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

e-DIPLOMA

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D2.1 Best practices report
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1.Introduction

1.1 Executive summary

The role of educational technologies has become increasingly transformative in shaping how individuals learn to solve problems. Artificial intelligence, and immersive learning technologies such as augmented, virtual and extended reality are beginning to reshape the practice based e-learning methods that have been commonly used in technology mediated realities. The research has indicated that practitioners are overtly optimistic about the benefits of new technologies in education, despite a lack of robust empirical evidence supporting their actual impact on learning outcomes. In an overview study Pata & Väljataga (2024) have demonstrated several cognitive, metacognitive, affective and psychomotor learning aspects with immersive learning environments, both beneficial to learning but also the critical ones. It was also evident in this overview that empirical studies often focus on the same learning effects, while the complexity of different learning effects is rarely considered and explored in the learning scenarios.

The aim of the deliverable is to demonstrate how effectively the e-DIPLOMA incorporated pedagogical paradigms into 3 prototypes' modules. We provide the validation of the prototypes in regards to the cognitive complexity elements and the achieved knowledge gain. The learning effects with immersive technologies are described in different educational levels in different settings; and by addressing learning of diverse social groups.

This deliverable provides the final report of e-DIPLOMA best practices using the pedagogical learning design complexity viewpoint. We used the data derived from e-DIPLOMA case studies. Empirically we illustrate our data with the learning situations from three e-DIPLOMA learning prototypes: Block programming, Social entrepreneurship and VR learning.

The report is structured into the sections describing cognitive complexity principles in designing practice based learning in immersive environments, illustrating how these principles were solved at the learning designs of e-DIPLOMA prototype modules, and evaluating which learning design elements can influence significantly learning gain with emerging technologies.

2. Methodology: Cognitive complexity analysis principles in e-DIPLOMA prototypes

As a variety of new and immersive technologies activating at the same time many sensory inputs and increasing users cognitive load, have become available and used in practice based elearning, aspects of cognitive ergonomics must be considered. Cognitive ergonomics uses scientific insights into human behavior and mental limits to enhance cognitive work (Lee, Wickens, Liu & Boyle, 2017), focusing on processes like perception, attention, memory, and decision-making in demanding, dynamic settings. Cognition and ergonomics refer to the mental processes involved in how people interact with tools, with the goal of designing these interactions to be as effective as possible (Dittmar et al., 2021) and centers on designing learning environments and technologies that support how people think, process information, and make decisions (Young et al., 2015). At its core, cognitive ergonomics aims to design systems that align with how people think and act, ensuring safe and reliable use (Branaghan, 2020) and to reduce the negative effect of learning and promote learner performance by optimising the relationship between the learner and technology, necessary also for learning situations with emerging technologies.

In particular, cognitive ergonomics is grounded in the human information-processing model outlining how people perceive, process, and respond to stimuli—represented as Perceptual Encoding, Central Processing, and Responding (Lee et al., 2017). Sensory input (e.g., vision, hearing, touch) is processed through bottom-up feature analysis, while at the same time long term memory provides top-down processing combining sensory information to form perceptions that help us interpret and recognize our environment. Sometimes, perception triggers immediate action, especially in urgent situations. Other times, we process it in working memory, where we combine it with other knowledge for tasks like planning, decision-making, and problem-solving. Working memory holds limited information briefly (Baddeley, 2012) and requires focused attention to maintain. With rehearsal, some of this information is encoded into long-term memory —a process when learning happens. Eventually, we act, and the resulting feedback restarts the cycle. This human information processing model highlights that cognitive resources—particularly attention and working memory—are limited, making it easy to become overwhelmed. This can lead to errors, poor communication, and reduced performance, especially in complex learning environments with new and immersive technologies which require many sensory inputs activation and information processing.

In this report we illustrate the cognitive complexity of learning designs for practice based learning with the examples taken from the e-DIPLOMA project prototypes. Complexity can be analyzed holistically combining different frameworks in the practice based learning model. The following frameworks and models were implemented to study the potential complexity of prototypes.

2.1 Learning goals and competencies

Learning goals and cognitive competencies define the complexity of learning design, especially when immersive technologies are used to simulate authentic, multi-layered scenarios. By aligning the sophistication of these technologies with the intricacy of the targeted competencies, the design process becomes more demanding in creating meaningful learning experiences.

2.1.1 Goal of the learning activity

Every learning activity has learning goals related to domain knowledge and a set of desired competences (cognitive, affective, psychomotor) a learner is expected to acquire. In our case the learning goals and competences are related to the e-DIPLOMA prototypes such as block programming and computational thinking, social entrepreneurial concepts and strategies, learning theories and principles' applicability, etc.

2.1.2 Cognitive competences

For analysing cognitive competences incorporated into the e-DIPLOMA prototypes, Bloom's taxonomy (Bloom, 1956) cognitive levels from lower-order to higher-order thinking were used:

1. Remember - recalling relevant knowledge from a long-term memory. Learner tasks can be for instance to list, recite, outline, define, name, match, quote, recall, identify, label, recognize (e.g., By the end of this lesson, the student will be able to recite Newton's three laws of motion).
2. Understand - explaining ideas or concepts. Learner tasks can be for instance to describe, explain, paraphrase, restate, give original examples of, summarize, contrast, interpret, discuss (e.g., By the end of this lesson, the student will be able to describe Newton's three laws of motion in her/his own words).
3. Apply - using information in new situations. Learner tasks can be for instance to calculate, predict, apply, solve, illustrate, use, demonstrate, determine, model, perform, present (e.g., By the end of this lesson, the student will be able to calculate the kinetic energy of a projectile).

4. Analyze - analyzing parts of a whole to understand their relationships and overall purpose. Learner tasks can be for instance to classify, break down, categorize, analyze, diagram, illustrate, criticize, simplify, associate (e.g., By the end of this lesson, the student will be able to differentiate between potential and kinetic energy).
5. Evaluate - making judgments and justifying decisions. Learner tasks can be for instance to choose, support, relate, determine, defend, judge, grade, compare, contrast, argue, justify, support, convince, select, evaluate (e.g., By the end of this lesson, the student will be able to determine whether using conservation of energy or conservation of momentum would be more appropriate for solving a dynamics problem).
6. Create - combining elements to create a unified whole or new structure. Learner tasks can be for instance to design, formulate, build, invent, create, compose, generate, derive, modify, develop (e.g., By the end of this lesson, the student will be able to design an original homework problem dealing with the principle of conservation of energy).

In addition, the number of concepts related to the study topic to be learned during the learning activity contributes to the complexity of the learning design and influences learners cognitive load.

2.2 Interaction in problem space

In educational and cognitive ergonomics contexts, understanding the problem space is essential for designing learning environments that align with how learners interact and are engaged. In addition, the complexity of the problem space such as the ambiguity and the type of the problem directly influences cognitive load and affects learners' ability to engage in meaningful learning and knowledge construction.

2.2.1 Problem typology

Complex problem solving needs strategies that are introduced through a structured approach that may involve the use of formulas, the application of specific rules, or a sequence of clearly defined steps. To carry out the learning task effectively, learners are required to use appropriate tools, which could include augmented reality (AR) applications, physical instruments, or measurement devices, depending on the context of the problem. The nature of the solutions can vary; some problems may have concrete, well-defined answers, while others may be open-ended, encouraging creative thinking and allowing for multiple valid solutions. According to Jonassen (2000) a list of problem types being on a continuum of well-structured to ill-structured were identified:

1) Logical Problems: abstract tests of reasoning that puzzle the learner
2) Algorithmic Problems: repeating a series of steps through a procedure or formula
3) Story Problems: story with formula or procedure embedded
4) Rule-Using Problems: clear purpose or goal that is constrained but not restricted to a specific procedure or method
5) Decision-Making Problems: selecting a single option from a set of alternatives based on a set of criteria
6) Troubleshooting Problems: fault state diagnosis
7) Strategic Performance: real-time, complex performance with competing needs
8) Case-Analysis Problems: complex, leisure-time system with multiple ill-defined goals
9) Design Problems: vague goal statement with few constraints; requires structuring
10) Dilemmas: situation with contradictory positions

2.2.2 Learner engagement

According to Kolb (1984) effective learning occurs through a continuous cycle of experience, reflection, conceptualization, and experimentation. Learner engagement in the activity in experiential learning phases follows Kolb's experiential learning cycle:

- Concrete Experience – The learner goes through a direct experience, which could be something entirely new or a fresh take on a past event based on new perspectives or ideas.
- Reflective Observation – The learner thinks deeply about the experience, comparing it to what they already know. They focus especially on any gaps or contradictions between what they expected and what actually happened.
- Abstract Conceptualization – From this reflection, the learner forms new ideas or updates existing theories. This stage represents the actual learning, where insights begin to take shape.
- Active Experimentation – The learner tests their new ideas in real-life situations, applying what they've learned to see the results and refine their understanding.

2.2.3. Learner interactivity

Immersive technologies afford multiple levels of learner interaction—ranging from basic navigation and exploration to complex problem-solving and collaborative engagement—which inherently increases the complexity of learning design. Based on Väljataga et al. (2015), the following category was taken as a basis for understanding learners' interaction with immersive technologies and content in the e-DIPLOMA prototypes:

- Consume - This is the most basic form of interaction with technology and content. Learners passively engage by watching, listening, or reading. The content remains unchanged and unaltered.
- Annotate - Users add personal or social meaning to existing content through actions like highlighting, liking, tagging, rating, or commenting. These annotations typically affect only the metadata and may be shared in online environments.
- Manipulate – Learners interact with elements within the content (e.g., clicking, dragging, or entering data), but they cannot change or add to the core content. These interactions may provide immediate feedback but are temporary and leave the original content untouched.
- Submit – Learners actively respond to prompts, solve problems, or engage with interactive tasks, with their input submitted for teacher or peer review. Although engagement deepens, the learners' contributions are not embedded into the original content.
- Expand - Learners add small contributions to existing content—such as completing gaps, adding a caption, or combining clips—while keeping the original material largely intact and recognizable.
- Remix - Learners transform content by changing, rearranging, or merging elements to create a new version. The original may become unrecognizable, and the meaning may shift significantly, reflecting the student's own creative expression.
- Create - Learners generate entirely original content from the ground up, without relying on pre-existing material. This represents the highest level of creative engagement.

2.3 Social learning

Social learning emphasizes the role of social interaction in acquiring knowledge, where learners construct understanding through collaboration, discussion, and shared experiences. It often involves scaffolding, where more knowledgeable peers or instructors provide structured support to help learners achieve tasks just beyond their current abilities.

2.3.1. Social interaction in learning

Learning is highly embedded in social interaction (Bandura, 2001; Vygotsky, 1978). In addition to interacting individually with the content and technology, interaction with the facilitator, peers or AI chatbots in collaborative groups introduces an interpersonal element to conceptual knowledge adding an extra level of complexity as different social interactions introduce a range of perspectives, communication styles, and interpersonal dynamics. When learners collaborate, negotiate, or engage in discussions, they must not only focus on the content but also navigate social cues, group roles, and varying levels of understanding among peers. It's important to develop mutual understanding of the content being learned, foster group cognition, and recognize how learning is co-driven by the group. Thus, different types of social interactions from individual, pair with facilitator, group with facilitator, peer-to-peer to AI-partnered were detected.

2.3.2 Scaffolding types

Scaffolding, a concept derived from Vygotsky's "zone of proximal development" (Vygotsky, 1978), involves using various strategies to help students complete tasks they would not be able to achieve on their own. As an instructional approach, scaffolding offers learners guidance, feedback, and support, which can be effectively delivered through well-designed technological tools. Scaffolding types refer to what type of support (scaffolding) is provided by humans or with technology. Four scaffolding types (conceptual, metacognitive, procedural, strategic scaffolding) have been determined by Hill and Hannafin (2001) and affective scaffolding by Steinert, Marin & Roeser (2022) as follows:

- conceptual scaffolding (mechanisms for supporting students to reason through complex problems as well as concepts where misconceptions are prevalent, e.g. providing a hint to help students to reach a solution, coaching comments, providing feedback and advice on performance);
- metacognitive (mechanisms for supporting underlying learning management processes and thinking about a task, e.g. students are encouraged to engage in introspection by being asked questions and having their weaknesses highlighted, prompted to recall a familiar experience or concept from their own lives);
- procedural scaffolding (mechanisms for emphasising various ways to utilise the available resources and tools within a given environment, e.g. teachers can provide continuous assistance and guidance on the functions and capabilities of the system, as well as how to utilise them);
- strategic scaffolding (mechanism for guiding students in examining and tackling learning tasks or problems, while emphasising the usefulness of alternative methods, e.g. informing the student about tools and resources that are accessible and could be beneficial in certain situations, while also offering instruction on how to utilise them)
- affective scaffolding (mechanisms for supporting emotions and motivation, e.g. environmental resources).

2.4 Presentation of the problem situation

The problem situation can be presented in multiple ways. Using a mix of multimedia types—such as text, images, audio, video, etc. —can help engage multiple sensory channels (visual, auditory, etc.), enhancing comprehension and retention. By strategically combining multimedia modes (e.g., narration with visuals), content can be presented in a more accessible and meaningful way, reducing cognitive load and supporting diverse learning needs.

2.4.1 Sensory channels

Emerging technology provides multiple sensorial media making possible the inclusion of layered sensory stimulation and interaction through multiple sensory channels (Ghinea et al., 2014). Immersive technology can bring in other sensory channels besides visual and auditory - tactile (processing touch information from the body), vestibular (sense of head movement, orientation and balance in the space), proprioceptive (sensations from muscles and joints of body, senses of the position, location, orientation, and movement of the body muscles and joints, sense of the relative position of neighbouring parts of the body and effort used to move body parts), gustatory (sensations from tastes), olfactory (sensations from smells).

2.4.2 Multimedia types

Emerging learning technologies provide new ways of affording learning within the practice based learning situations. The problem solving guidance with different digital content forms (multimedia, mulsemedia (Mayer, 2005)) supplied by immersive technologies and adaptive AI support creates the medium and object for practice where cognitive, metacognitive, affective and psychomotor and embodied learning effects may be differently experienced and facilitated. In immersive technologies the practice based learning situations have become multilayered (AR), multisensorial (XR), the search area is immersive surrounding (VR, XR) that opens up different spatial and 3-dimensional perspectives of the problem space. In e-DIPLOMA prototypes a list of immersive technologies such as VR, AI chatbot, AR, XR, virtual games, TEAMS chat were implemented to mediate learning experiences.

2.4.3 Multimedia modes

In the context of immersive technology, multimedia modes—such as visual, auditory, and kinesthetic—are integrated to create rich, interactive learning experiences. Virtual and augmented reality environments engage multiple senses simultaneously, combining 3D visuals, spatial audio, and haptic feedback. This multimodal approach allows for more embodied and experiential learning compared to traditional media.

2.5 Analysis of e-DIPLOMA prototypes based on problem space complexity

To understand the complexity of learning designs in e-DIPLOMA three prototypes, we analyzed each module in the e-DIPLOMA prototypes based on problem space complexity, problem representation and the interactivity. Modules in the prototypes were analysed according to 11 different aspects of learning design (presented above) on a scale from 0 - 4 divided into four dimensions:

I Learning goals and competencies:

- number of concepts related to the prototype's study topic to be learned - from 0 no concepts mentioned to 4 (or more concepts);
- number of expected learning effects (metacognitive, cognitive, affective, psychomotor) - from 0 not mentioned to 4 or more learning effects;
- purpose of the learning scenario according to Bloom's taxonomy (Bloom, 1956) (remember, understand, create, apply, analyse, evaluate) - from 0 no purpose mentioned, 1 remember or understand, 2 create or apply, 3 analyse, to 4 evaluate;

II Interaction in problem space:

- problem solving types (Jonassen, 2000) - from 0 not mentioned, 1 logical or algorithmic or story problems, 2 rule using or decision making or troubleshooting, 3 diagnosis-solution, strategic, situated case policy, 4 design problems or dilemmas;
- learner interactivity level according to (Väljataga et al., 2015) learner interactivity levels with the learning content - from 0 not mentioned, 1 consume, 2 annotate or manipulate or submit, 3 expand or remix to 4 create;
- experiential learning phase according to experiential learning model (Kolb, 1984) - from 0 not mentioned, 1 concrete experience, 2, reflective observation, 3 abstract conceptualisation to 4 active experimentation;

III Social learning

- types of learning modes considering individual, pair with facilitator, group with facilitator, peer-to-peer, AI partnered - from 0 to 4 or more learning mode types;
- number of scaffolding types according to (Hill & Hannafin, 2001) (conceptual, meta-cognitive, strategic and procedural scaffolding) - from 0 to 4 or more scaffolding types;

IV presentation of the problem situation

- number of sensory channels such visual, text reading, haptic, auditive, vestibular - from to 4 or more different sensory channels;
- number of multimedia types such as VR, AI chatbot, AR, XR, virtual game, Teams chat - from 0 to 4 or more different multimedia types;
- number of multimedia modes such as image, text, sound, model avatar, heuristic, video - from 0 not mentioned to 4 or more different multimedia modes.

In case the learning design of a module at the same time consisted of, for example, many different levels of problem solving types, different experiential learning phases, different levels of learner interactivity, etc. the highest number was chosen to be included to the analysis to demonstrate the cognitive demand required to complete the module. The data was visualised as radar graphs.

3. Results: The cognitive complexity of learning practices in the e-DIPLOMA prototypes

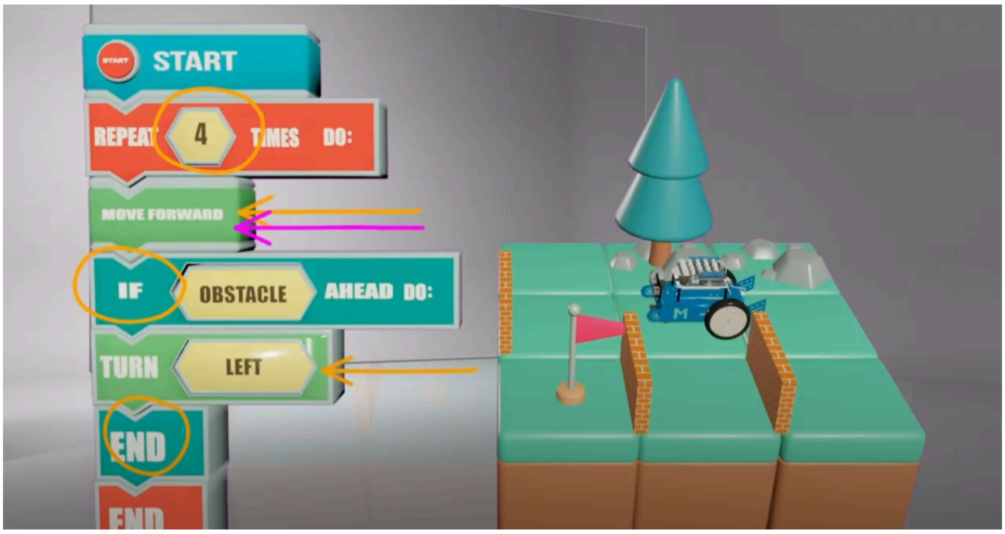
This chapter explores the cognitive dimensions of learning as they emerge within the e-DIPLOMA prototypes, a series of innovative digital learning environments designed to enhance student engagement and understanding. As education increasingly incorporates immersive technologies and multimedia tools, the nature of learning practices becomes more complex, involving not only content mastery but also the navigation of diverse sensory channels, interactive interfaces, and collaborative dynamics. The e-DIPLOMA prototypes offer a unique lens through which to examine how learners process information, solve problems, and construct meaning in digitally mediated contexts. By analyzing these practices, this chapter aims to shed light on the evolving cognitive demands placed on learners and the pedagogical approaches needed to support them effectively.

3.1 Prototype 1 - Block programming

Prototype 1 aims to provide students with basic knowledge of programming and electronics, enabling them to experiment through immersive virtual reality and augmented reality while receiving theoretical lessons via an innovative video-based format. The primary objective was to encourage students from any field of study to engage with computer science and develop digital competencies. The students were to acquire the following competencies: Knowledge, design, and efficient use of the most appropriate coding structures and commands to solve problems; Ability to understand, analyze, and evaluate the structure and architecture of microcontrollers; Ability to design and evaluate human-computer interfaces that ensure accessibility and usability. In sequential modules the students had to: Translate basic algorithms expressed in natural language into code, logic, and proper functions; Describe the different types of input and output sensors available; Explain the main sensor-based interaction techniques; Develop basic programs to interact with various types of sensors. Prototype consists of 5 learning modules that used VR and AR for simulating practice in elearning.

3.1.1 Prototype 1 Module 1

Module 1 introduces theoretical concepts via audiovisual content on general programming topics, which are practiced in the next module. The learners are individually expected to understand and learn three different concepts related to general programming supported by videos, thus participating in the module with low interactivity. Figure 1 presents the cognitive complexity assessed by the learning design elements as described in the methodology section.



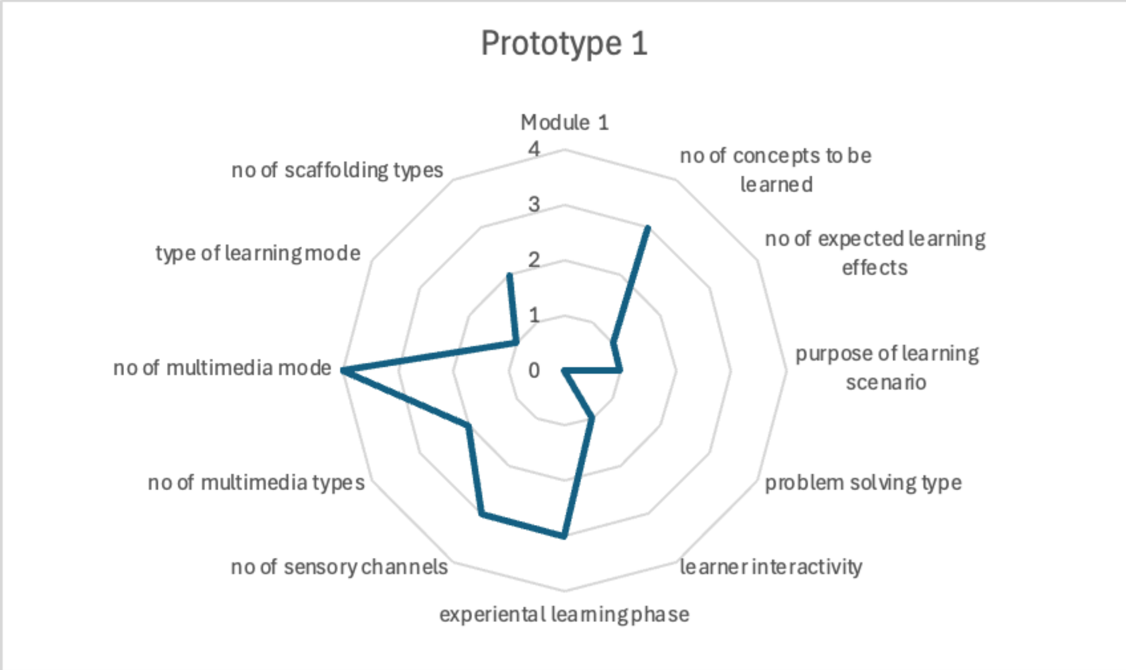


Figure 1. Screenshot from the module and cognitive complexity radar in module 1 (Prototype 1).

3.1.2 Prototype 1 Module 2

Module 2 features an interactive activity with practical block-based programming exercises in an immersive virtual environment (VR) using a Head-Mounted Display (HMD). The learners are individually expected to actively experiment in a VR environment to solve simple problems, with the goal of implementing three previously acquired programming-related concepts. Figure 2 presents the complexity of the learning design in module 2 and the screenshot from the learning environment.

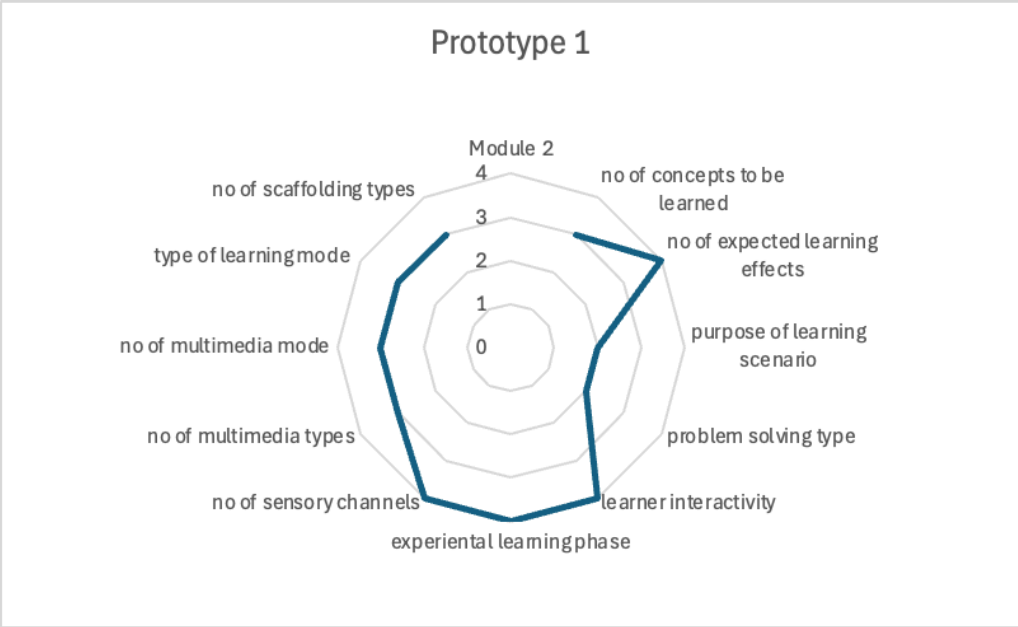
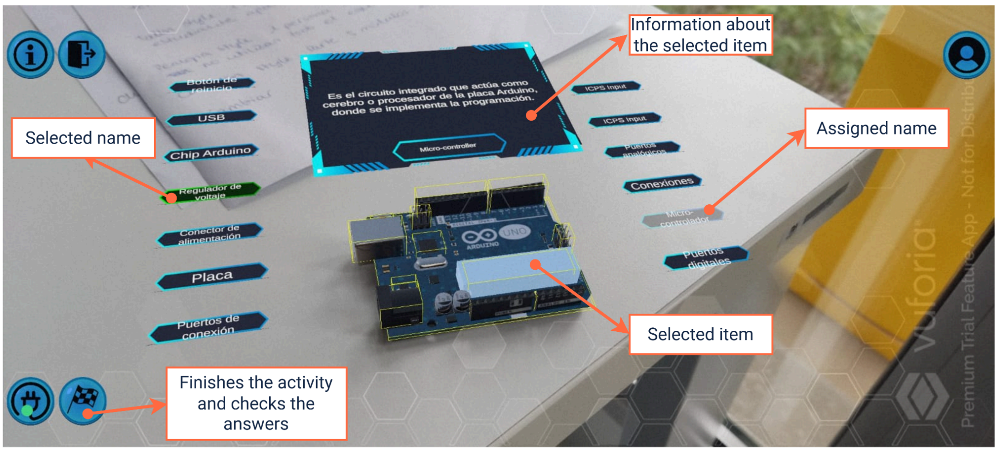


Figure 2. Screenshot from the module and cognitive complexity radar in module 2 (Prototype 1)

3.1.3 Prototype 1 Module 3

Module 3 presents theoretical concepts via audiovisual content on the basics of electronics: the Arduino board, sensors, actuators, and how they are assembled. The learners are expected to understand the concepts by watching videos individually. Figure 3 presents the screenshot and the complexity of the learning design in module 3.



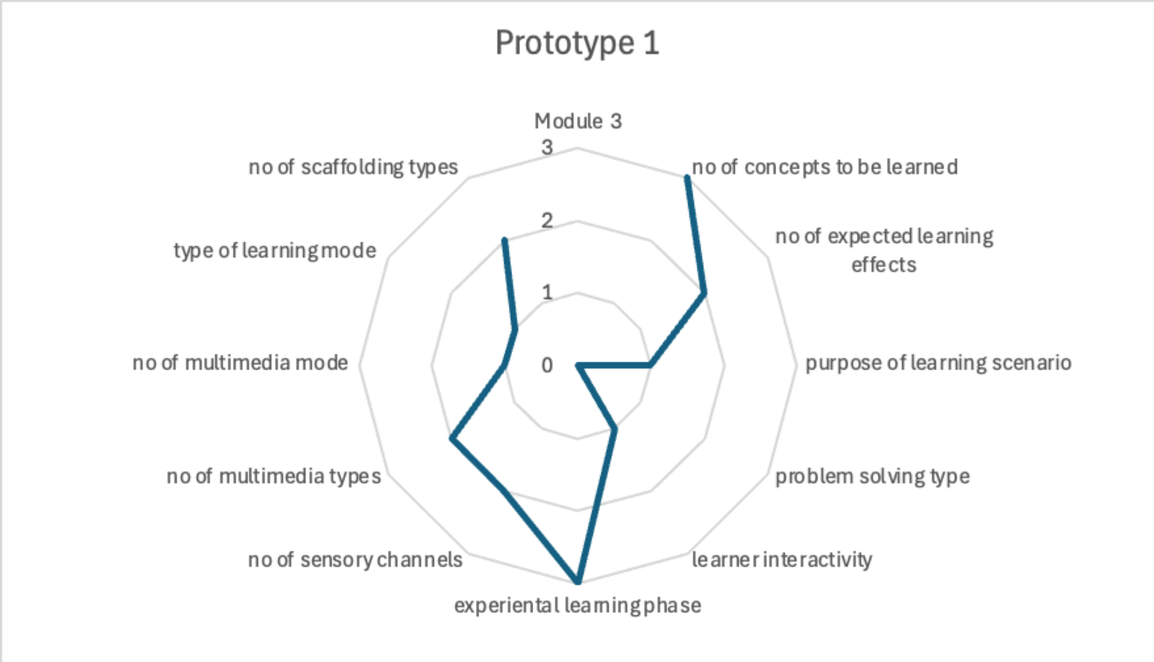
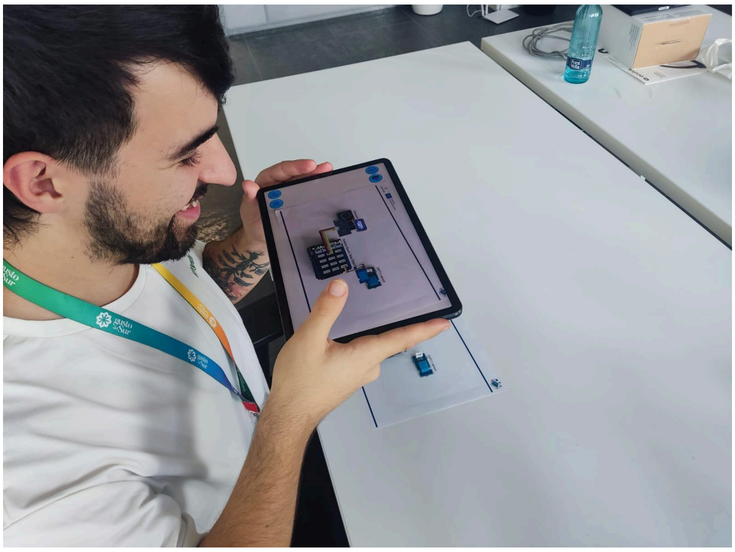


Figure 3. Screenshot from the module and cognitive complexity radar in module 3 (Prototype 1).

3.1.4 Prototype 1 Module 4

Module 4 uses augmented reality (AR) to identify the various devices covered in the course, display key information about them, and allow students to complete exercises related to their connections and communication. The learners are individually expected to understand and actively experiment with the concepts acquired in the previous modules supported by AR technologies. The screenshot and the cognitive complexity of module 4 is presented in Figure 4.



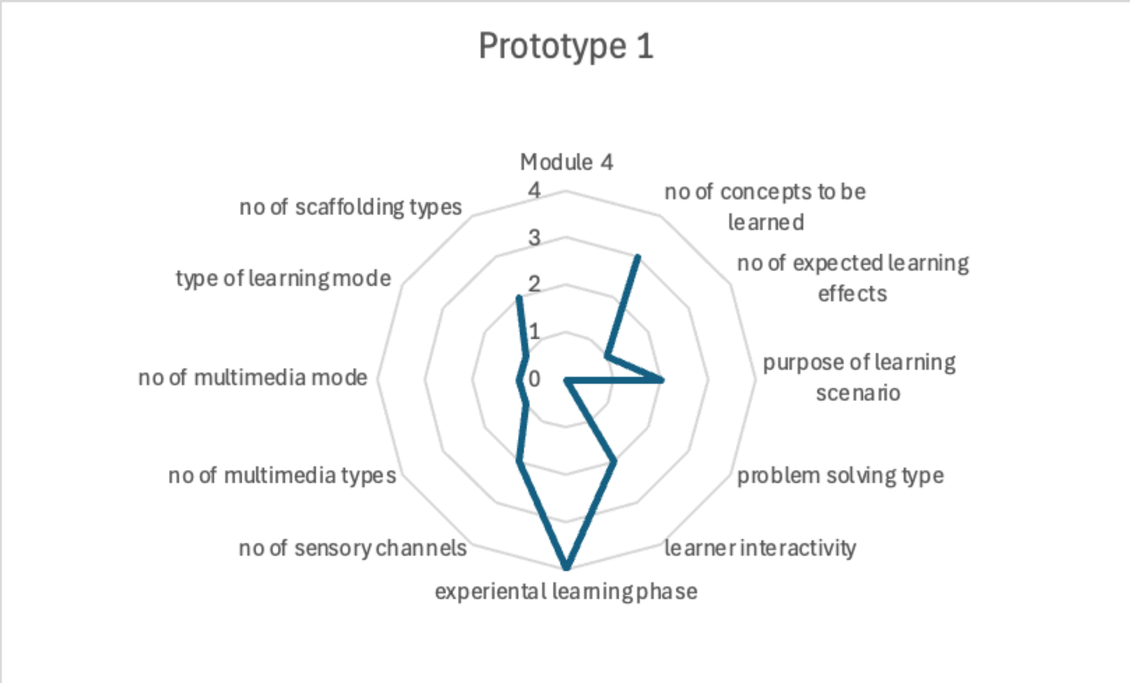


Figure 4. Screenshot from the module and cognitive complexity radar in module 4 (Prototype 1).

3.1.5 Prototype 1 Module 5

Finally, module 5 retains the final project titled *Saving the Earth*. In pairs, within an immersive virtual reality VR environment using HMD, students collaborate to achieve a common objective by applying the knowledge they have gained in electronics and programming. The cognitive complexity of module 5, along screenshots, are presented in Figure 5.

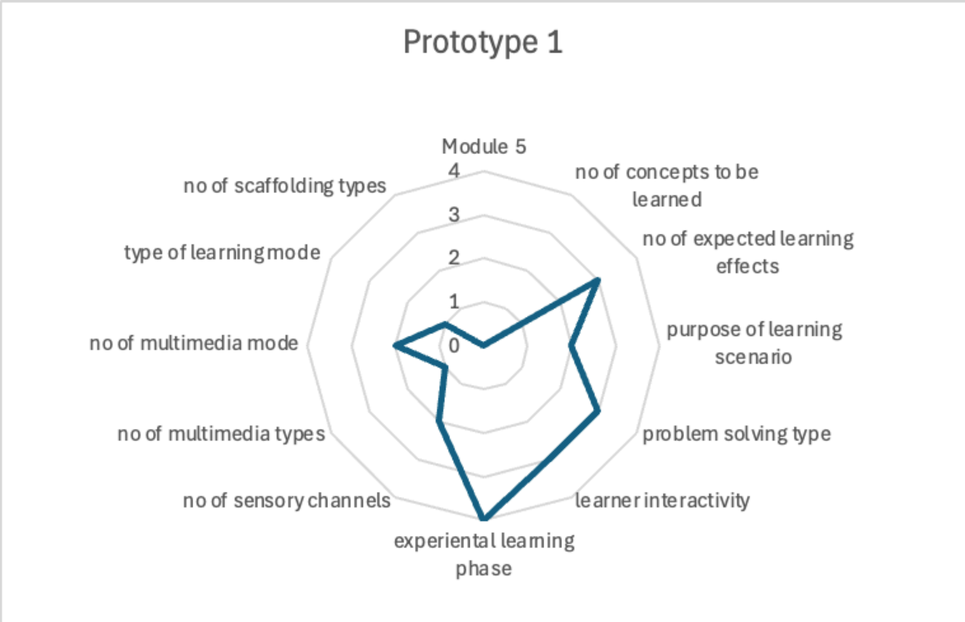


Figure 5. Screenshots from the module and cognitive complexity radar in module 5 (Prototype 1).

3.1.6. Summary of cognitive complexity in prototype 1

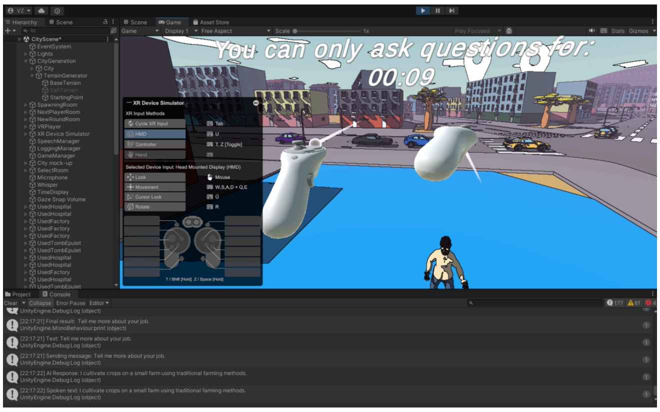
The analysis of cognitive complexity across the five modules of Prototype 1, as illustrated in the radar charts above, highlights notable variations in the balance of instructional features and cognitive demands.
As a result, it becomes evident that Modules 1 and 3 assume lower cognitive demand, and engage learners to self-learning without using immersive learning environments. Module 1 emphasizes multimedia use, with moderate levels of scaffolding and experiential phases, but minimal learner interactivity and problem-solving. This suggests a focus on content exposure rather than active engagement. Module 3 on the other contrary focuses on conceptual depth and experiential learning, while scoring low in interactivity and problem-solving. Its design promotes reflective understanding but limits opportunities for applied, collaborative learning. Moreover, Module 4, where learning takes place with AR has a similar cognitive complexity as the activities with multimedia. Module 2 where learning with VR assumes solving a simple rule-based problem requires the highest cognitive demand due to many aspects such as the number of multimedia types, learning modes and expected learning effects was rated on the highest hierarchical levels. Yet Module 5, where students work collaboratively on a rule based cloud programming task, had a lower complexity than Module 4, as less scaffolding provided. This progression suggests a differentiated pedagogical design within Prototype 1, where each module addresses distinct aspects of the learning process, though with varying degrees of cognitive complexity.

3.2 Prototype 2 – Social entrepreneurship

e-DIPLOMA prototype 2 aims to address the development and management of social enterprises in an e-learning training course featuring emerging or disruptive ICT innovations. The general aim of the prototype is to create awareness about social economy and social enterprises, highlight the role of social entrepreneurship that creates social change, deepen participants understanding of the world around them, and to inspire them to create a vision where their passion and desire for change meets self-employability, while testing ICT innovations for e-learning. Students in this course will gain knowledge about social entrepreneurs and how they develop solutions to address societal problems, learn how to develop creative solutions to address social problems, and gain self-empowerment by viewing social entrepreneurship as a force for social change.

3.2.1 Prototype 2 Module 1

Module 1 “Lodestars – The Social Entrepreneur” has a complex problem space representation that requires the use of multiple sensory channels. It is an immersive VR game, where the players need to talk in the microphone to AI chatbots representing social entrepreneurs and other characters like criminals, regular social workers, plain old school for-profit businesses, and customers. They can discuss their experiences, ambitions and may learn about other characters in the city to whom players can teleport using hand controllers. The game itself is played by multiple people, each taking turns venturing into the virtual world, after which they return to their groups to discuss the conversations they had, fostering social learning. The problem-solving situation includes elements of procedural scaffolding. The problem is presented ambiguously. Rule-based problem solving is to be used where learner interactivity is low and at concrete experience level - learners manipulate controllers, microphone, ask questions, but cannot analyze collected information during their game turn, but need to remember what they learnt for later discussions. The cognitive complexity of module 1 of the prototype 2 is presented in Figure 6 together with some screenshots from the learning environments.



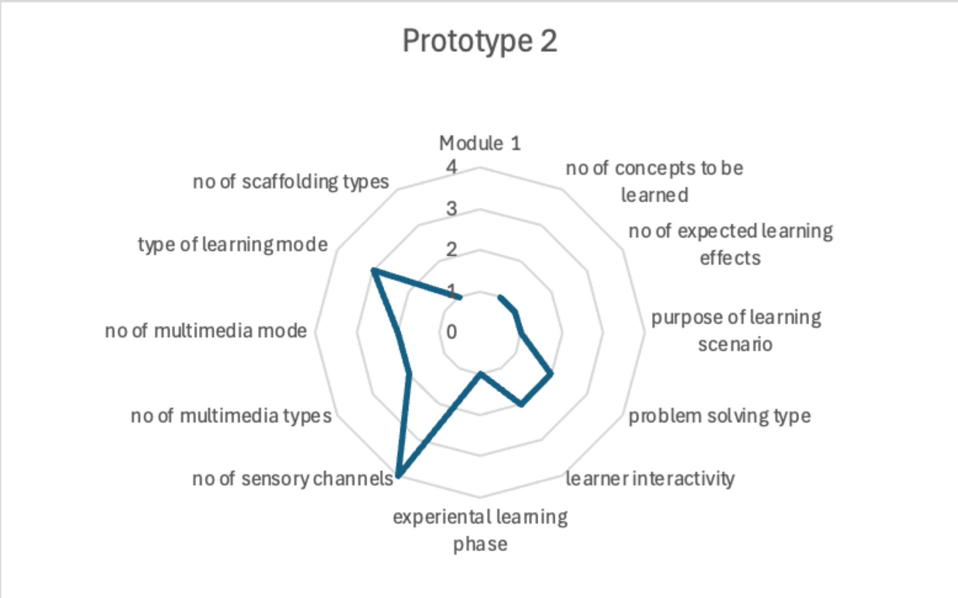
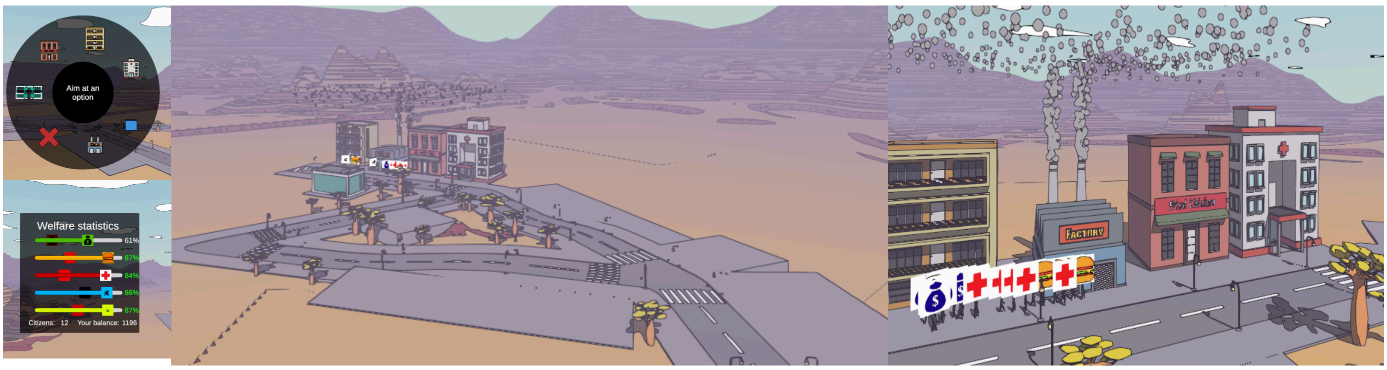


Figure 6. Screenshots from the module and cognitive complexity radar in module 1 (Prototype 2).

3.2.2 Prototype 2 Module 2

Module 2 “Heroes: Stakeholders and societal change” presents a complex, dynamically evolving, multisensory gamified learning environment where learners needed to control the handheld controllers, monitor dashboards, as well as to pay attention to the changes in virtual town. The concepts to be learned are holistic, focusing on collaborative city planning that considers mutual benefits. Heroes is a multiplayer game teaching collective dynamic decision-making when building a city with shops, hospitals, cinemas and factories in appropriate neighborhoods. Learners need to control and monitor money, health, pollution and energy levels visible at dashboards to keep citizens happy. This requires active experimentation with application of abstract concepts into the decision-making situations where analysis and evaluation are important. Each player could act autonomously in VR, but they could communicate in the physical room to collaborate. The players could approve or delete each other's constructions. Players could cooperate but this was not specifically asked. They needed to act fast as there was a race against time, to expand the town to a certain size. The instructional scaffolding was given only in the beginning of the game. Figure 7 presents screenshots from the learning environment and the cognitive complexity of module 2.



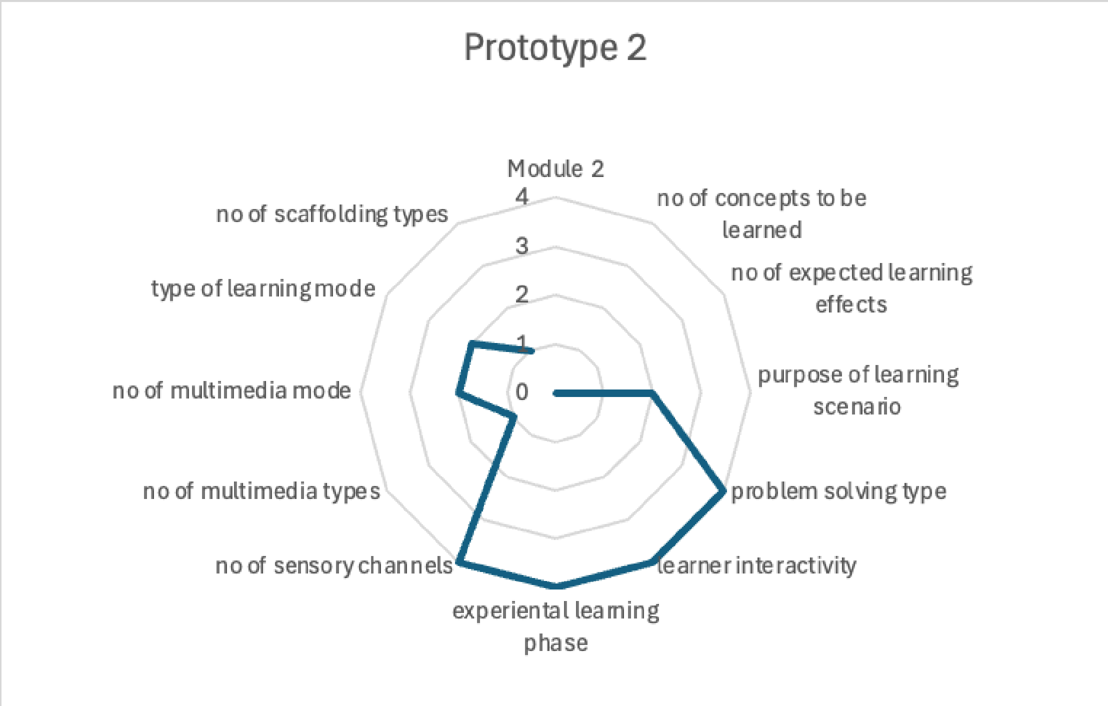


Figure 7. Screenshots from the module and cognitive complexity radar in module 2 (Prototype 2).

3.2.3 Prototype 2 Module 3

Module 3 "Painters - business planning" was designed for the participation of 4 students in VR and a moderator who also acts as the experimental session controller. The learning room was created by the integration of Moodle and AWS virtual machines running Brainstorm Edison Software where the Business model canvas project was running. The students were invited by the moderator in turn to carry out the completion of the business model canvas areas during a determined time duration. Using the Teams conferencing tool, students could query and consult four AI Personas developed for the prototype. The personas' knowledge was focused on social entrepreneurship and the students were supported on this topic while they were completing the business model canvas exercise. The students were asked to communicate within the group in the MS Teams conferencing tool room to discuss the items that were to be added at every canvas area. The complexity of the module is presented below together with some screenshots from the learning environment in Figure 8.

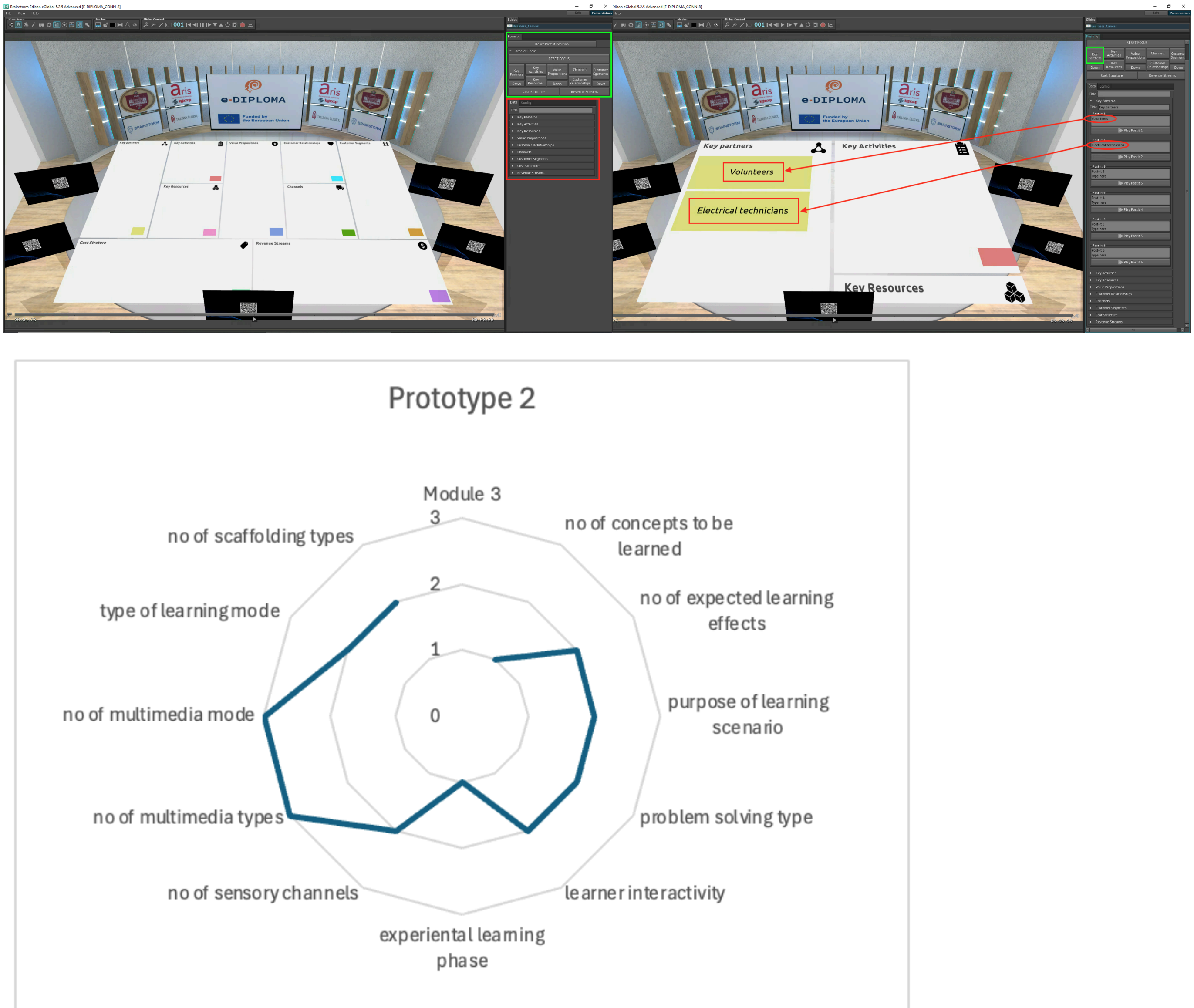


Figure 8. Screenshots from the module and cognitive complexity radar in module 3 (Prototype 2).

3.2.4 Prototype 2 Module 4

Module 4 "Allies – Social Human Resources and Team Management" is a single-player dynamic decision-making game, where the player must recruit and manage an efficient team as a social entrepreneur to sell used goods. The recruitment and managing must be done simultaneously. During interviews the player talks with applicants roleplayed by a Large Language Model (LLM) to discover their personality traits and negotiates the wages. In the managing part the hired team members must be assigned to roles in the company, monitoring their performance and behavior and reacting accordingly. The dashboards must be monitored to see how well the company is doing. The game is time-limited, and the player's performance is measured based on the final team's effectiveness, along with the company's growth, revenue, and social impact. The game requires multitasking as time is not stopped during an interview. On the contrary, new tasks and problems can arise dynamically and must be handled swiftly. Figure 9 presents the cognitive complexity and screenshots of module 4.

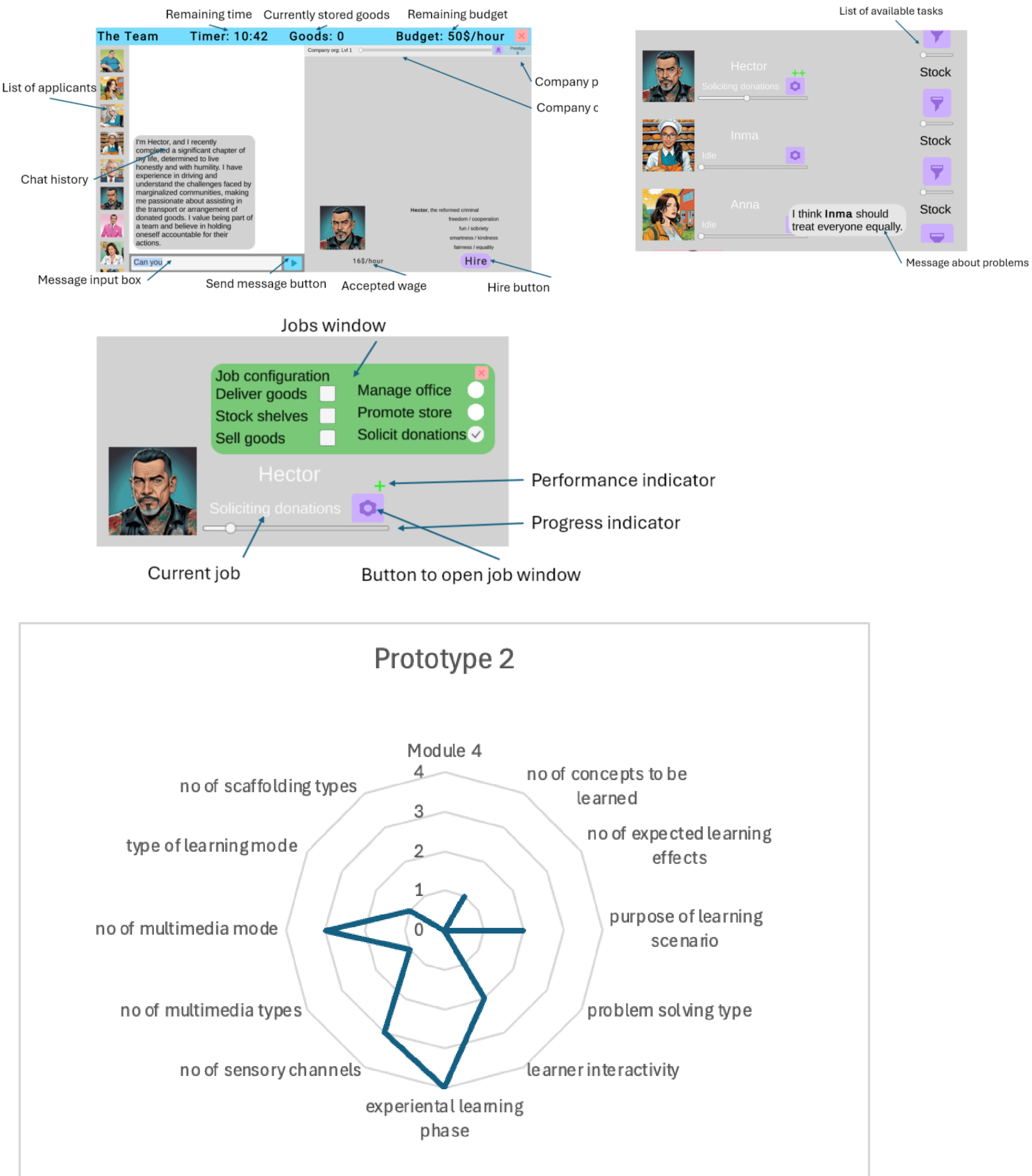


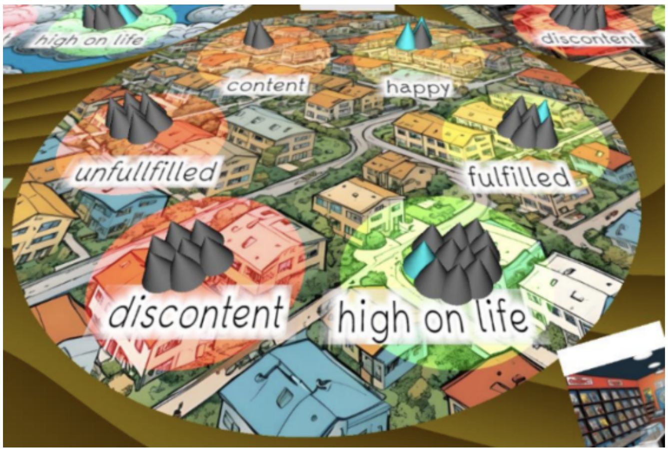
Figure 9. Screenshots from the module and cognitive complexity radar in module 4 (Prototype 2).

3.2.5 Prototype 2 Module 5

Module 5 “Angels – Social Product Management and Marketing” is an online board game played by four players featuring an underlying market simulation. It teaches financing options, market research, product positioning, and marketing in a learning-by-doing approach. The game is set in a fictional city, with four districts, represented by textured discs. Every district has 36 representative citizens, represented by pawns. All citizens are categorized into six groups based on seven social indicators.

While playing the game is a group activity, it is a competitive game simulating market dynamics, where outcompeting rivals or following leaders could be fruitful strategies.

The game consists of *rounds* and *phases*. The first round has a single, *starting* phase where players cannot perform any action, but they can navigate the play area, hover the mouse over game elements, and read corresponding tooltips. They learn about the basics of the game in this phase. Later rounds all consist of three phases: *Carousel phase*: a set of cards rotates slowly over the game area. Players can pick cards that are in the quarter of the carousel closest to them, as long as they have enough *picks*. Cards represent business development opportunities, and the number of picks depends on the financing and sales the player has. The choice between several cards is the main mechanism in the game. Making this choice can be based on the knowledge displayed on the cards in the form of imagery, short catchphrases, but also slightly more detailed tooltip explanations. Picked cards move to the player's hand. *Planning phase*: players can, independently, play any number of cards from their hands. These actions are not revealed to the other players. *Sales phase*: the results of the actions are evaluated and displayed to all players. Sales are performed and tallied. Figure 10 presents the screenshots and the cognitive complexity of module 5.



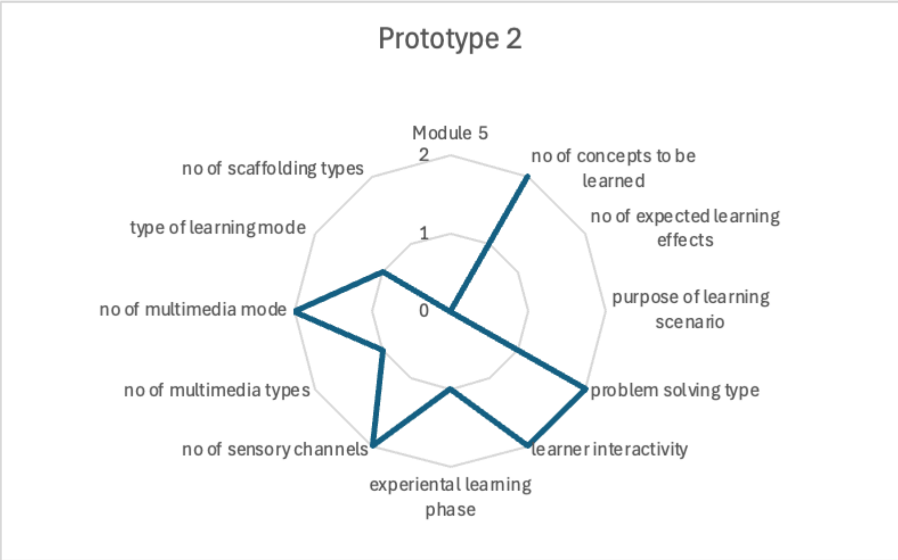


Figure 10. Screenshots from the module and cognitive complexity radar in module 5 (Prototype 2)

3.2.6 Summary of cognitive complexity in Prototype 2

The analysis of Prototype 2nd five instructional modules reveals varying levels of cognitive complexity across multiple dimensions, as visualized in the radar charts. Module 1 emphasizes a sensory-rich and multimedia-driven learning experience, excelling in the number of sensory channels and multimedia modes but showing lower complexity in problem-solving, experiential learning, and interactivity, suggesting a more passive and information-oriented design. It is designed to present information rather than actively engage learners in problem-based or experiential activities. In contrast, Module 2 exhibits higher cognitive complexity in problem-solving, learner interactivity, and experiential learning, pointing toward an active, practice-oriented approach, albeit with limited theoretical depth. Module 3 adopts a more balanced structure. It maintains moderate to high levels across several dimensions, combining conceptual understanding with interactive and multimedia elements, though it places less emphasis on experiential learning. Module 4 demonstrates moderate performance, particularly in experiential learning and multimedia modes, but falls short in problem-solving, scaffolding, and purpose-driven learning scenarios. Finally, Module 5 emerges as the most content-rich and interactive, excelling in conceptual density, learner interactivity, sensory engagement, and multimedia integration, although it remains limited in scaffolding and expected learning effects.

Taken together, the five modules display complementary strengths: Module 1 focuses on sensory engagement, Modules 2 and 4 emphasize experiential dimensions—with Module 2 further enhancing interactivity and problem-solving—Module 3 balances theoretical and interactive elements, and Module 5 integrates content richness with active, multisensory engagement. This diversity suggests that Prototype 2 is designed to address multiple facets of the learning process, offering a multifaceted instructional approach.

3.3 Prototype 3 - Virtual Reality in education

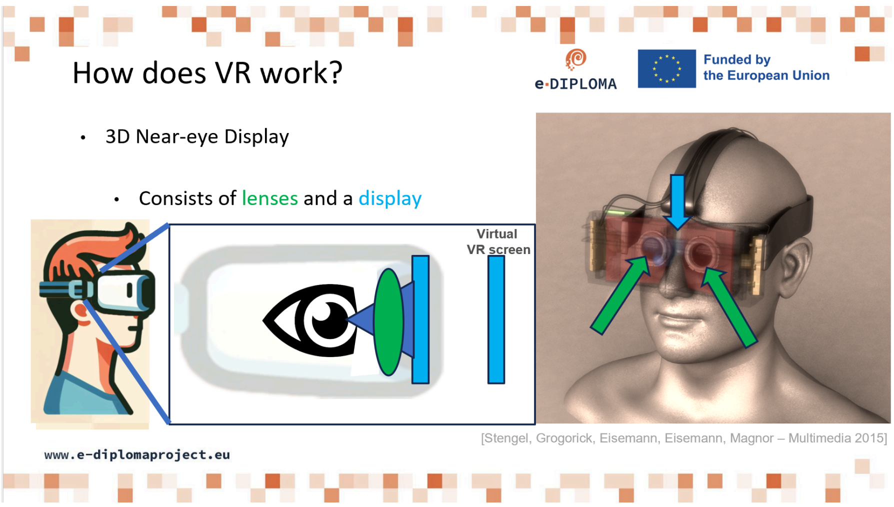
This prototype aims to teach, explore, and promote the use of VR solutions in education. It targets both current and future educators and covers advantages and limitations of VR environments. The prototype includes diverse examples and actively involves participants. Due to its generality, this prototype intends to be independent of a particular area and will focus on general elements in VR, such as VR technology limitations, interaction, display possibilities, or presence and immersion. Educators and those involved in the production of educational materials are being prepared for VR.

Participants in this course will gain knowledge of VR technology and its educational applications. They will learn to apply VR and become able to judge appropriate options. They will also be able to identify and address common pitfalls in VR education and increase their awareness with regards to inherent limitations. They will further develop an understanding of how to design educational material for virtual reality environments. Furthermore, they will learn about how VR can bring new possibilities to teaching, as well as its pitfalls.

The course curriculum consists of lectures starting with a video and then an HMD experience, as well as a final project (a paper manual in combination with an HMD activity): (below is a shortened overview of the original outline)

3.3.1 Prototype 3 Module 1

Module 1 "Introduction" (passive) constitutes a short overview session of VR/AR and the related technology, part of it provided as a video. Figure 11 presents a screenshot and the complexity radar of module 1 in prototype 3.



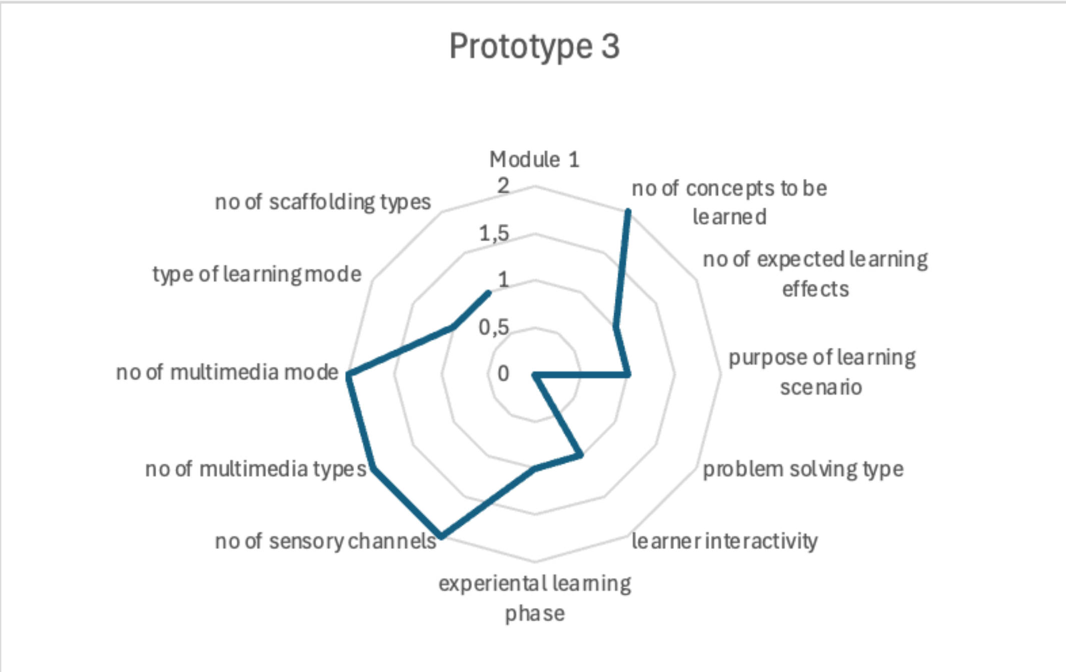


Figure 11. Screenshot from the module and cognitive complexity radar in module 1 (Prototype 3)

3.3.2 Prototype 3 Module 2

Module 2 - "Navigation" (passive+active) introduces different standard navigation methods in a virtual-reality environment, such as teleportation, fly-through, or dragging motion. In this context, simulator sickness is addressed and explained. This element explores the use of the VR controllers to interact with virtual objects. It starts with a lecture that covers the basics and provides an overview of emerging technologies. The interactive part takes the form of a minigame, where the scenario is a Kindergarten setting, in which the user needs to place virtual objects in predefined locations. In some cases, these objects need to undergo transformations, like rotations or scaling. In all situations, the software focuses on standard mechanisms to ensure a wide applicability in other contexts. The active HMD components cover 5 activities; stacking of objects (teaching grabbing and placing), telegrabbing (teaching stationary interaction with distant objects), Orientation (teaching rotations and placement), Gesture interaction (two examples). Figure 12 provides an overview of the complexity of module 2.

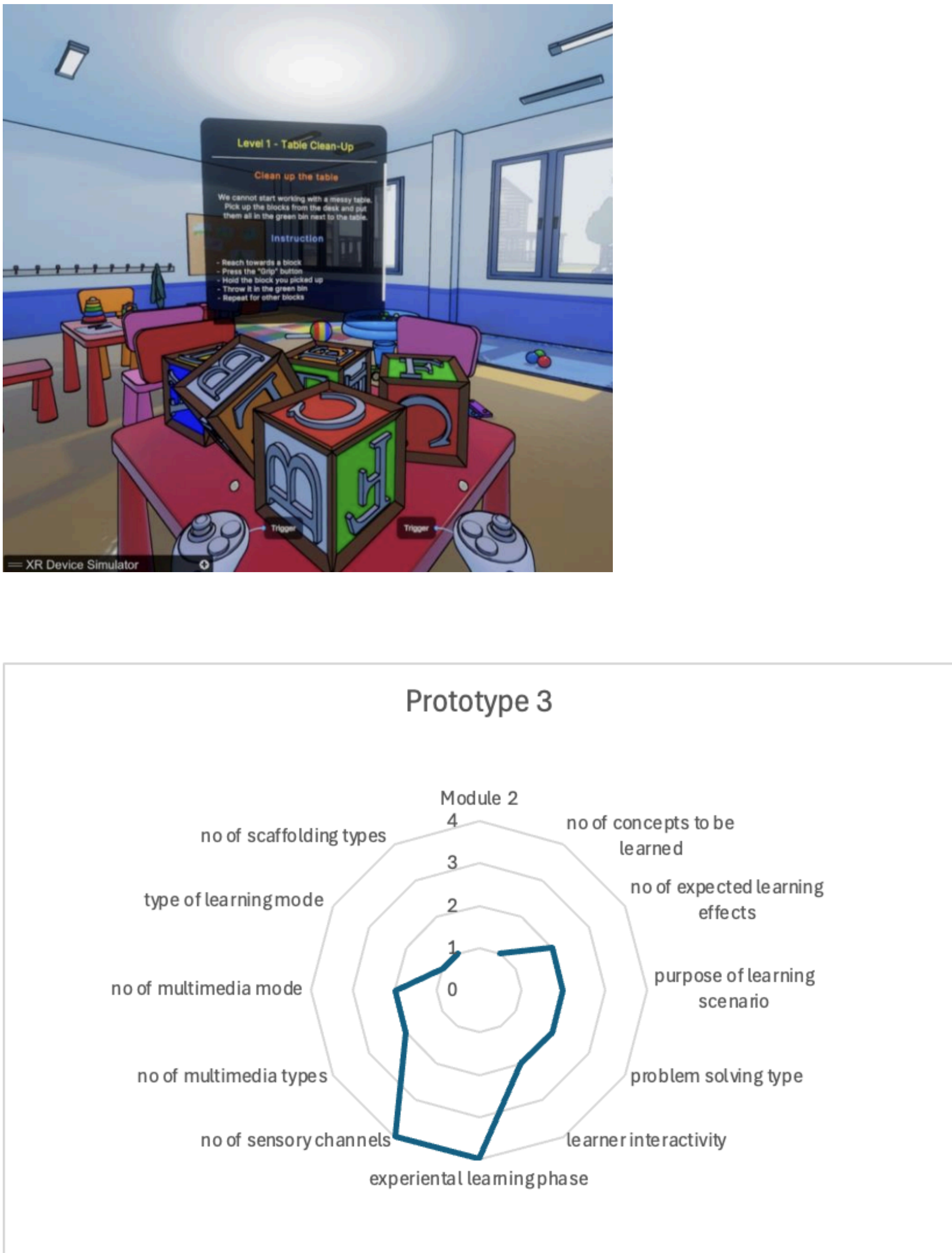


Figure 12. Screenshot from the module and cognitive complexity radar in module 2 (Prototype 3)

3.3.3 Prototype 3 Module 3

In this module “Navigation” (passive+active) some interaction and presentation techniques are covered. Starting with the standard integration of augmented-reality and controller-based interaction. Finally, advanced topics are presented as an outlook covering haptic devices and their limitations. This module starts with a lecture on navigation techniques. It covers practical, as well as theoretical insights. The supporting HMD activity is presented as a mini game with multiple stages, in which a user acts as a shepherd and needs to navigate a virtual environment to bring sheep to predefined locations. The difficulty arises from the fact that the sheep cannot be directly impacted but are indirectly affected by the user. Whenever the user is close enough to a sheep, it will move away in the opposite direction. In consequence, the user builds up the necessary skills to navigate the environment. The game consists of several levels, each making use of different typical navigation metaphors; smooth motion, teleporting, minimap, or flying. Cognitive complexity is presented in Figure 13 below together with the screenshot from the learning environment.

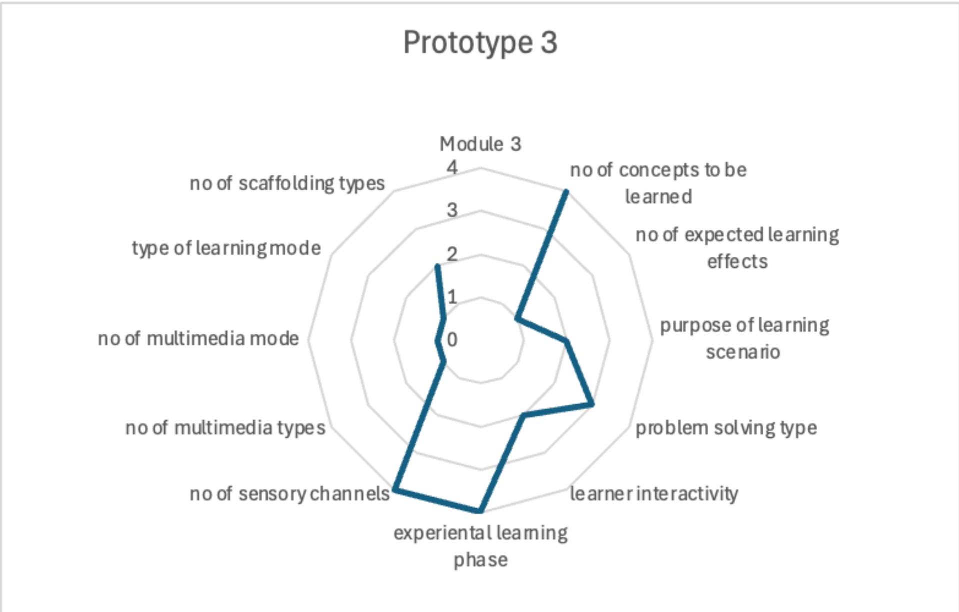
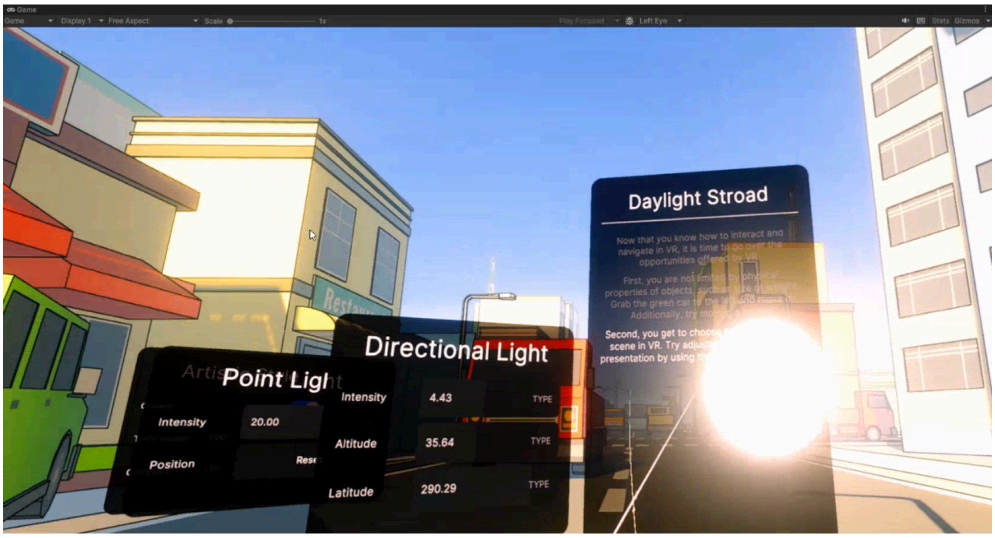


Figure 13. Screenshot from the module and cognitive complexity radar in module 3 (Prototype 3)

3.3.4 Prototype 3 Module 4

Module 4 "Visualization" (passive + active) focusing on how to make use of visualisation functionalities. While part of the original intent, VR is no longer restricted to reproducing the real world in every aspect. For educational purposes, many times abstractions and simplifications are more effective. This lecture teaches different solutions and shows use cases illustrating the underlying potential for their use in VR.

To understand these aspects, perceptual properties of the human visual system will be linked to concrete examples. This module focuses on the fact that virtual scenes recreated with 3D graphics require us to define light sources and materials. These have a huge impact on the appearance of the environment. For example, a light source placed at the position of the observer will eliminate most of the surface cues. We start with a short lecture explaining the basics of lighting and object appearance. This is followed by an interactive experience. Here, a user will first position, then illuminate a car and play with different lighting settings. Further, they can explore some non-realistic depiction. We also used this implementation as a basis for our exploration of the visualization style on the effectiveness of recognition and memorization tasks, which was prepared as a research paper. Cognitive complexity is presented in Figure 14 below together with the screenshot from the learning environment.



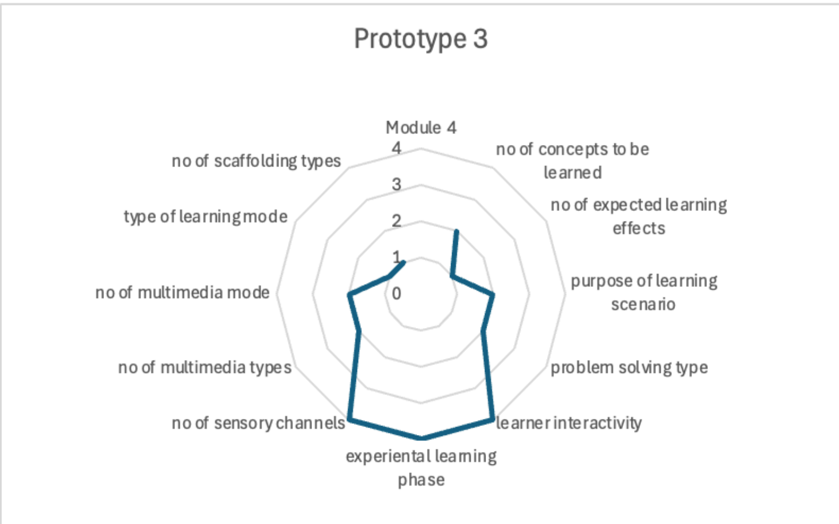


Figure 14. Screenshot from the module and cognitive complexity radar in module 4 (Prototype 3)

3.3.5 Prototype 3 Module 5

In module 5 “Collaboration” (passive+active) in VR, users are not necessarily located in the same physical space. Interaction is therefore more difficult to achieve. The lecture first talks about problems of co-locating people in the form of avatars together in virtual environments and gives an overview of some of the techniques used to guide user attention. After this passive part, the user can then experience examples of related techniques. The first asks users to imitate a motion demonstrated by a virtual avatar and to remember the motion that is initiated. Such “ghost instructor” solutions have shown to be very effective for motion/action learning. The task is repeated multiple times and the accuracy of the user is measured. Upon this basis, we also explored novel schemes, to determine whether they could enhance motion learning, which was documented in a research paper. In another experience, the user is able to perceive the impact of personal comfort zones in VR. In the real world, we keep a natural distance from others, and this behaviour translates into VR. The user can explore this effect with a virtual avatar using different facial expressions and facial animations in VR, which are important for VR, but can cause discomfort when the face appears uncanny to a user. To investigate the latter point, also different rendering styles are explored. As an alternative to avatar-based interaction, a highlighting scheme is shown in the last example that illustrates how to guide users and their gaze in VR. Figure 15 below illustrates the cognitive complexity of module 5 and presents some screenshots from the module.

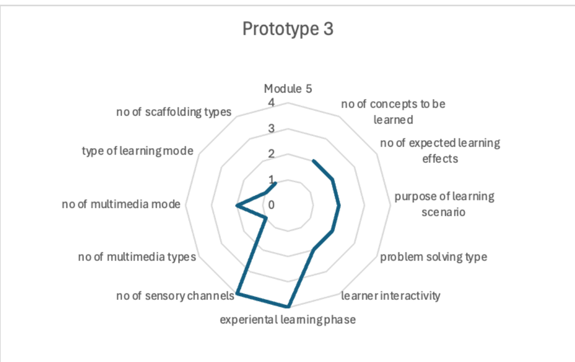


Figure 15. Screenshots from the module and cognitive complexity radar in module 5 (Prototype 3)

3.3.7 Summary of cognitive complexity in Prototype 3

The comparative analysis of the five radar charts for Prototype 3 (Modules 1–5) reveals a structured escalation of instructional complexity across the modular sequence. Module 1 is characterized by relatively low multidimensionality, with a dominant emphasis on the number of concepts to be learned and minimal engagement with multimedia diversity or learner interactivity. In contrast, Modules 2 and 3 demonstrate a pronounced expansion of design complexity, with heightened representation in the experiential learning phase, the activation of multiple sensory channels, and increased learner interactivity, suggesting a deliberate pedagogical shift toward more immersive and participatory learning modes. Module 4 presents a more balanced configuration, with moderate-to-high values distributed across most dimensions, indicative of a phase of integration and consolidation of prior learning elements. Module 5, while comparatively narrower in scope, reinforces experiential and sensory engagement, potentially reflecting a strategy of targeted deepening rather than broadening of instructional modes. Collectively, these findings suggest an intentional pedagogical trajectory in which early modules establish conceptual foundations, intermediate modules amplify multimodal and experiential engagement, and later modules culminate in the orchestration of high-level interactivity and problem-solving demands, thereby progressively layering the cognitive, sensory, and interactive dimensions of the learning experience.

4. How cognitive complexity at e-DIPLOMA prototypes influences knowledge gain

In the context of complex learning scenarios involving immersive and multi-sensory technologies, cognitive ergonomics also plays a critical role in supporting effective knowledge gain. When learning environments are designed to align with the limitations and strengths of human cognitive architecture, learners are better equipped to process and integrate new information. By managing cognitive load—such as reducing extraneous demands on attention or segmenting information to match working memory capacity—learners can more effectively encode information into long-term memory. This supports not just surface-level understanding but deep conceptual learning, enabling the transfer of knowledge to novel contexts and the development of problem-solving skills. Thus, cognitive ergonomics not only reduces cognitive strain but actively enhances meaningful learning outcomes in demanding, technology-enhanced educational settings.

Each module of the e-DIPLOMA prototypes was tested by learners from e-DIPLOMA partner countries (see Table 1).

Table 1. Overview of e-DIPLOMA prototypes piloting countries.

Prototype	Piloting countries
Prototype 1. Block programming	Spain (UJI), Hungary (BME), Cyprus (CSI)
Prototype 2. Social entrepreneurship	Hungary (BME), Estonia (TLU), Italy (ARIS)
Prototype 3. VR	Spain (UJI), Hungary (BME), Cyprus (CSI)

4.1 Methodology for analysis

To measure the learning gains in e-DIPLOMA prototypes, pre- and post-questionnaires were developed for each module (see in WP5 D.5.2, D.5.4). They contained knowledge questions relevant to what was learnt in the module. Participants completed a 15-item multiple-choice test designed to measure specific learning objectives within each module. The tests and their reliability are described in WP5 deliverables. Tests were content-validated by a panel of three subject matter experts. In total 10 points could be obtained in each questionnaire; pre- and post-questionnaires were identical.
To compare the knowledge gain in different modules we calculated the average success % in pre and post-test, and calculated the knowledge gain (post - pre). Knowledge gain is the normalized gain score, calculated as the difference between post-test and pre-test summarised scores for each participant.
The sample of learning events involved in the piloting of the prototypes was 992. Note that the same person usually tested 5 different modules in one prototype. Also they could refuse to participate or not fill in some of the questionnaires (pre or post).
P1 Module 1 - 70
P1 Module 2 - 70
P1 Module 3 - 70
P1 Module 4 - 70
P1 Module 5 - 70
P2 Module 1 - 66
P2 Module 2 - 66
P2 Module 3 - 66
P2 Module 4 - 66
P2 Module 5 - 66
P3 Module 1 - 63
P3 Module 2 - 70
P3 Module 3 - 66
P3 Module 4 - 62
P3 Module 5 - 51

The total dataset we could use for analysis comprises learning events (N = 985) that were distributed across 15 learning modules in 3 prototypes.

- Modules 1–5, 12–15: 70–73 per module
- Modules 6–10: n = 64 per module
- Module 11: n = 22

The One-way Anova (Welsch's) analysis with individual variables of the cognitive complexity was used to compare the average knowledge gain across the modules. We measured the average knowledge gain differences in regards to each cognitive complexity element (see descriptions in the section 2 above) across the learning modules.The balanced sample sizes across most modules support the stability of the Welch analysis.

Due to the small number of participants in each module, we analyzed the effects across all modules collectively. To account for unequal group sizes and violations of the homogeneity of variance assumption (confirmed via Levene's test), Robust Welch's ANOVA was additionally utilized. This approach provides a more accurate Type I error rate than standard ANOVA in heterogeneous conditions. This method provides a more accurate p-value than traditional One-Way ANOVA when the assumption of equal variances is violated.

4.2 Overall cognitive complexity and knowledge gain in modules

Cognitive complexity in e-DIPLOMA modules of the three prototypes varied between modules. Figure 16 below provides an overview of the total sum of cognitive complexity levels in each module.

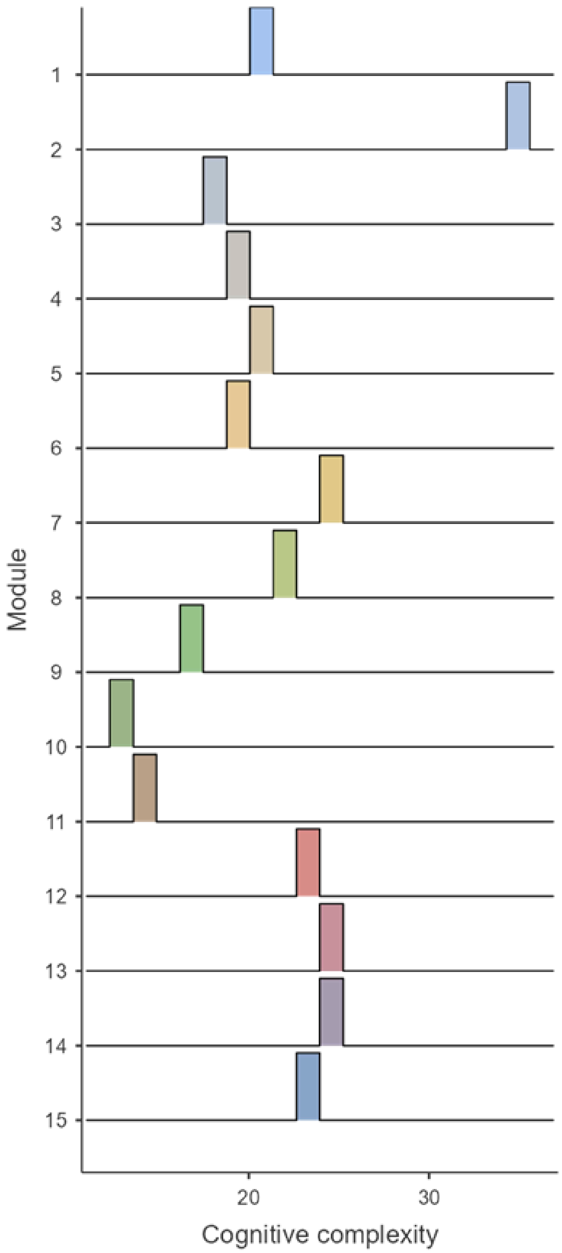


Figure 16. The total cognitive complexity level in all three prototypes. We numbered each module respectively Prototype 1 (M1-5), Prototype 2 (M6-10), Prototype 3 (M11-15). Total cognitive complexity was a sum of different aspects of complexity.

Prototype 1 (modules 1-5) stands out with its one peak in module 1 while the rest demonstrate average cognitive complexity. Prototype 2 (modules 6-10) shows a rather linear regression towards less complex modules while the Prototype 3 (modules 11-15) demonstrates rather complex modules except the first one providing an introductory lesson to the modules.

Knowledge gain in each module also differs quite significantly as it is presented across 15 instructional modules in Figure 17 below.

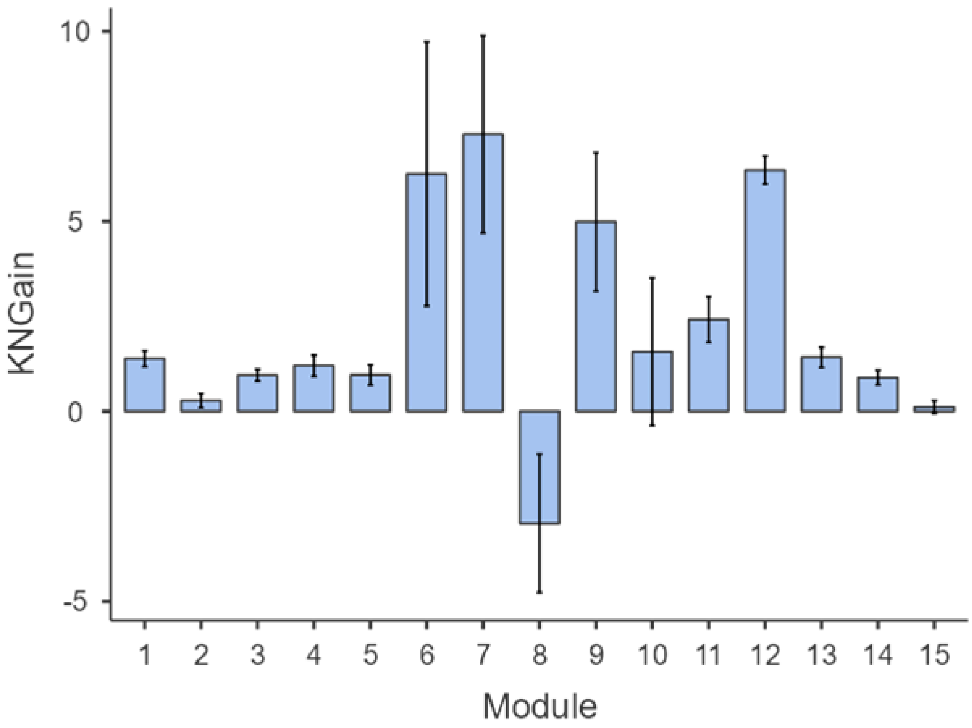


Figure 17. Knowledge gained in each module. We numbered each module respectively Prototype 1 (M1-5), Prototype 2 (M6-10), Prototype 3 (M11-15). In M12 we did not have the pre-knowledge level so we demonstrated only the final knowledge level, and not knowledge gain.

Overall, the results reveal substantial variation in knowledge gains between modules. Modules 6, 7, and 9 demonstrate the highest increases in knowledge acquisition. These modules also exhibit relatively larger error margins, suggesting greater variability in learning outcomes among participants. In contrast, most of the remaining modules show modest knowledge improvements. Module 8 is an exception, where the average knowledge gain is negative, indicating a decline in performance, though the associated error bars suggest considerable variability.

4.3. Empirical validated best practices of designing learning in immersive environments

Overall we found that the learning (knowledge gain) with the e-DIPLOMA prototypes was significantly ($p<0.05$) influenced by the specific learning design elements that caused increased cognitive complexity (see Tables 2, 3). Bonferroni correction for multiple comparisons was not used as the study was explorative, and the variables may have had interdependencies as they all represent some aspects of cognitive complexity of learning designs. In Table 2 (univariate Welch ANOVA), the estimated η^2 values range roughly from 0.02 to 0.055, indicating small effects, with a few variables (e.g., number of expected learning effects and scaffolding types) approaching the small-to-medium boundary.

Table 2. One-Way ANOVA (Welch's) How cognitive complexity aspects determine knowledge gain (pre- and post-test difference), the dataset from e-DIPLOMA prototypes 1-3

	F	df1	df2	η^2	p
N of expected learning effects	5.67	4	386	0.055	<0.001*
N of concepts to be learnt	3.59	4	310	0.044	0.007*

Purpose of the learning scenario	0.25	2	144	0.003	0.776
Problem solving type	3.18	3	246	0.037	0.025*
Learner interactivity	2.60	3	314	0.024	0.052
Experiential learning phase	6.88	2	447	0.030	<0.001*
N of sensory channels	7.12	2	385	0.036	<0.001*
N of multimedia types	8.71	2	388	0.043	<0.001*
N of multimedia modes	3.62	3	343	0.031	0.013*
N of scaffolding types	8.76	3	490	0.051	<0.001*
Learning types (individual, pair, group)	0.23	2	182	0.003	0.794

*p<0.05 marks factors that show significant effects in the univariate Welch ANOVA analyses. Effect size: η^2: ~0.01 (small), ~0.06 (medium), ~0.14 (large)

The robust Welch ANOVA Analysis was conducted to evaluate how various factors affect knowledge gain. Welch's ANOVA is specifically designed for situations where variances across groups are unequal, providing a more reliable assessment than traditional univariate ANOVA. In a reproducibility package, effect size reporting ω^2 is superior to Eta^2 because it is an unbiased estimate. Table 3 (multivariate regression using ω^2) reports systematically smaller effect sizes (≈ 0.005–0.023), all firmly within the small range. This reduction reflects the adjustment for overlapping variance between predictors in the multivariate model. The interpretation is that no single design factor has a strong effect — learning gains come from combined interactions of multiple factors, not individual variables. Overall, both tables indicate that individual instructional design factors have only modest effects on knowledge gain, but Table 3 demonstrates that their unique contributions are even smaller once interdependencies are controlled for, reinforcing the conclusion that learning outcomes are driven by the combined influence of multiple factors rather than any single variable in learning design.

Table 3. Multiple Robust Welch Analysis Regression (HC3) shows the unique contribution of each factor when all others are held constant.

Variable	B	SEHC3 Standard error	95% Confidence Level	B	Z	ω^2 Effect Size	p
(Constant)	-0.19	2.80	[-5.68, 5.31]	—	-0.07		.946
Experiential learning phase	3.19	0.79	[1.64, 4.74]	3.86	4.03	0.012	.001*
Learner interactivity	-2.06	0.61	[-3.26, -0.87]	-2.04	-3.38	0.005	.052
N of expected learning effects	-1.86	0.56	[-2.96, -0.77]	-2.05	-3.35	0.019	.001*
N of multimedia modes	-1.12	0.40	[-1.90, -0.34]	-0.93	-2.82	0.008	.005*
N of multimedia types	2.35	1.02	[0.36, 4.35]	1.67	2.31	0.015	.021*

Type of learning mode	3.23	1.45	[0.39, 6.06]	2.32	2.23	<0.001	.026*
Purpose of scenario	-2.63	1.20	[-4.98, -0.29]	-1.58	-2.20	<0.001	.028*
N of concepts	-1.19	0.94	[-3.03, 0.65]	-1.40	-1.27	0.010	.205
N of scaffolding types	-1.28	1.73	[-4.67, 2.10]	-1.11	-0.74	0.023	.457
Problem solving type	0.38	0.41	[-0.41, 1.18]	0.47	0.94	0.007	.348
N of sensory channels	0.38	0.75	[-1.08, 1.85]	0.35	0.52	0.012	.606

Note. N = 985. * indicate statistical significance at $p < 0.05$ and it identifies predictors that remain statistically significant after controlling for other variables in the multivariate model. The p values in Table 3 are more conservative as they represent the unique effect of a factor after controlling for all other variables in the model. Effect size thresholds: Effect size (ω^2): ~0.01 (Small), ~0.06 (Medium), ~ 0.14 (Large).

The results in Tables 2 and 3 indicate that several instructional design factors have statistically significant effects on knowledge gain at the $p < 0.05$ level, although their influence varies depending on the type of analysis. Table 2 and Table 3 represent different levels of analysis regarding how instructional design factors influence knowledge gain across the project's prototypes. Table 2 (Univariate) looks at each factor one by one. It asks: *"Does Sensory Channels affect learning?"* without looking at what the other variables are doing. In Table 2 (univariate Welch ANOVA), multiple factors—including the number of expected learning effects, number of concepts, problem-solving type, experiential learning phase, sensory channels, multimedia types and modes, and scaffolding types—show significant associations with knowledge gain when examined individually. This suggests that each of these elements appears to play a role in learning outcomes when considered in isolation. Table 3 represents a "Multivariate" or "Adjusted" model (Multivariate/Adjusted): This table looks at all factors at the same time. It asks: *"Does Sensory Channels affect learning after we have already accounted for Interactivity, Scaffolding, and Multimedia? etc."* Table 3 (multivariate regression with ω^2 effect sizes) provides a more conservative and refined view by accounting for the simultaneous influence of all variables. Here, only a subset of factors—namely experiential learning phase, number of expected learning effects, multimedia types and modes, learning mode, and purpose of the scenario—remain statistically significant at $p < 0.05$. This indicates that these variables have a unique contribution to knowledge gain beyond shared variance with other factors. The differences between the two tables highlight the role of interdependencies among instructional design elements. Some variables that are significant in Table 2 lose their significance in Table 3, suggesting that their apparent effects are explained by overlap with other factors (multicollinearity). Overall, while several design features are associated with learning outcomes, only a limited number demonstrate independent predictive value, and even these effects are relatively small, pointing to the importance of considering the combined influence of multiple elements in complex learning environments. The effect values (ω^2) in Table 3 indicate that effects of individual factors in learning design are generally small (typically ranging from 0.01 to 0.03). This suggests that while these individual design choices are "best practices," they only explain a small portion of why a student learns; the true impact likely comes from the complex interaction of all these elements combined. Based on these findings of the learning design elements that significantly enabled learners to gain more knowledge we formulated the best practices for developing learning scenarios for practice based immersive learning. The descriptive tables 4-18 below illustrate the significant principles of learning design in practice based immersive learning environments.

Table 4. Group Descriptives of learning effects' impact on learning gains

	N of expected learning effects in cognitive, metacognitive, affective or psychomotoric domains	N	Mean	SD	SE
Knowledge gain	0	192	4.614	17.25	1.245
	1	373	2.156	11.74	0.608
	2	280	1.249	7.90	0.472
	3	69	0.960	2.18	0.262
	4	71	0.282	1.59	0.189

Principle 1

The learning designs in immersive learning environments better support the focused learning goals (e.g. on cognitive, metacognitive, affective or psychomotoric domains) rather than several of them in the same task.

For instance, in prototype 1 modules 1 and 4, in prototype 2 modules 1,2,4,5 and in prototype 3 modules 3 and 4 incorporated only a few learning effects.

Table 5. Group Descriptives of the impact of concepts to be learnt in immersive environments on learning gains

	N of concepts to be learned	N	Mean	SD	SE
Knowledge gain	0	133	4.005	14.77	1.281
	1	265	3.749	17.40	1.069
	2	232	0.977	8.27	0.543
	3	282	0.954	1.80	0.107
	4	73	1.420	2.26	0.265

Principle 2

The smaller the number of concepts to be learnt, the better the knowledge gained from practice-based learning with immersive technologies. Too many concepts increase cognitive complexity.

For instance in prototype 1 the number of content related concepts to be learned in module 5 was just 1. The same was in prototype 2 with modules 1,2,4 and in prototype 3 with module 2 demonstrating higher knowledge gain also shown in Figure 17.

Table 6. Group Descriptives of problem solving type impact on learning gains in immersive environments

	Problem solving type	N	Mean	SD	SE

Knowledg e gain	No clear problem	297	2.09	7.11	0.413
	Simple problem: Rule using or decision making or troubleshooting	482	1.80	13.14	0.599
	Complex problem: Diagnosis-solution, strategic, situated case policy	142	1.20	2.23	0.187
	Highly complex problem: Design problems or dilemma	64	7.29	20.76	2.595

Principle 3

The learning gain in immersive problem solving environments was higher with complex dynamic decision-making problems.

For instance, in module 5 of the prototype 1, in modules 2,3 and 5 in prototypes 2 and modules 3 and 6 in prototype 3 the tasks were representing complex problems such as design or dilemma type of problems.

Table 7. Group Descriptives of the learner's task interactivity type impact on learning gains in immersive envi

	Learner interactivity	N	Mean	SD	SE
Knowledge gain	Consume	163	1.339	1.81	0.141
	Annotate, submit, manipulate	545	2.367	13.36	0.572
	Expand or remix	69	0.960	2.18	0.262
	Create	208	2.651	11.94	0.828

Principle 4

The knowledge gain in immersive practice situations was higher with the tasks with specific interactivity types - immersive environments afford better manipulation or creation, and the tasks of remixing or consuming knowledge resulted with smaller knowledge gain.

For instance in all the modules in prototype 3, learner interactivity was either manipulating the learning content or creating something new. In prototype 1 and 2, modules 2 and 4 and modules 1,2,4,5 respectively engaged learners to interact with the learning content or create something.

Table 8. Group Descriptives of the tasks' experiential learning phase (Kolb, 1984 model) impact on learning g immersive environments

	An experiential learning phase	N	Mean	SD	SE
Knowledge gain	1.Concrete experience	214	1.70	19.3	1.325
	3. Abstract conceptualization	141	1.17	1.54	0.130
	4. Active experimentation with abstract concepts	630	2.53	8.65	0.345

Principle 5

Knowledge gain was larger in immersive practice based learning situations where abstract concepts could be actively experimented. It is difficult to go from situative learning to abstract conceptualization. For instance, almost all the modules in prototype 1 and 3 presented active experimentation with abstract concepts. In the prototype 2 modules 2 and 4 engaged learners to actively experiment. We had no tasks with reflective observation in e-DIPLOMA prototypes.

Table 9. Group Descriptives of the number of activated sensory channels' impact on learning gains in immersive environments

	N of sensory channels	N	Mean	SD	SE
Knowledg e gain	2	359	0.506	9.23	0.487
	3	135	3.092	10.24	0.882
	4	491	3.109	12.91	0.583

Principle 6

Using more sensory channels in immersive practice-based learning supported the knowledge gain. It must be noted here that all the modules in prototype 3 incorporated several sensory channels, while in prototype 1 only module 2 and in prototype 2 modules 1,2,5 engaged learners with many sensory channels.

Table 10. Group Descriptives of the number of multimedia types used in immersive learning situations and their impact on learning gains in immersive environments

	no of multimedia types	N	Mean	SD	SE
Knowledg e gain	Visual channel	477	2.41	11.2	0.513
	Auditive and visual channel (dual channel effect)	373	3.07	11.9	0.614
	Visual (video + reading texts) and	135	-1.25	10.2	0.876

auditive (Cognitive overload in short term memory processing)

Principle 7

The optimal number of multimedia types is lower 1-2, larger numbers of multimedia types used in immersive learning environments reduced the learning gains, possibly because of the learners' cognitive overload. This is especially visible in most of the modules in prototype 2 and 3 as well as in module 5 of the prototype 1, where only a few multimedia types were designed into the learning activity.

Table 11. Group Descriptives of the number of multimedia modes used in immersive learning situations and their impact on learning gains in immersive environments

	N of multimedia mode	N	Mean	SD	SE
Know ledge gain	1	213	1.194	2.00	0.137
	2	502	3.232	13.88	0.620
	3	199	0.756	12.10	0.857
	4	71	1.385	1.76	0.209

Principle 8

The large number of immersive learning environment modes (VR, AI chatbot, AR, XR, virtual games) used in a practice based learning situation does not increase the knowledge gain, rather the optimal way is combining up to 2 types of learning environment modes. This can be seen in prototype 3, where most of the modules incorporated only a few multimedia elements, some modules in prototype 1 and 2 as well.

Table 12. Group Descriptives of the number of learning modes used in immersive learning situations and their impact on learning gains in immersive environments

	type of learning mode	N	Mean	SD	SE
Knowledge gain	Individual learning	722	1.98	6.84	0.255
	Learning in pairs	128	2.17	18.58	1.642
	Group learning	135	3.11	19.32	1.663

Principle 9

Learning in the group in immersive learning environments resulted in almost the same knowledge gains as learning individually and in pairs (no statistically significant differences). For instance, learning tasks in groups were mainly designed to modules in prototype 2, while in prototype 3 the tasks were carried out individually.

Table 13. Group Descriptives of the number of scaffolding types used in immersive learning situations and their impact on learning gains

	No of scaffolding types	N	Mean	SD	SE
Knowledge gain	0	197	2.465	12.28	0.875
	1	369	3.946	14.77	0.769
	2	348	0.471	6.65	0.356
	3	71	0.282	1.59	0.189

Providing scaffolding simultaneously for several aspects has negative effects on knowledge gains.

5. Learning differences in educational levels and in diverse social groups

Overall, there were almost no significant differences in the knowledge gain of different age groups when learning in immersive environments with e-DIPLOMA prototypes (see Tables 14-18 below). There were no significant differences in knowledge gain between the learners from different genders. The statistical gender difference we found is related to the defined and non-defined gender groups, but there was no significant difference in knowledge gain between male and female groups. There was a significant difference in the knowledge gained in immersive learning environments of learners who were at different educational levels, it was significantly lower at technical and vocational education groups compared with higher educational levels. This may be related to their lower learning skills in general. The learners' previous experience with VR and immersive technologies showed significant differences between the users who use it daily and the others who do it less frequently. However, the number of daily users was very low and there were no significant differences in knowledge gain between learners who use an immersive environment with different frequency.

Principle 10

Overall we may conclude that the sociodemographic factors did not significantly influence learning gains, compared with the complexity of learning designs in immersive learning environments.

Table 14. One-Way ANOVA (Welch's) Knowledge gain differences with different sociodemographic factors

	F	df1	df2	p
Age	0.78	3	39.5	0.511

Gender	36.6	2	23.0	< .001
Educational level	6.22	3	64.6	< .001
Previous usage of immersive technologies	57.1	4	17.2	< .001

Note. The Gender difference is related to defined and non-defined gender groups, there is no significant difference in knowledge gain between male and female groups. The Previous use difference is also contributed by a very low number of daily users, and no significant differences are between others who use immersive environments with different frequency.

Table 15. Descriptives of age and knowledge gain in immersive learning environments

	Age	N	Mean	SD
Knowledge gain	16-26	112	3.43	5.26
	27-40	46	4.32	4.64
	41-55	30	2.83	4.49
	55 onwards	11	2.66	4.94

Table 16. Descriptives of the knowledge gain of learners from different educational levels in immersive learning environments

	Level of education	N	Mean	SD
Knowledge gain	High School	34	3.460	5.15
	Postgraduate	50	4.184	4.70
	Technical or vocational education	20	-0.654	4.53
	University	95	4.037	4.81

Table 17. Descriptives of the knowledge gain between the learners who use immersive learning environment with different frequencies

	Frequency of use of immersive technologies	N	Mean	SD
Knowledge gain	Daily	2	10.89	0.453
	Frequently (once a week or several times a week)	6	2.75	2.962
	Never	100	3.45	4.692

Occasionally (once a month or twice a month)	20	2.40	5.359
Rarely (1-5 times per year)	71	3.74	5.353

Table 18. Descriptives of the knowledge gain across different fields of study

	Field of study	N	Mean	SD
Knowledge gain	Art and culture	16	4.252	5.599
	Computing	75	4.403	4.700
	Economy and business	9	4.753	4.457
	Education	28	3.644	4.969
	Engineering	31	3.464	5.609
	Law	1	6.810	NaN
	Medicine and health	6	3.170	4.200
	Other	20	-0.375	4.619
	Science	5	1.664	2.728
	Social studies	5	1.240	3.279
	Tourism and services sector	2	6.985	0.643

6. Conclusion

In the report, we aimed to open up the conceptual background for designing new types of practice based elearning with some new technologies (VR, AI based chatbots, AR). We asserted that it is important for learning designers to adopt a clear learning sciences and cognitive perspective to consider how new technological settings may support but also disrupt learning. The instructional designer would need to focus on the questions of how learning occurs, what role technology plays in the learning process, and what types of learning outcomes are intended (Driscoll & Burner, 2005). In this report we examined different learning design elements and their effects as a complex system. We discussed why some learning design aspects if used concurrently might have caused a negative impact on learners.

In this report, we aimed to empirically show the evaluation of practice based learning design situations in complex learning designs with new technologies (AR, VR). The evaluation results demonstrated that in the observed prototypes the complexity for interactive learning was formed of many simultaneous elements, which all together might have caused in some learning situations the higher demand for the learners that could disrupt the cognitive learning process. We demonstrated with different prototypes with innovative technologies about how the cognitive complexity caused by immersive learning technologies has positive learning effects and also the negative effects that disrupt learning.

The report aimed to empirically evaluate practice-based learning design in complex scenarios involving immersive technologies (AR, VR). The complexity of interactive learning arises from multiple simultaneous elements, which may increase cognitive demands and potentially disrupt learning. Using various prototypes with innovative technologies, we demonstrated both the positive learning outcomes and the potential cognitive challenges posed by immersive learning environments. Learning designs that integrate multiple diverse design aspects—such as immersive technologies, complex problem types, multiple sensory channels, varied multimedia modes, etc.—can create cognitively demanding learning situations in which knowledge gain may be impaired. Our findings indicate that certain design features are particularly likely to hinder knowledge acquisition when the resulting learning environment becomes excessively complex. This suggests that instructional designers should carefully balance the richness of multimodal and multisensory inputs with the learner's cognitive processing capacity, in order to avoid cognitive overload and ensure optimal learning outcomes.

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