline
    c. Cognitive tasks
    d. Pre-experimentation knowledge
    e. Evaluation of emotional state
3. Realisation of the learning experience (XR)
4. Post evaluation
    a. knowledge exam
    b. Evaluation of the emotional state
    c. Usability Questionnaire (at the end of each prototype)

4.1 Informed consent

The participant attends the site in person where the experiment will take place. Before the start of the experimental protocol, the individual is informed about the purpose of their participation and the data that will be collected. Finally, they are asked to sign an informed consent form. The individual must sign this informed consent for each of the prototypes they will test.

4.2 Baseline

A baseline refers to the initial measurement or observation before any experimental manipulation occurs. It serves as a reference point for comparison against later measurements or observations.

The baseline provides essential information about the starting point of the studied variables, allowing researchers to assess changes or effects caused by the experimental intervention. It helps to clearly understand participants' natural state or behaviour before any external factors are introduced.

For example, in a study investigating the effects of a new therapy on anxiety levels, researchers might measure participants' anxiety levels before they receive any treatment. This initial measurement serves as the baseline against which the post-treatment anxiety levels will be compared.

In this project, the experimental design for this learning process entails establishing a baseline assessment of cognitive skills, psychophysiological (collecting the measures of electrodermal activity and heart rate variability) and level of knowledge (see Figure 7).

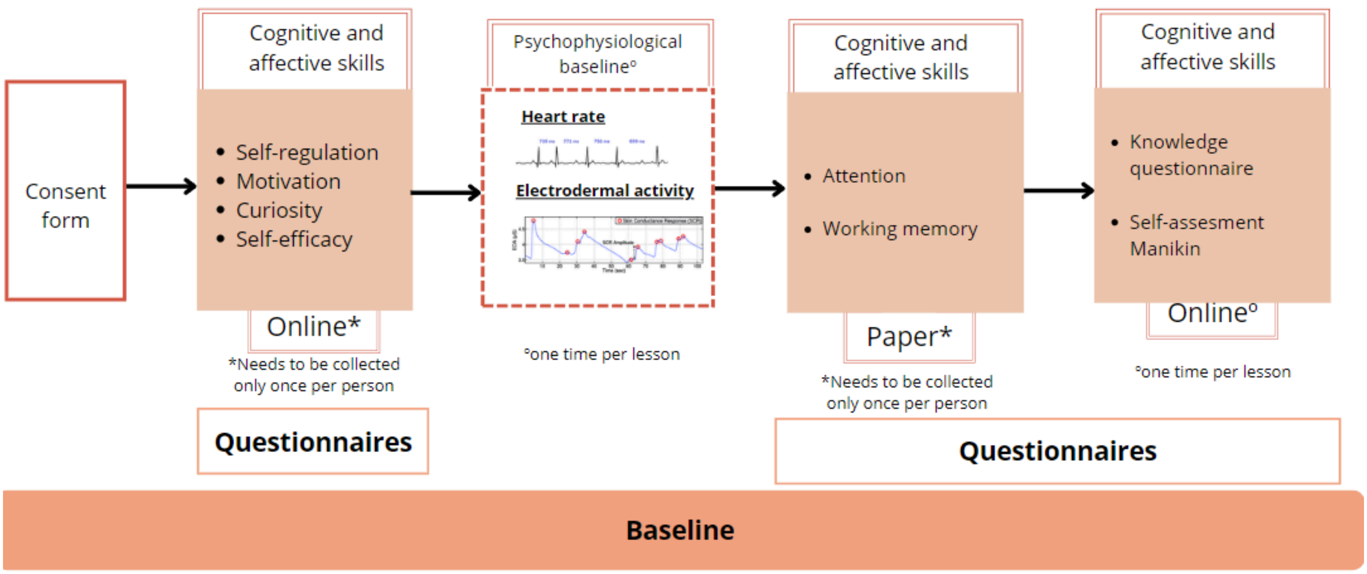

Figure 7: Baseline of the experimental protocol of e-DIPLOMA

4.2.1 Cognitive and Affective Skills Baseline

Here, the questionnaires are administered to provide scores indicating the levels of different individuals in various cognitive characteristics being measured.

The cognitive and affective skills measured are the following:

Skill	***Questionnaire***	***Time***	***Modus***
Motivation	Scale of Rotter (Locus of control)	10 minutes	online
Self-efficacy	The general scale of self-efficacy	4 minutes	online
Curiosity	Curiosity and exploration inventory-II (CEI-II)	5 minutes	online
Attention	D2	4 minutes	Presential
Emotional self-regulation	ERQ	5 minutes	online
Working memory	Digit Span	5 minutes	Presential

Table 3: baseline Cognitive and affective Skill questionnaires

ll these questionnaires (see Table 3) are administered only at the beginning of each prototype or once per person (i.e., if the same person completes all three prototypes, the questionnaires only need to be completed at the start of the prototype). They are conducted online (except for two cognitive tasks-attention and working memory-- which will be on paper). The questionnaires must be completed before the experiment begins.

A baseline assessment of cognitive skills is undertaken to determine the proficiency level of each participant. This facilitates the construction of a cognitive map, delineating the skills that influence the learning process and acquisition of new knowledge.

4.2.2 Psychophysiological baseline

4.2.2.1Device collocation

The device must be placed before the cognitive tasks (attention and working memory) are performed. Once the informed consent form is signed, the device is placed on the inner forearm of the non-dominant hand so as not to hinder the execution of the task.

This device will collect psychophysiological metrics, such as electrodermal activity or heart rate variability, during the experimental phase until the prototype is finished.

4.2.2.2 Collection of the Psychophysiological Baseline

After the device is placed, baseline psychophysiological signals (HR and EDA) are collected. These baseline signals will later be compared with those collected during the learning process mediated by disruptive technologies. Once the device is appropriately placed and transmits correctly, the collection of psychophysiological signals begins. A two-minute video is presented, during which the individual must sit in front of the screen and watch the video.

This baseline must be collected before each day's sessions. For instance, if prototype 1 lasts for three sessions over three days, the baseline will be collected at the beginning of each of the three days. Consequently, there will be a baseline for each day that the individual learns for each prototype.

4.2.3 Emotional state (SAM)

Before completing the cognitive task, a questionnaire measuring the individual's baseline emotional state is administered. This questionnaire uses pictograms to ask how the person feels regarding arousal, dominance, and valence, to which they respond using a Likert scale.

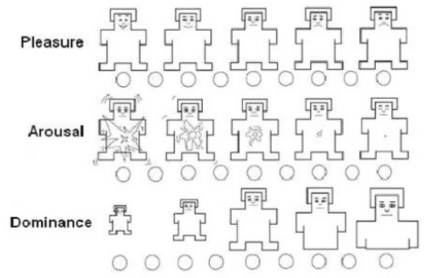

Figure 8: Example of SAm questionnaire

This task (see Figure 8) is conducted before and after each lesson, meaning it must be repeated independently for each session, as its objective is to evaluate the pre- and post-lesson states for each session.

4.2.4 Cognitive tasks

After collecting the psychophysiological baseline, the participant will perform two cognitive tasks that belong to the cognitive skills baseline. These tasks serve as a reference for measuring the learning process. These tasks are administered after collecting the psychophysiological baseline and are only carried out in the first session. Performing these tasks after the baseline collection has two purposes: to avoid affecting the baseline measurements and to test the efficacy of the psychophysiological data collection. Movement of the device during these tasks will cause interferences that must be accounted for during signal analysis.

These tasks are:

- To measure attention: D2
- To measure working memory: Digit span

The collection of the data of these tasks is on paper and will take 12 minutes to complete.

4.2.5 Knowledge baseline

After the cognitive tasks are finished, the knowledge baseline takes part.

The knowledge baseline should start, and an assessment of pre-existing knowledge should be performed to determine the participant's initial proficiency level. This assessment enables the identification of the starting level of knowledge, which will subsequently be compared with the same assessment conducted after the extended experience.

This allows us to compare the difference between the knowledge levels, the one the person has before the XR experience starts and the one acquired during learning after the experiment.

Additionally, the self-assessment manikin is done just before and after the knowledge exam takes part; this is a non-verbal pictorial questionnaire that directly measures a person's affect and feelings in response to exposure to an object or an event. This measure allows us to compare the emotional state before and after the experience and see if it has emotionally affected the user. Example of a question done in the prototype:

What does the 'Move Forward' instruction mean
a) Move to the last available cell regardless of the direction of the object being moved.
b) Move to the next available cell regardless of the direction of the moving object.
c) Move to the next available square regardless of the direction of the moving object
d) None of the above is correct

Table 4: Example of questionnaire of knowledge

4.3 Learning Experience

After the baseline is set, the participant starts learning through the disruptive technologies experience.

- Prototype 1: block programming and managing sensors over a virtual environment, which contains four lessons (using AR, VR technologies and content making by Edison technology)
- Prototype 2: Social Entrepreneur contains five lessons (AR; VR, and Edison program).
- Prototype 3: Learning how to move in VR contains six lessons.

The prototype is divided into different lessons. In each one the content and the technologies are different. The protocol for each lesson is the same, but the device used changes.

- Lessons in VR use the HP Omnicept glasses and the device, which measures HR and GSR.

- Lessons in AR used the HoloLens glasses and the device which measures HR and GSR.
- A lesson on the computer screen uses the computer and the device which measures HR and GSR.

During the experience, metrics (see Figure 10) will be collected, such as behavioural metrics (actions the participant does and eye tracking) and physiological measures (EDA, HR).

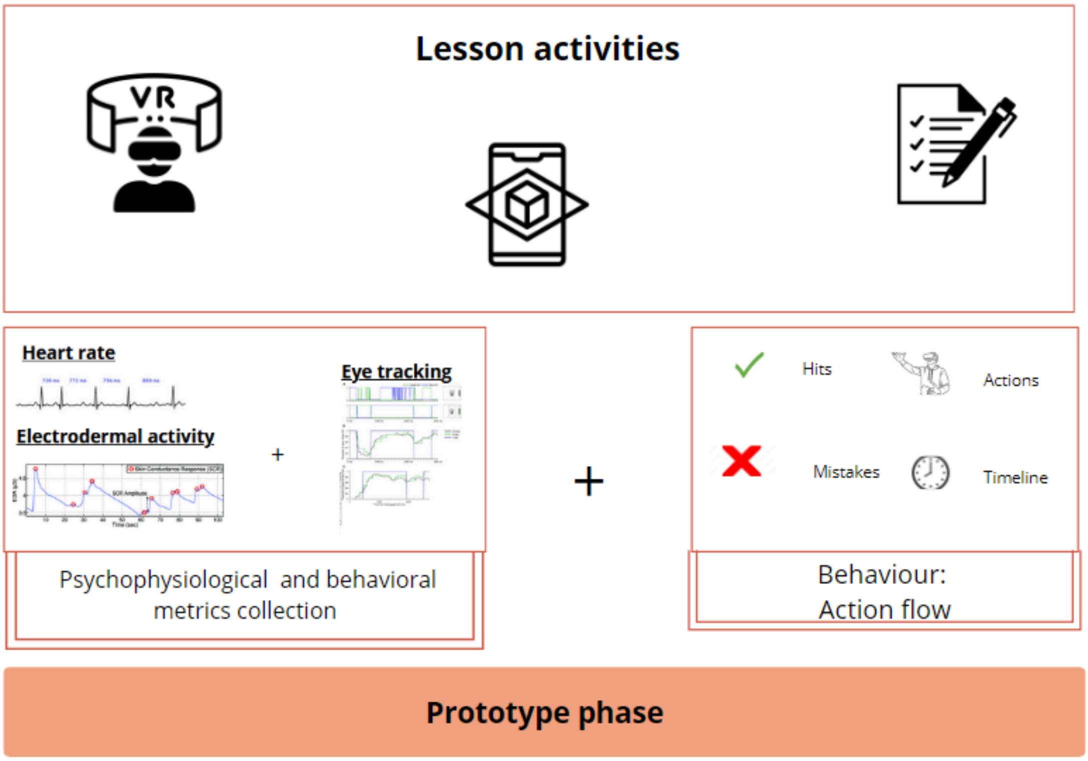

Figure 9: Schema of metrics collected during disruptive lesson

Here is an example of prototype 1, which contains four lessons on different technologies:

- Lesson 1 is a non-disruptive lesson which contains theoretical content presented in video
- Lesson 2 is a virtual reality interaction, which is a block programming lesson
- Lesson 3 is with augmented reality AR-HoloLens
- Lesson 4 is a collaborative one.

In the case of the control group, the same learning contents will be presented as those presented in the experimental group, although the form of presentation varies. In this group, the contents will be presented without using any type of disruptive technology.

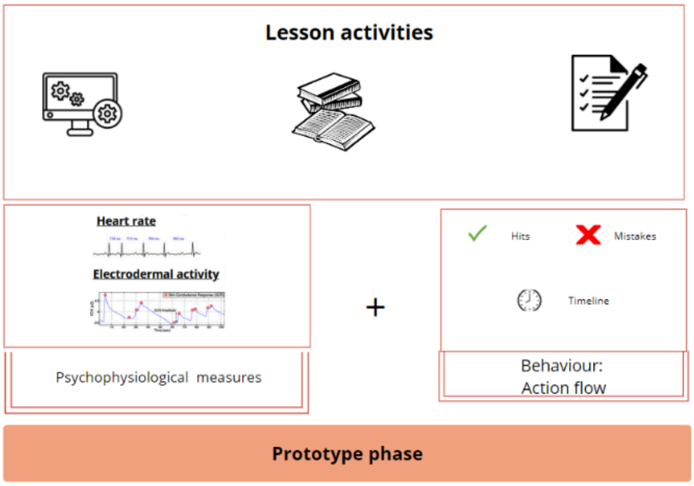

Figure 10: Schema of metrics collected during non-disruptive lesson

All prototypes are divided into lessons, which will be carried out in different sessions depending on the duration of each lesson, considering that a session cannot last more than one hour and a half.

4.4 Post-evaluation

After one of each lesson, a post-evaluation exam is proposed, which measures the knowledge acquired with the same evaluation test which was done before; this allows us to compare the knowledge before and after the learning experience. Hence, people do this quiz each time they finish the lesson; for example, if the prototype has four lessons, the person does this quiz eight times (the same test is done at the beginning and end of the lesson).

Additionally, a post-test evaluation will be conducted upon completion of the entire experiment. This methodology enables a comparison of the effectiveness of different technologies for achieving effective learning and retention in long-term memory.

Moreover, an arousal and emotional quiz, Self-assessment Manikin, is done to observe the stress and valence of the learning experience; this test is done each time the person finishes a lesson.

After the prototype is finished, a usability questionnaire is collected; this test uses a Likert scale, which allows us to collect information about the interface's usability, movement, interaction, presence, and agency of the XR environments. Also, information about motivation and self-efficiency is collected in this questionnaire.

These questionnaires are presented on the online platform Moreover, the participant needs to complete them before finishing the experimental session.

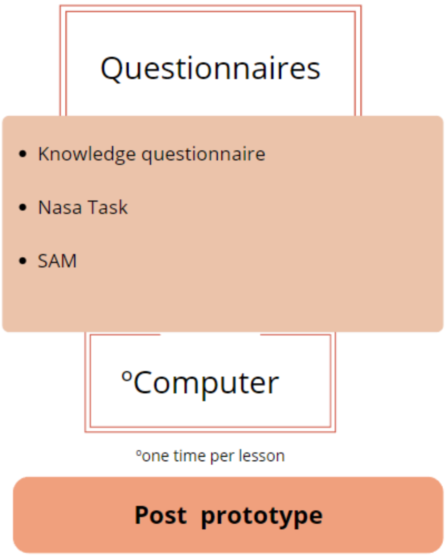

Figure 11: Questionnaires after each lesson

Diagram of the experimental protocol e-DIPLOM (Experimental group)

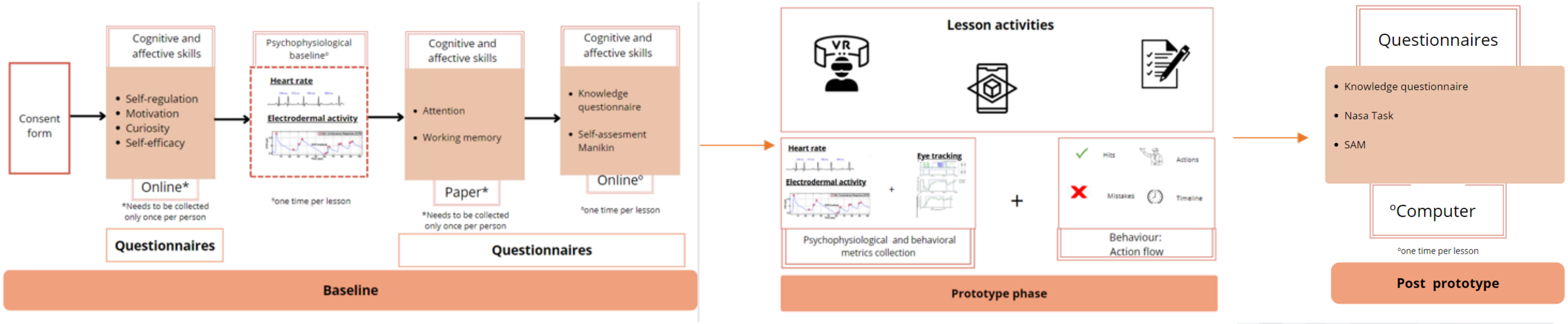

Figure 12: Experimental group protocol

Diagram of the experimental protocol (control group)

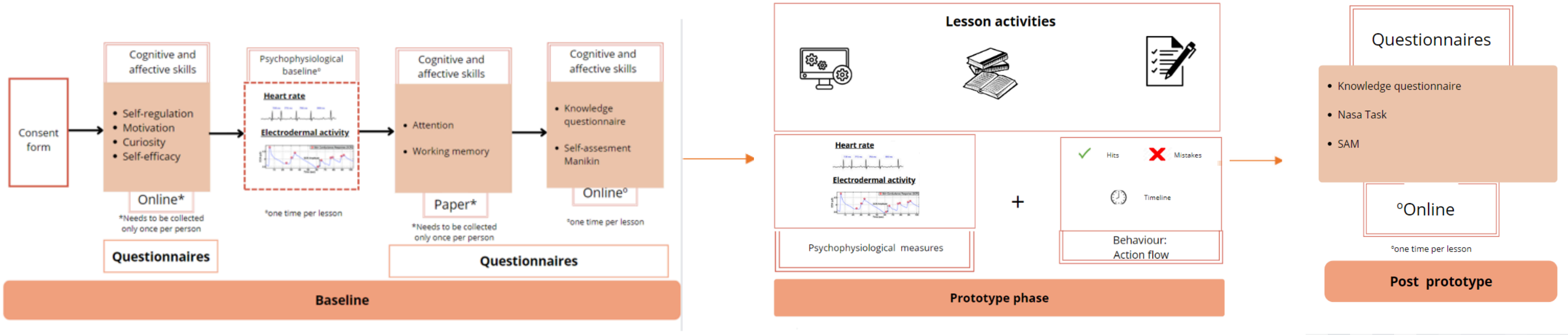

Figure 13: Control group protocol

5. Experimental protocol timeline

5.1 Baseline measurement timeline

Here are the detailed times required for each part of the data collection at baseline. The figure displays the estimated minutes that participants are expected to take for this initial baseline; here, the total amount of time is 34 minutes; these questionnaires are done online and only need to be collected once per person.

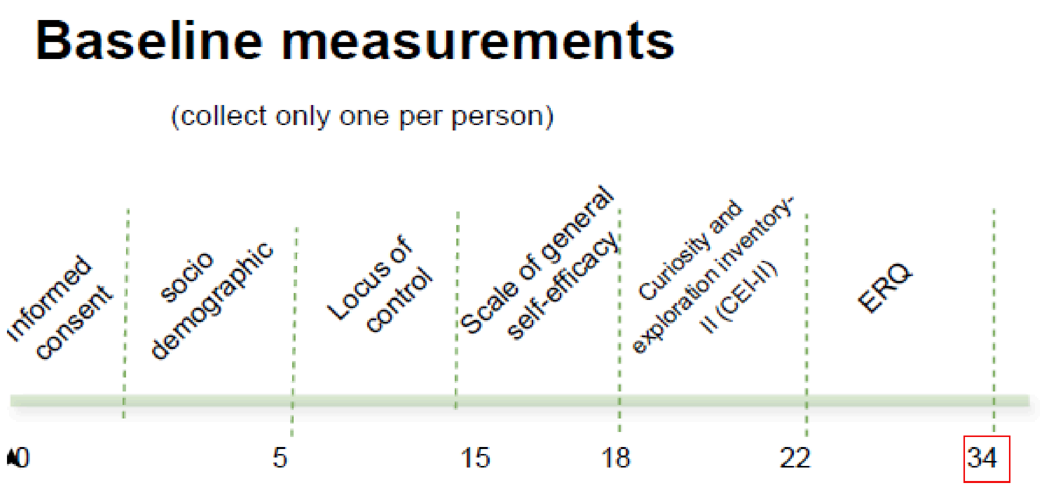

Figure 14: Timeline of the baseline

Firstly, the **Informed consent** form will be signed per the ethical guidelines of each place where the prototypes will be tested. Subsequently, a **socio-demographic questionnaire** will be used to collect data such as age, gender, profession, etc. After the socio-demographic questionnaire, a **questionnaire measuring motivation** and locus of control will be completed. After which, the **questionnaire measuring self-efficacy** will be carried out, and finally, the following questionnaires will be carried out. Lastly, the curiosity questionnaire and the self-regulation questionnaire will be done.

All these questionnaires establish the baseline cognitive and affective characteristics, which will later be measured using psychophysiological and behavioural metrics in the various learning prototypes.

5.2 Timeline of the activities before and after each lesson

At this point we distinguish three sections:

- Device collocation (Initial setup): Placement and connection of all required devices for the lesson, including VR goggles, AR devices, or computers, and connecting the EmotiBit device, ensuring it is transmitting and collecting data properly.

- Psychophysiological baseline: Electrodermal activity and cardiac variability will be recorded in the participant's natural state during this phase. The participant will remain comfortably seated with the device connected and relaxed for approximately two minutes.
- SMDT and Digit Span: These are two tasks to measure cognitive skills; SMDT is going to give us the baseline of attention, and the Digit Span task is going to give us the baseline measure of working memory (to be carried out only once at the beginning of each prototype).
- Knowledge questionnaire: This is a test of approximately 2 to 5 minutes; this questionnaire should reflect the knowledge to be taught in each lesson.
- SAM: to measure three dimensions repeatedly described as underlying affective appraisal, liking or affective valence, arousal and control or dominance.

This concludes the psychophysiological and cognitive baseline, which is estimated to take approximately 23 minutes in total.

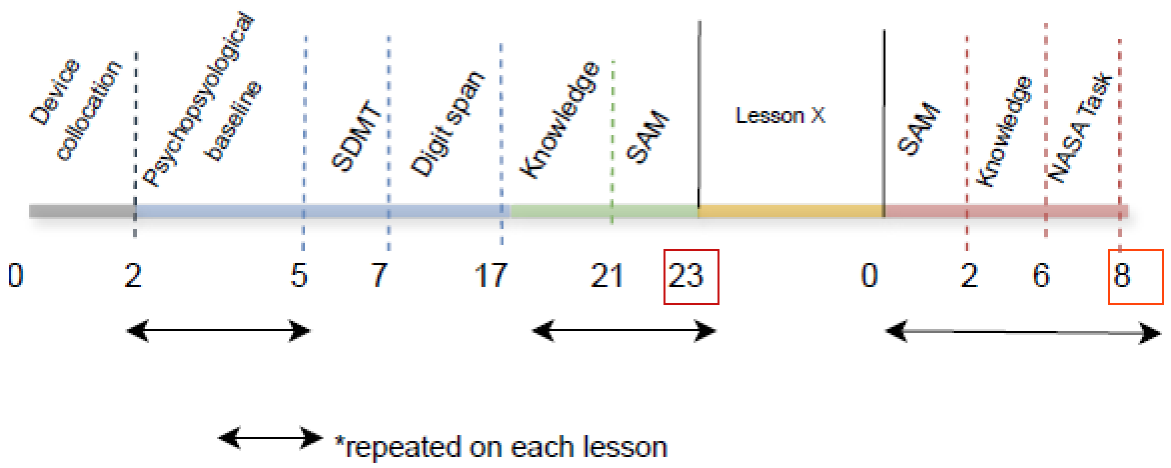

Figure 15:timeline questionnaires and task before each lesson

After the lesson ends, the participant needs to complete a few tasks, such as (1) the SAM scale, (2) the knowledge questionnaire, and (3) the NASA Task. These three activities will take approximately 8 minutes to complete.

After completing all the lessons of one prototype a usability questionnaire is needed to be answered, this takes 5 minutes. And contain questions of usability, presence and engagement of the prototype within disruptive technologies.

6. Conclusions

This deliverable proposes a methodology to analyse and test the different objectives of the study, focusing on the general question of the project: are disruptive technologies effective in learning? Therefore, this study will focus on the effectiveness of the use of disruptive technologies, the type of content presented and the mental model (cognitive and affective skills) that the person presents to approach learning.

Considering that the questions to be answered in the study are as follows:

RQ. Are disruptive technologies enhancing learning?

- RQ1: which technology (disruptive or non-disruptive) is the most effective for improving learning?
- RQ2: Which competences (logical, social and psychomotor) are best enhanced using different technologies?
- RQ3: How do cognitive and affective skills modulate learning using disruptive technologies?

We compare the experimental and control groups to answer the first research question (RQ1). This will be achieved by dividing the sample into a control group (no use of disruptive technologies) and an experimental group (use of disruptive technologies). This approach allows the same participant to complete lessons with and without disruptive technology within the same prototype.

This analysis aims to identify significant differences between learning facilitated by disruptive technologies and learning that is not. We anticipate that learning mediated by disruptive technologies will yield better results in acquiring new concepts. We will focus on comparative analyses of the pre-and post-lesson knowledge questionnaires for each lesson to obtain these results.

Following this initial analysis, we consider it essential to explore whether the type of content mediates learning outcomes across different technologies (disruptive and non-disruptive), answering the second question (RQ2). This analysis will continue to consider dividing groups into experimental and control. We will examine whether content impacts learning by separating data based on technology use and prototype (explained content). Different technologies (control group and experimental group) are compared by dividing the groups based on content. Significant differences are expected to be observed among the various contents.

Significant differences in learning outcomes across the various proposed contents are expected to be observed. To achieve this, pre- and post-knowledge questionnaire measures will be collected and completion times across the different prototypes.

After analysing the use of technologies and the influence of content, the next step is to observe whether the disposition and utilisation of cognitive characteristics impact learning outcomes. The aim is to analyse cognitive characteristics that positively enhance the learning process and those that may hinder or make it less optimal. Consequently, through machine learning, we aim to derive an optimal set of cognitive characteristics with which learning will be optimised, both in environments mediated by disruptive technologies and those that are not.

For this purpose, initial values from various questionnaires will be used, along with values from psychophysiological variables such as EDA (Electrodermal Activity) and HR (Heart Rate), as well as data collected from behavioural measures, specifically ET and activity flow.

With these three questions accomplished, a comprehensive analysis will be obtained regarding the effectiveness of technologies in learning across different content areas. Additionally, information will be gathered on optimal affective and cognitive characteristics conducive to effective learning.

References

Filgona, J., Sakiyo, J., Gwany, D. M., & Okoronka, A. U. (2020). Motivation in Learning. *Asian Journal of Education and Social Studies*, *10*(4), 16–37. https://doi.org/10.9734/ajess/2020/v10i430273

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. Sustainable operations and computers, 3, 275-285.

Harackiewicz JM, Smith JL, Priniski SJ. Interest Matters: The Importance of Promoting Interest in Education. Policy Insights Behav Brain Sci. 2016 Oct;3(2):220-227. doi: 10.1177/2372732216655542. Epub 2016 Jun 30. PMID: 29520371; PMCID: PMC5839644

Hart, S. E. S. G. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research Sandra. *Power Technology and Engineering*, *52*(5), 139–183. https://doi.org/10.1007/s10749-010-0111-6

Hidi, S., & Ann Renninger, K. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Jackson, J. W. (2002). Enhancing self-efficacy and learning performance. *Journal of Experimental Education*, *70*(3), 243–254. https://doi.org/10.1080/00220970209599508

Makransky, G., & Petersen, G. B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review*, *33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Mislevy, R. J., Steinberg, L. S., & Almond, R. G. (1999). On the roles of task model variables in assessment design. (CSE Technical Report 500). *Educational Testing Service*, *1522*(310). https://files.eric.ed.gov/fulltext/ED431804.pdf

Paas, F., & Sweller, J. (2012). An Evolutionary Upgrade of Cognitive Load Theory: Using the Human Motor System and Collaboration to Support the Learning of Complex Cognitive Tasks. *Educational Psychology Review*, *24*(1), 27–45. https://doi.org/10.1007/s10648-011-9179-2

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63–71. https://doi.org/10.1207/S15326985EP3801_8

Php. (s. f.). *EmotiBit.com*. EmotiBit. https://www.emotibit.com/

Renninger, K. A., & Hidi, S. E. (2022). Interest development, self-related information processing, and practice. *Theory into Practice*, *61*(1), 23–34. https://doi.org/10.1080/00405841.2021.1932159

Wu, C.-H., Tzeng, Y.-L., & Huang, Y. M. (2014). Understanding the relationship between physiological signals and digital game-based learning outcome. *Journal of Computers in Education*, *1*(1), 81–97. https://doi.org/10.1007/s40692-014-0006-x

e-DIPLOMA

Funded by
the European Union