VIRTUAL LABORATORIES IN HEALTH SCIENCES EDUCATION

Exploring Pedagogical Value and Educators' Perceptions and Intention to Use

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Eleni Dafli, Reader, Aristotle University of Thessaloniki

Date: February 2026

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Abstract

Higher Education is rapidly transforming driven by digital technologies and the need for flexible and inclusive learning environments. Although traditional laboratories remain pedagogically valuable, Virtual laboratories (VLs) offer simulated experimental environments that can enhance conceptual understanding, inquiry skills, and preparation for hands-on practice. This study explores educators' perceptions, experiences, and adoption intentions regarding the VHEalthLab online toolkit and its VLs as digital learning tools designed to support biology laboratory teaching across higher and secondary education contexts. Grounded in a dual theoretical framework combining Inquiry-based Learning (IBL) and the Technology Acceptance Model (TAM), the research examines both the pedagogical value attributed to VLs and the factors influencing educators' intention to use them. A mixed-methods design was employed, integrating quantitative survey data (N = 70) with qualitative insights from focus groups conducted across four European countries. Quantitative findings indicated high internal consistency across most questionnaire themes and consistently positive evaluations of usability, clarity, and learning design. Educators reported strong intention to use the toolkit, particularly when materials were perceived as pedagogically valuable and aligned with IBL principles. Qualitative findings reinforced these results, revealing broad cross-country agreement that VLs are intuitive, pedagogically meaningful, and effective as complements, though not substitutes to physical laboratories. Overall, the findings suggest that while acceptance of VLs is consistently high, sustainable adoption depends on pedagogical design quality, inclusive features, structured guidance, and institutional support. The study contributes empirical evidence on educators' perspectives and offers practical implications for scaling digital laboratory innovations in science education.

Keywords: Virtual Laboratories, Inquiry-based Learning, Biology education, Educators' perceptions

JEL Classification: I21, I23

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Glossary

Virtual Labs (VLs)

Inquiry-based learning (IBL)

Inquiry-Based Science Education (IBSE)

Higher Education (HE)

Science, Technology, Engineering, and Mathematics (STEM)

Information and Communication Technologies (ICT)

Technology Acceptance Model (TAM)

General Data Protection Regulation (GDPR)

Aristotle University of Thessaloniki (AUTH)

Introduction

Emerging information and communication technologies (ICTs) have significantly reshaped educational practices, influencing how knowledge is accessed, delivered and constructed across learning environments (Reginald, 2023). The emergence of the COVID-19 pandemic further accelerated this digital transformation, heightening the importance of remote learning and home-based study in pedagogical practices (Poo et al., 2023). The encouragement to keep learning while adhering to the required health precautions was crucial. As a result, digital teaching and learning approaches moved from being supplementary options to becoming essential components of the educational process (Govender & Khoza, 2022).

Within Science, Technology, Engineering, and Mathematics (STEM) education Technology, engineering, and science lab experimentation expanded as a result of the internet and accelerating technical breakthroughs, which promoted e-learning or distant learning through virtual and remote laboratories (Poo et al., 2023). Enabled by internet connectivity and technological advancements Virtual Labs (VLs) have emerged as interactive simulation environments that replicate real-world experimental processes in a digital space (Lynch & Ghergulescu, 2017). VLs can optimize time and space flexibility to enhance time efficiency and streamline intricate processes, allowing for the execution of increasingly complex workshops (González-Pérez & Ramírez-Montoy, 2022). Additionally, it provides a convenient and safe workshop setting for student learning evaluations. Students can access the platform from home or at anytime, anywhere, or at their school. Empirical research has highlighted the potential of VLs to enhance learning, deepen comprehension, and boost academic achievement, according to research (Cakir et al., 2021; Lynch & Ghergulescu, 2017; Wästberg et al., 2019). Consequently, their adoption has widely appeared in different educational levels ranging from primary schools to higher education and across a wide range of disciplines, including physics, chemistry, biology, medicine, engineering, and other STEM-related fields (Jia et al., 2020; Kapilan et al., 2021; Whitworth et al., 2018).

In the case of laboratory-based subjects such as Biology, or health-related sciences, the use of experimental methods, data analysis, and the scientific method of investigation is crucial (Pedaste et al., 2015). The introduction of digital laboratories in such subjects is, therefore, not only an important innovation in terms of technology, but it may also have implications for the pedagogy of such subjects, particularly in the context of health education (World Health Organization, 2016). Though the technological potential of VLs is increasingly recognized, their educational value does not derive from their technological potential in itself. The

educational potential of VLs largely derives from how they are pedagogically conceived, supported, and articulated in relation to other educational practices (Mishra & Koehler, 2006). Digitalized lab environments that are not conceived as providing structured processes of inquiry, pedagogical support, and reflection are at risk of being conceived as technological frills in themselves (Selwyn, 2013). Thus, pedagogical framing and support become essential.

Despite the ever-increasing number of studies conducted to prove the efficiency of VLs in improving student learning outcomes (Brinson, 2015; Reeves & Crippen, 2021), gaps exist in the existing body of knowledge. A large number of existing studies have concentrated on the performance of students and cognitive developments (Li & Liang, 2024; Zaturrahmi et al., 2020), while very little attention has been devoted to the perception of educators regarding these tools and digital innovations in the field of science education. Educators play a crucial role in the effective implementation and utilization of digital innovations in the field of science education (Tondeur et al., 2019; Ertmer et al., 2012). At the same time, inquiry-based learning (IBL) is recognized as a fundamental aspect of effective science education such as Biology (National Research Center, 2000; Learning, 2013). However, limited empirical evidence exists concerning the views of educators to the degree to which virtual laboratory settings can contribute to the IBL process. These gaps become even more pronounced in cross-context and cross-country settings where a lack of cross-country comparative evidence is emphasized, especially with regard to the institutional, pedagogical, and cultural factors that influence the acceptance and pedagogical value of digital laboratory innovations by educators. Most importantly, although a number of digital tools have been designed and developed in various STEM fields (De Jong et al., 2013), very few initiatives have focused on the implementation of a fully integrated virtual laboratory toolkit that incorporates simulation tools, pedagogical support tools, inquiry-based learning tools, problem-based learning tools, self-assessment tools, and instructional support tools.

Taken together, these limitations highlight a clear need for research that investigates the implementation of VLs with a particular focus on educators' perceptions of usability and inquiry-based learning support, and their intention to adopt such tools in future teaching practice, including the factors that shape this intention. In response to these needs, this thesis aims to evaluate the VHEalthLab online toolkit, which is an integrated digital learning environment that includes virtual laboratories and pedagogical support to complement and extend laboratory-based Biology teaching in Higher Education and secondary education.

The main aim of this thesis is to examine and evaluate the educators' perceptions and experience with regard to the pedagogical value, usability, and support for inquiry-based

learning (IBL) provided by the online VHEalthLab toolkit and VLs. At the same time, this study aims to investigate the relationship between educators' intentions to use the online toolkit for their future practice, as well as to examine the exploratory relationships between intention to use and various perceived factors such as clarity, pedagogical value, learning design, usability, and IBL support. The significance of this thesis is in offering empirical evidence on educators' perceptions of a comprehensive STEM VL toolkit rather than individual simulations and investigating the relationship between pedagogical value and intention to adopt using a combined IBL and Technology Acceptance Model (TAM) approach. Finally, the provision of cross-country comparative findings is conducted focusing on the factors influencing adoption and contributing to the design principles of transferable and sustainable digital educational initiatives that support IBL and the development of digital and scientific competences in health-related education.

1. Literature review

1.1. Virtual Laboratories in Higher Education

The post pandemic era was characterized by a wide embrace of digital technologies in various facets of human endeavour, including the field of education (Nwibe & Ogbuanya, 2025). The significant integration of several technologies aiming at digitizing the teaching and learning process has led to rapid changes in the global education landscape (Rapanta et al., 2021; Rosli & Saleh, 2023). In response to these developments, there has been increasing scholarly interest in the fields of technology integration as a means of pedagogical reform. In alignment with the global emphasis on achieving twenty-first century learning skills, where digital literacy is one of the core goals, a growing, understandable desire to incorporate more educational technologies into the classroom is emphasized (Dakhi et al., 2020; Smetana & Bell, 2012; Tarbutton, 2018). Scholars and practitioners widely agree that, when incorporated into instruction, educational technology may revolutionize the learning process by giving teachers and students access to pertinent information (Tarmo, 2022). Consequently, universities are encouraged to investigate new, individualized, intelligent experimental teaching modes that combine online and offline instruction to meet the demands of rapid economic and social development for talent cultivation (Zhang & Liu, 2024).

In this context, the expanding integration of technology in education has contributed to the emergence of VLs, an innovative approach to bridging theoretical concepts and practical application (Tuli et al., 2022; Singh et al., 2019). VLs have thus become a significant tool for

improving learning quality and practical experience, as well as for resolving several issues with actual laboratory operations (Kharki et al., 2020).

VLs are technology-mediated experiences in either two- or three-dimensions that situate the student as being in an emulation of the physical laboratory with the capacity to manipulate virtual equipment and materials via the keyboard and/or handheld controllers (Reeves & Crippen, 2021, p. 16).

In contemporary education, particularly within STEM (science, technology, engineering, and mathematics) curricula, the experiential learning component is widely acknowledged as a crucial aspect of the educational process. Such experiential approaches often encompass activities such project design, lab sessions and hands-on investigations, all of which contribute to deeper conceptual understanding and skill development (Chen et al., 2019). Numerous examples of the application of VLs and experiments are currently available in a variety of scientific fields, such as mathematics, physics, chemistry, biology, medicine, and geology (Jia et al., 2020; Wei et al., 2020; Whitworth et al., 2018). VLs have also been successfully applied in disciplines outside the traditional Information and Communication Technologies (ICT) spectrum, including Biochemistry and Molecular Biology, Mechanical Engineering (Kapilan et al., 2021), Optics (Gamo, 2019), and Rehabilitative Sciences (Puzziferro & McGee, 2021). Additionally, the application of VLs has improved collaborative learning in HE related to biological sciences (Manchikanti et al., 2019).

Beyond these applications, research highlights the pedagogical affordances of VLs. Science education researchers and teachers recognise that VL can encourage better conceptualisation of concepts and strengthen a constructivist approach by enabling students to be more immersed in their studies (Vaez & Potvin, 2021). One of the key features that distinguishes VLs is the high level of technical support they provide in conducting, presenting, and reproducing laboratory experiments, which in turn promotes teacher-student interactions (Al-Juhani, 2013). Moreover, VLs facilitate visualization, enabling learners to better conceptualize complex phenomena and abstract concepts. According to Woodfield et al. (2005), VLs offer an open environment that simulates a real science lab, links theory to practice, teaches thinking skills, and gives students total autonomy to make decisions without any negative consequences. Furthermore, because virtual experiments ensure safety and protection, they may overcome many of the temporal and spatial limitations associated with traditional laboratory work (Anter, 2009). Use of VLs in STEM HE makes it possible for educators and students to simulate experiments that otherwise

must be performed in a teaching laboratory, provide learners with an interactive experience that allows them to test hypotheses, collect data, and analyze results through the manipulation of virtual equipment and materials (Brinson, 2015; Reeves & Crippen, 2021).

Empirical studies also suggest that VLs help students interact with situations in a natural way and foster positive attitudes toward learning science (Ahmed, 2010; Al Musawi et al., 2015). Consequently, VLs are increasingly considered as viable alternatives to traditional laboratories, as they provide students with virtual experiences that similarly resemble direct experimentation, while simultaneously addressing barriers that hinder the practice of authentic experiences (Al-Hafiz and A. Johar, 2013). As noted by Al-Shehri (2009), VLs allow students to perform experiments that might otherwise be impossible in traditional settings due to factors such as risks, lack of equipment or instruments, high costs, time constraints, or shortage of materials.

The theoretical foundations of VLs further support their effectiveness since their pedagogical use is strongly grounded in established learning theories, particularly the experiential learning theory of David Kolb (1984), which draws on constructivist principles and the earlier work of John Dewey (Ouyang & Stanley, 2014). As early as 1938, Dewey emphasized that meaningful learning occurs through practice and active student participation. Building on Dewey's emphasis on active participation, Kolb advanced the concept of "learning by doing", arguing that knowledge is constructed through the interaction of cognitive processes and direct experience (Kolb & Kolb, 2005). Furthermore, the efficacy of VLs in facilitating better learning outcomes is validated by other theoretical underpinnings as well. For instance, Siemens (2004) defines learning as the process of creating a network and connecting concepts, emphasizing the relational aspect of knowledge creation. This perspective aligns with Vygotskys' constructivist theory, which views learning as a dynamic process and not a product, emphasizing the significance of social interaction and symbolic tools in achieving deep understanding and problem-solving skills. Within this framework, VLs can be seen as advanced symbolic tools enabled by the latest technological advancements, facilitating interactive, experiential, and socially mediated learning (Hassan et al., 2022).

1.2. Virtual Labs and their role in Higher Education Biology

Building upon the general pedagogical affordances of VLs discussed above, it is particularly important to examine their role within biology HE, where laboratory practice is not supplementary but foundational to disciplinary identity and competence development. While educational technologies are used across teaching and learning contexts, they are particularly

effective in science education, where research shows that technology adoption can significantly support student learning (Byukusenge et al., 2024). Thus, academics who focus on scientific education support the smooth incorporation of educational technology in science classrooms (Afgan, 2015; Nelson, 2019; Kulaksız & Karaca, 2023). The goal of using technology in science education is to provide students with interesting and real-world experiences that relate to current concerns, problems, and situations. This pedagogical approach fosters profound, deep, purposeful, and participatory learning, empowering learners to attain proficiency in fundamental scientific skills and principles. Consequently, it is imperative to regard science education technologies as supplementary teaching tools that augment the teaching-learning process. This necessitates a shift in focus towards experiential learning opportunities facilitated by technology (Kulaksız & Karaca, 2023).

At the same time, biology education is increasingly called to move beyond the traditional teacher-centered instructional models, where the educator is the only source of knowledge and information, toward more flexible and open learning environments that focus on providing and employing technological innovations and supporting students' active engagement, exploration and technological innovation (Byukusenge et al., 2024). This involves paying attention to the learning biology environment, providing all appropriate learning opportunities, and bringing about fundamental changes in teaching and learning methods to keep up with the global development in the field of biology education (Abdulrahman, 2022). Given the experimental nature of biology, limited access to practical exercises may affect students' ability to fully grasp complex biological concepts, potentially affecting their academic performance (Muhamad et al., 2012).

In response to such challenges, educational technologies, particularly VLs, have gained prominence as alternative or supplementary tools to conventional labs, with the aim to reshape pedagogical approach of biology instruction and learning (Dyrberg et al., 2017; Muhamad et al., 2012). VLs are increasingly integrated and used across diverse educational settings, as they enable educators and students to broaden educational possibilities, while simultaneously enhancing students' engagement and interest in learning (Ramli et al., 2019; Zervas et al., 2014; Toth & Toth, 2016; Aljuhani et al., 2018; Abdulrahman, 2022). Their growing integration is particularly evident in biology education, a discipline where laboratory experimentation constitutes a core pedagogical component offering multiple opportunities for engaging students, improving their comprehension, and fostering positive attitudes toward the subject (Hawkins & Phelps, 2013; Hofstein & Mamlok-naaman, 2007). Through computer-based simulations, VLs offer students interactive learning environments in which they can investigate and experiment

with biological phenomena in a structured but flexible way at the same time (Martín-Gutiérrez et al., 2017). In this framework, VLs provide students with the ease and security of actual laboratory experiments, allowing for an accessible and economical means of bridging the theory-practice divide (Pearson & Kudzai, 2015).

This function is particularly significant given that biology laboratory learning depends heavily on the acquisition of essential practical skills and familiarity with specialized equipment. VLs can serve as preparatory or supplementary environments, allowing students to rehearse procedures, visualize microscopic or abstract processes, and build confidence prior to engaging in physical laboratory sessions (Gallagher & Wiley, 2008). Empirical evidence further supports their pedagogical value with several studies reporting positive effects on students' cognitive load, skills development and motivations increase. For instance, Falode (2018) found thar VLs promote active participation and provide students with the opportunity to revisit complex concepts at their own pace (Falode, 2018). Similarly, Ambuisaidi et al. 2018 observed that VLs support not only procedural knowledge but also teamwork skills, data analysis competencies and familiarity with laboratory equipment (Ambuisaidi, Musawi, & Balushi, 2018). Comparative studies between virtual and traditional labs reveal nuanced findings. Flowers (2011) showed that students who used VLs demonstrated improved conceptual understanding of biology concepts compared to those in traditional labs, although participants acknowledged that physical laboratories remain more effective for developing hands-on equipment skillst. Likewise, research comparing in-person and VL experiences indicates that while students often perceive face-to-face labs as more beneficial since they provide immediate feedback and interpersonal interaction, they also recognize the value of VLs in improving engagement and community building when utilized for collaborative work (Stuckey-Mickell and Stuckey-Danner, 2007). Other studies suggest that, in certain topic areas, computer simulations may even surpass traditional approaches in promoting conceptual learning (Gibbons et al., 2004).

Blended models in integrating and using VLs seem to emerge as the common practice in most studies. Makransky et al. (2016) in a study on microbiology education, demonstrated that when combined with physical teaching laboratories, the usage of VLs significantly increases student knowledge and self-efficacy, while also strengthening intrinsic motivation. Similarly, research exploring the use of VLs as preparatory tools for undergraduate microbiology labs found that virtual demonstration can be as effective as face-to-face demonstration in preparing students for hands-on activities (Makransky et al., 2016). Findings from biotechnology education highlight that students perceive VLs as useful for both comprehending and inspiring

the experiments, despite challenges brought on by a lack of ICT expertise (Radhamani et al., 2015). Instructors also report that VLs can be successfully integrated alongside conventional teaching methods, supporting their role as complementary rather than replacement tools (Sypsas & Kalles, 2018).

1.3. Educators' attitudes & adoption of Virtual Labs

In recent years, there has been growing support for integrating ICT in education, as they offer significant potential to enhance sustainability and scalability in teaching and learning processes (Raja & Priya Lakshmi, 2022). This trend is reflected in the growing recognition among science educators of the educational technology's benefits in science teaching and learning environments (Byukusenge, 2024). In this context, VLs emerged as a withstanding digital tool that has the potential to improve conceptual understanding, self-efficacy, and online laboratory practice, while at the same time offering a paradigm change in laboratory teaching techniques (Kolil et al., 2020). Indeed, in many developed countries, VLs have gained considerable traction, with educators reporting positive outcomes, highlighting the value of VLs in transforming passive learning environments into interactive, student-centred spaces, even in contexts with robust technological infrastructure (Khukalenko et al., 2022). Despite widespread recognition of the importance of lab work in science education, such technological advancements have been incorporated into teaching methods gradually and slowly (Kolil et al., 2020), while traditional teaching techniques that call for teacher-led presentations are still widely used in many regions of the world. The factors of this situation include inadequate infrastructure, poor service delivery (Bostain, 2024; Khethiwe, 2023) as well as reluctance to alter long-standing instruction and provide sufficient training to use ever-evolving technologies with ease (Kolil et al., 2020).

Understating educators' perceptions of VL is crucial to increasing their use in these contexts. Research has consistently shown that science educators play a monumental role not only in imparting scientific skills amongst students but also invoking inquisitiveness, engagement and perseverance required for excellence (Fauth et al., 2019; Ben Ouahi et al., 2022). In this regard, their attitudes are especially influential, as they strongly shape their willingness to adopt new technologies in the classroom (Davis, 1989). This complexity is highlighted by Mishra (2019) who asserts that the effectiveness of educators' technology integration corresponds to a great degree to their context and their perceptions. Within the specific context of VLs, these contextual factors may encompass a range of influences, including educators' awareness of available technologies, their understanding of institutional

structures and the ways which organized dynamics and school politics can shape decisions related to their teaching with technology.

Despite these challenges, literature overwhelmingly supports the use of technology in teaching-practices towards positive student outcomes (Achuthan et al., 2020). Crucially, however, research suggests that the effectiveness of such technological innovations depends not only on their design or availability, but also on educators' perceptions. According to Caratachea and Monty Jones (2024), educators' perceptions and attitudes play a critical role in determining the success of technological integration. Similarly, Ertmer (2005) argues that attitudes and beliefs of educators are among the strongest predictors whether technology will be integrated in classrooms. As Zeichner (2021) further observes, even educators with strong technical skills may hesitate to adopt digital tools if they question their pedagogical value. Therefore, fostering more positive and favorable perceptions of VLs emerges as a key condition for their effective integration. Considering this, understanding what motivates educators to adopt VLs is also a crucial step in helping them integrating ICT into laboratory instruction.

Most of the research on VL that is currently available focuses on how it affects students' attitudes toward the VLs in science learning (Lestari & Supahar, 2020; Banda & Nzabahima 2023) and their scientific achievement (Banda & Nzabahima 2023). However, as educators and students may have different reasons for embracing an educational technology like VL, it is worth exploring educators' perceptions and attitudes as these influence whether they embrace or reject educational innovations, which could have an impact on how they integrate technology into their lessons (Suparjan, 2021; Yazici & Nakıboğlu, 2024).

1.3.1. Pedagogical role of educators in Inquiry-based Learning-supported VLs environments

Beyond adoption, effective pedagogical use of VLs requires careful instructional design and appropriate teaching approaches. One such approach that aligns closely with the affordances of VLs is Inquiry-based Learning (IBL).

The effective implementation of IBL, however, is not straightforward. Educators play a pivotal role in facilitating and shaping the inquiry process, ensuring that students' exploration is productive and leads to meaningful engagement with scientific concepts. Rather than simply transmitting knowledge, teachers become facilitators, mentors, and guides who support students throughout the learning process (Artigue et al., 2012). The role of educators needs to be active in terms of providing students with the necessary scaffolding that supports them in navigating the inquiry process effectively (Constantinou et al., 2018). It is essential to clarify two key

notions in this context: *scaffolding* and *guidance*. Scaffolding refers to the provision of tailored support based on students' needs, with a gradual transfer of responsibility from teacher to learner as students gain independence. Guidance, on the other hand, determines the degree of autonomy granted to students, establishing four levels of inquiry - verification, structured, guided, and open - depending on whether students are allowed to formulate their own research questions, collect data, and interpret results autonomously (Fernández-Monteira et al., 2020). The educators' role in IBL using VLs can be enacted in the following ways:

Facilitator: Educators create a student-centered learning environment that encourages students' exploration and questioning. They scaffold learning experiences, helping students navigate through virtual experiments and draw meaningful conclusions (Constantinou et al., 2018).

Resource provider: VLs offer access to interactive activities and experiments, but the teacher must provide additional resources (e.g., videos, articles, datasets) to support students' inquiries (Teig, 2021).

Instructor: IBL can promote students' autonomy, but educators provide direct instruction on experimental techniques, safety protocols, and scientific reasoning for engaging students in inquiry (Lazonder & Harmsen, 2016).

Mentor and guide: Educators guide students in formulating hypotheses, designing investigations, and analyzing data. They provide feedback for supporting students in the processes of refining their approaches/hypotheses and deepening their understanding of the problem investigated (García-Carmona, 2020).

Assessor: Effective assessment in IBL VLs requires evaluating students' engagement and performance in the process of inquiry, not just their final answers. Educators can implement portfolios, reflective reports, and project-based assessments to capture students' learning progress (Constantinou et al., 2018).

2. Analytical framework

The current research uses a two-fold theoretical approach to investigate educators' perceptions on VLs and their intention to integrate them into their teaching practice. It incorporates the learning theory approach and the technology adoption approach as two theoretical lenses. Drawing upon Osanloo and Grant's (2016) perspectives, it becomes evident that researchers can draw upon one or more suitable theoretical frameworks that align with their study. This strategic selection of multiple theoretical frameworks empowers researchers to construct a robust foundation for their investigations and potentially gain multi-dimensional insights into the phenomena under scrutiny.

On one hand, the learning theory approach focusses on exploring how educators consider the pedagogical value of VLs for supporting student inquiry. On the other hand, the technology adoption approach focuses on exploring the way that educators' perceptions influence their intention for adopting VLs in their teaching practice. The current research combines the two approaches to create a two-fold interpretive framework that encompasses both the meaning-making process and the technology acceptance process. The following sections describe the two approaches and their roles in the analytical framework of the current research.

2.1. Learning theory lens: Inquiry-based Learning (IBL)

In this study, IBL is used as an analytical lens to interpret whether educators perceive VLs as environments that support student investigation and autonomy.

Inquiry can be understood as a question-driven, open-ended process that supports students in developing knowledge and investigative skills to explore, internalize and apply new concepts and solutions to questions or problems that can be addressed through science (Bevins & Price, 2016). IBL can be defined as an educational approach that emphasizes active student engagement in the learning process through investigation and problem-solving. Rather than delivering information directly, teachers facilitate learning by posing thought-provoking questions, presenting real-world scenarios, and guiding students to explore, analyze, and derive conclusions independently (Lazonder & Harmsen, 2016). The main goal is to facilitate meaningful learning by enabling students to construct their own knowledge. IBL aligns with Dewey's (1938) philosophy of learning through experience and is widely recognized as an effective strategy in science education (Lazonder & Harmsen, 2016). According to Dewey, learning experiences should be collaborative and placed in a frame of active learning (Constantinou et al., 2018). Today, it is a recommended approach for science instruction in school since it can provide learners with key knowledge and skills, as well as contribute to their motivation for learning (Crawford, 2014).

IBL follows a structured yet flexible cycle of inquiry, usually involving stages such as observation, hypothesis formulation, experimentation, data analysis, and conclusion drawing. This approach enhances students' ability to develop problem-solving skills and scientific competencies that are fundamental in modern education (Teig et al., 2021). Research suggests that IBL fosters deeper conceptual understanding and improves knowledge application compared to traditional instructional methods, particularly when students receive appropriate guidance (Lazonder & Harmsen, 2016). To better understand how inquiry operates in educational contexts, it is useful to examine the structure of the inquiry cycle, such as the model

proposed by Pedaste et al. (2015), which includes five key phases: *Engage, Problem Definition, Investigation, Conclusion, and Discussion*. This cyclical process illustrates how inquiry-based learning functions as a general pedagogical framework that can be applied across disciplines (Fig. 2.1).

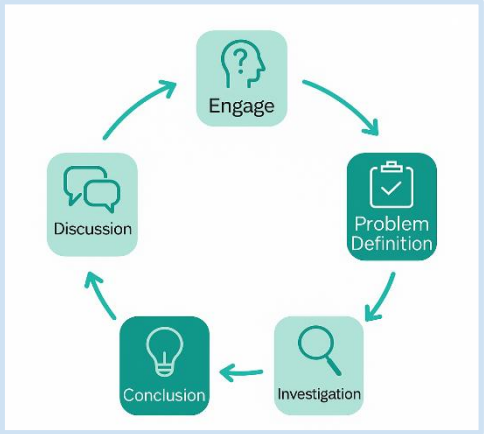


Figure 2.1 The inquiry cycle based on Pedaste et al. (2015).

Within science education specifically, this framework is operationalized through Inquiry-Based Science Education (IBSE) a process that "involves engaging students in using critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening [one's] understanding by using logic and evidence about the natural world" (Crawford, 2014, p. 515). This definition includes central scientific practices and refers to a learning process in which learners are actively engaged to understand scientific concepts and processes, as well as the nature of science. It also encompasses skills that are highlighted in 'Program for International Student Assessment' (PISA) 2024, such as creativity, innovation, problem solving, and critical thinking (Vincent et al., 2019; Strat et al., 2023). While IBL serves as a broad instructional framework applicable across disciplines, IBSE specifically adapts these principles to science education, emphasizing scientific reasoning and methodologies (Constantinou et al., 2018). IBSE plays a crucial role in virtual science laboratories by fostering student practices of critical thinking and scientific reasoning. Traditional science education often relies on predefined experiments with clear instructions and expected outcomes, which help develop technical skills but may not always encourage independent thinking or problem-solving. In contrast, IBSE within virtual labs enables students to actively explore scientific concepts by posing questions, formulating hypotheses and analyzing results (Constantinou et al., 2018; De Jong et al., 2013). This approach not only deepens conceptual understanding but also mirrors authentic scientific processes, preparing

students for real-world research and STEM careers. Some of the benefits of integrating IBSE into VLs Biology Education are described below:

Enhancing scientific inquiry and problem-solving: VLs offer a safe and flexible environment for conducting experiments that may be too hazardous, costly, or impractical in a physical setting. By engaging in open-ended investigations, students develop essential skills such as evidence-based reasoning, critical analysis, and problem-solving. Instead of passively following instructions, they must interpret data, refine their hypotheses, and draw conclusions — an experience that strengthens their ability to tackle complex scientific challenges beyond the classroom (Lazonder & Harmsen, 2016; García-Carmona, 2020).

Motivation, engagement, and digital competences: When students take an active role in their learning, they are more likely to stay engaged and motivated. VLs, enhanced by IBSE, create interactive and immersive learning experiences where students can experiment freely, fostering curiosity and perseverance. Additionally, these digital platforms help students develop technological literacy by using scientific software, simulation tools, and data analysis techniques—competencies increasingly relevant in modern scientific research and professional environments (Teig, 2021; Lazonder & Harmsen, 2016).

Understanding the nature of science and scientific practice: Beyond technical skills, IBSE in VLs cultivates a deeper understanding of the nature of science. As García-Carmona (2020) highlights, scientific inquiry involves not only experimentation but also hypothesis generation, argumentation, and the critical evaluation of results. Virtual labs enable students to experience how scientific knowledge is constructed, validated, and refined over time, providing a more authentic perspective of scientific practice and its role in addressing real-world problems.

2.2. Technology theory lens: Technology Acceptance Model (TAM)

Several variables affecting the adoption of a new technology tool—in this case VLs—inevitably come up when it is included into teaching and learning environments. These elements could include user attitudes and perceptions as well as opposition to its use. Carver (2016) claims that between 60 and 70 percent of all technology-related projects fail due to a lack of acceptability of the technology rather than technical difficulties. Similarly, Davis (1989) notes that perceptions and other aspects of technology acceptability have a role in the success or failure of new technologies. Therefore, Davis (1989) and Carver (2016) emphasize how crucial it is to examine issues of user technology acceptance before thinking about real technology use. Numerous models of technological acceptance have been created over time, but Technology

Acceptance Model (TAM) (Davis, 1989) is one of the most popular frameworks that addresses how perceptions impact technology integration.

In 1989, Davis created TAM "TAM deals with feelings, attitudes, perceptions, beliefs, and behaviors related to technology acceptance," according to Davis (1989:23). However, TAM "presently enjoys the status of being the prime tool for examining user acceptance of new technologies," according to Kriek and Stols (2010:13). TAM is based on the idea that when people are presented with new technology, several factors influence their decisions about if, how, and when to utilize it, according to Siegel et al. (2017:15). Furthermore, TAM asserts that a person's intention to integrate technology is contingent upon how they view those technologies.

The TAM claims that perceptions, that is, “Perceived Ease of Use (PEOU) and Perceived Usefulness (PU), are the two essential determinants of user acceptance of technology” (Davis, 1989:123). The PEOU refers to “the extent to which an individual believes that using a specific technology would be effortless or require minimal effort” (Davis 1989:231). The PU refers to “the degree to which a person believes that using a particular technology will improve his or her work performance” (Davis, 1989:230). Thus, TAM theorises that PEOU influences PU; that is, if Life Sciences teachers in rural secondary schools find an educational technology (VL) “easy to use,” they are likely to perceive it as being “useful.” The TAM presents the contributing inter-relationships of these two elementary constructs (PU and PEOU) together with three other constructs: “attitude toward using (ATT),” “behavioural intention to use (BI),” and “actual use (AU).” Therefore, Life Sciences teachers’ positive attitudes and perceptions of VL could result in an intention to utilise the technologies (Fig. 2.2).

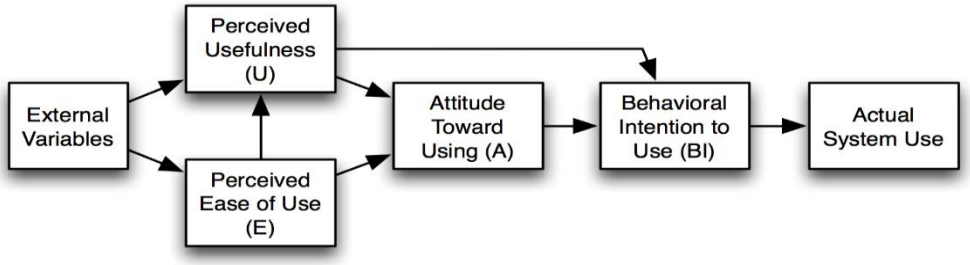


Figure 2.2 Constructs of the Technology Acceptance Model (TAM).

2.3. Analytical framework of the study

Although IBL has been extensively debated in the literature as a learning methodology that encourages active knowledge construction, in this thesis, it is not investigated as a learning methodology per se but rather as a lens for interpreting educators' views of VLs. More specifically, IBL is employed in this research as a conceptual framework for assessing whether teachers view VLs as places that facilitate the basic inquiry processes of questioning, investigating, data interpretation, and autonomy for students.

Instead of investigating the actual implementation of inquiry processes in educational settings, this research investigates teachers' views of the degree to which virtual laboratories can facilitate inquiry-based learning environments. In this respect, IBL is employed as a lens for interpreting educators' views of virtual laboratories, and survey questions were designed to reflect educators' views of the capacity of virtual laboratories to facilitate inquiry-based learning principles such as exploration, hypothesis testing, experimentation, and evidence-based reasoning. By employing IBL in this analytical fashion, the research can go beyond general attitudes toward technology and instead investigate whether teachers perceive virtual labs as meaningful tools that are consistent with constructivist learning principles. Therefore, IBL becomes the pedagogical component of the analytical framework, in addition to the Technology Acceptance Model, which addresses the technological adoption component.

In addition, TAM was chosen as the major conceptual framework for this thesis, owing to its intensive validation and extensive usage in the process of studying user acceptance of new technologies (Siegel et al., 2017). TAM is especially relevant in the field of educational technology studies, since it is centered on the study of how users' perceptions, beliefs, and attitudes shape their decisions to accept or reject technological innovations (Casey et al., 2021). As can be seen, the current study focuses on the perceptions of Life Sciences teachers regarding virtual laboratories, and the Technology Acceptance Model offers a sound conceptual framework for the analysis of these perceptions and their subsequent translation into adoption-related intentions. A key strength of TAM lies in its ability to account for both internal cognitive factors and contextual variables that may shape technology acceptance. In addition to its core constructs, Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), the model allows for the inclusion of external variables. This flexibility makes it particularly suitable for educational contexts, where adoption decisions are rarely determined by perceptions alone but are also influenced by structural and environmental constraints (Byukusenge et al., 2024).

In the current research, particular emphasis is placed on the construct of **Behavioural Intention to Use (BI),** as it is the most proximal predictor of technology adoption. In the TAM model, BI is the mediator that translates perceptions and attitudes into actual behaviour. The analysis of teachers' BI enables the current research to go beyond the assessment of overall attitudes towards virtual laboratories and instead evaluate their preparedness and willingness to adopt these tools in the classroom. By shifting the focus of analysis to BI, a more specific interpretation of adoption potential is enabled, given that intention is generally considered a robust predictor of future behaviour in technology acceptance studies. In this context, the TAM model is used not only as a descriptive framework but also as an interpretive device that facilitates the systematic analysis of the complex interplay between educators' perceptions, contextual factors, and experiences that influence their intention to use virtual laboratories in educational practice. By shifting the focus of analysis to BI, the framework is directly related to the objective of the current research, which aims to identify the factors that influence whether teachers are likely to adopt virtual laboratory technologies in educational practice.

3. Study Context: The VHEalthLab online toolkit and Implementation

This master's thesis is situated within the VHEalthLab project and draws directly on its pilot implementation phase. Rather than focusing solely on learning outcomes or student performance, the study adopts the perspective of university educators as key agents in the successful adoption and pedagogical use of VLs. Educators play a central role in mediating IBL, calibrating guidance and scaffolding, and aligning digital tools with curricular goals and assessment practices. Understanding their experiences, perceptions, and needs is therefore critical for evaluating the educational potential and sustainability of virtual laboratory platforms.

This chapter presents the empirical context within which the present study was conducted. It introduces the VHEalthLab European project as the institutional and pedagogical setting of the research and outlines the main components of the platform, including the VLs, the pedagogical framework, and the accompanying training modules. This information provides the necessary background for understanding the design of the study, the data collection procedures, and the interpretation of the findings presented in the subsequent chapters.

3.1. The VHEalthLab project

VHEalthLab (https://www.vhealthlab.eu) is an innovative European research project designed to enhance Health Sciences education by using open-access VLs. Focused on Biology,

VHEalthLab provides students and educators with engaging, hands-on virtual lab experiences that bridge the gap between theoretical knowledge and practical application. VHEalthLab acts as an open online platform that combines VLs with an educational online toolkit to enable high quality practical science learning in safe, scalable, and inclusive ways. It addresses long standing constraints of physical laboratories, including cost, safety, access, and capacity, while responding to the post pandemic demand for flexible and blended provision. The platform strengthens digital readiness, supports inquiry-based teaching, and contributes to more resilient, equitable, and future oriented STEM education across Europe. The project is a collaborative effort between leading institutions, including the University of Nicosia, Aristotle University of Thessaloniki, Universidade de Santiago de Compostela, Ascendia, and the Ministry of Education, Sport and Youth of the Republic of Cyprus, all aiming to support the pedagogical integration of VLs through a combination of digital learning activities, pedagogical guidelines, and training modules.

VHEalthLab responds to the growing need for innovative learning solutions in STEM education. Considering the global shift towards blended and distance learning, this project provides a timely solution by making high-quality, interactive Biology labs accessible to a wider audience. By fostering essential skills like critical thinking, creativity, and digital literacy, VHEalthLab equips students with the tools they need to thrive in today's complex world. More specifically, the VHEalthLab project pursued the following objectives:

- Identify Biology lab curricula in Health-related programs in HE across the EU
- Design and develop open-access VL Biology scenarios for HE
- Translate the VLs in all partner languages (English/Greek/Spanish/Romanian)
- Design and develop a VHealthLab e-learning environment and OERs' (an interactive toolkit) to integrate VLs in HE curricula
- Design and develop pedagogical guidelines to support HE educators on how to implement VLs in their curricula in various forms (face to face or remotely) and provide open access training to educators in the partner countries
- Raise awareness on the need and value of integrating Open-Access VLs

A pioneering online toolkit for STEM topics integrates VLs activities, pedagogical guidelines, and educators' training modules, offering a structured yet flexible environment that supports inquiry-based science education across different educational settings and national contexts.

3.2. Overview of the VHEalthLab training content and VLs

3.2.1. Virtual Labs

VHEalthLab offers a coherent suite of fourteen (14) VLs activities that cover core domains of Biology and Health Sciences while modelling an IBL approach. Each activity follows a consistent structure: clear learning objectives, a guided investigation pathway, embedded checks for understanding, and prompts for interpretation and communication of results, so that educators can deploy them in group, individual, or remote scenarios. Collectively, the labs progress from foundational techniques (light microscopy, lab safety, use of basic equipment) to discipline-specific practices (cell division, electron microscopy, restriction digestion, DNA isolation/PCR, microbial culture) to integrative reasoning (biomolecules, enzymology, probabilities/biostatistics, cell culture). Objectives are written at multiple cognitive levels (identify/describe, apply/interpret, analyse/evaluate/design) to support curriculum alignment and assessment. All materials are available in English, Spanish, Greek, and Romanian, with inclusive design features that reduce cognitive load and promote equitable participation. Table 1 summarises each VL alongside its targeted learning outcomes (Table 3.1).

Table 3.1 VL activities included in the VHEalthLab online toolkit.

VL	Description
Light Microscopy	This VL introduces the basic structure and operation of the compound light microscope and guides students in the preparation and observation of wet mounts for the examination of microscopic specimens.
Cell Division I (Mitosis)	This activity focuses on the stages and biological significance of mitosis, enabling students to observe and interpret mitotic phases in prepared cell samples and relate them to growth and tissue regeneration.
Cell Structure and Function	This laboratory explores osmosis and selective permeability through experiments on plant and animal cells, allowing students to predict and interpret cellular responses to different osmotic conditions.
DNA Isolation and PCR	This virtual experiment introduces genomic DNA extraction and polymerase chain reaction techniques, guiding students in performing genotyping and interpreting electrophoresis results in a molecular biology context.
Biomolecules	This activity examines the identification of major biomolecules through qualitative biochemical tests and relates their presence in biological samples to physiological and pathological conditions.
Metabolism of Cell Enzymes (temperature and pH)	This laboratory investigates the effects of temperature and pH on enzymatic activity, enabling students to determine optimal reaction conditions using amylase as a model enzyme.
Lab Safety	This module introduces essential laboratory safety principles, good laboratory practices, and hazard recognition, providing foundational training for safe and responsible experimental work. This activity presents the principles and applications of electron microscopy, guiding students in comparing SEM and TEM techniques and understanding their use in studying subcellular structures and tumor models.
Electron Microscopy	This laboratory introduces DNA digestion with restriction enzymes and the analysis of resulting fragments by gel electrophoresis, highlighting key applications in molecular biology.
Restriction Endonuclease digestion	This activity explores fundamental genetic concepts and Mendelian inheritance through problem solving with Punnett squares and the analysis of hereditary diseases.
Mendelian Genetics and Genetic Problems	This virtual laboratory focuses on aseptic techniques, selective and differential media, and quantitative methods for isolating, culturing, and characterizing bacterial populations.

Microbial culture and growth	This module introduces the correct use of essential laboratory instruments, emphasizing precision, good laboratory practices, and the prevention of common technical errors.
Using basic lab equipment (pipettes, scales, centrifuge, spectrophotometer)	This activity introduces probability concepts in genetics and cytogenetics, guiding students in applying statistical rules to predict inheritance patterns and chromosomal abnormalities.
Biostatistics: Introduction to probabilities	This activity introduces probability concepts in genetics and cytogenetics, guiding students in applying statistical rules to predict inheritance patterns and chromosomal abnormalities.
Cell Culture	This laboratory introduces mammalian cell culture techniques and experimental design, enabling students to evaluate treatment effects on cancer cell behavior under controlled conditions.

3.2.2. Pedagogical framework of VHEalthLab

VHEalthLab is grounded in IBL and its science-specific adaptation IBSE. In this approach, learners construct understanding by asking questions, formulating hypotheses, investigating phenomena, analyzing evidence, and communicating conclusions. The framework prioritizes the development of scientific reasoning, problem-solving, and data-informed decision-making - competencies aligned with contemporary European priorities for digital transformation, creativity, and critical thinking. The inquiry cycle used in VHEalthLab follows five (5) flexible phases: *Engage, Problem Definition, Investigation, Conclusion,* and *Discussion*. Learning scenarios begin with real-world prompts that spark curiosity, then guide students to design or follow investigations, interpret findings, and reflect on limits and implications. Crucially, the cycle is iterative rather than linear: learners may revisit earlier steps as new insights emerge, mirroring authentic scientific practice. Educators' practice is central. VHEalthLab positions educators as facilitators, instructors, and mentors who calibrate scaffolding (targeted supports that fade as competence grows) and guidance (the degree of learner autonomy) across four inquiry levels: verification, structured, guided, and open. This calibration enables safe, purposeful exploration in virtual labs while maintaining alignment with curricular goals and assessment standards.

Furthermore, assessment emphasizes process as well as outcomes. In addition to content knowledge, educators evaluate inquiry practices, e.g., quality of questions and hypotheses, appropriateness of methods, rigor of data analysis, and clarity of argumentation, through reports, presentations, portfolios, discussion forums, and built-in activity quizzes. This balances accountability with an authentic demonstration of skills. The framework is delivery-agnostic and supports multiple implementations: group collaboration, self-paced individual work, and remote/asynchronous use, so institutions can adapt to timetable, infrastructure, and cohort needs. Across settings, the design encourages metacognition (learning journals, reflection prompts) and real-world transfer (challenge-based tasks and application discussions).

Inclusion is also addressed explicitly and specific measures to reduce the potential gender gap are taken. These include balanced participation, rotating group roles, bias-aware questioning and assessment, use of female role models, support of diverse learning needs through multimodal resources, chunked tasks, self-paced progression, language supports and multiple formats for demonstrating learning. These recommendations are aligned with platform features such as multilingual availability, stepwise pathways and gender-inclusive narratives. Finally, VHEalthLab embeds practical preparation for hands-on laboratories: virtual experiences introduce procedures, equipment, and safety, reducing errors and increasing efficiency when students transition to physical labs. This coherent, evidence-based pedagogy ensures that the platform is not merely a digital repository but a structured environment for cultivating inquiry, resilience, and scientifically literate graduates.

3.2.3. Educators' training modules

Training module 1: Introduction to VHEalthLab and IBL

This module introduces VHEalthLab and outlines the benefits and limitations of VLs, then anchors implementation in an IBL framework. Educators are guided through the inquiry cycle with concrete VHEalthLab examples, and are supported to adopt multiple roles (facilitator, mentor/guide, etc.). The module provides examples of guidance vs. scaffolding, offering practical strategies to engage students in inquiry-based learning from less structured to more structured educators' guidance. Finally, it presents three classroom implementation scenarios (group work, individual/self-paced, and remote use), each with inquiry opportunities, teacher actions, and inclusion considerations, highlighting multilingual access and design choices that help reduce gender and accessibility gaps. The module closes with an interactive planning task so educators can adapt a chosen VHEalthLab case to their context.

Training module 2: Pedagogical strategies for implementing VLs with the IBL approach

This module turns the IBL framework into classroom practice for VHEalthLab. It gives educators concrete strategies to design, run, and assess inquiry across pre-, during-, and post-lab phases. It begins by revisiting IBL's essentials: question-driven learning, staged inquiry, scientific skills, active student roles, and then tackling practical teacher challenges with targeted, ready-to-apply advice. Educators are guided to craft IBL situations in seven steps: setting objectives; launching a real-world scenario to spark curiosity; structuring guided exploration in the virtual lab; using evidence for analysis and conclusions; facilitating communication and debate; assessing both process and outcomes; and connecting learning to authentic applications. This is illustrated with short examples (e.g., Cell Division, Enzyme

Metabolism) and ready-to-use prompts. Inclusion is embedded via equitable roles, gender-inclusive examples, flexible formats, and adaptations for diverse learning needs. The module also provides indicators to recognise whether students are applying for inquiry, to help educators recognise and adjust their teaching practice in real time. It closes with a brief planning task so educators can adapt a chosen VHEalthLab activity to their context immediately.

Training module 3: Addressing diverse learning needs and gender gap in VHEalthLab This module translates the pedagogical guidance on inclusion into practical classroom action. It clarifies what inclusive science education entails and why it matters for inquiry-based virtual labs, then focuses on two fronts: (1) understanding and reducing the gender gap in STEM, and (2) identifying and supporting diverse learning needs. Educators get concrete strategies to counter bias in group dynamics and evaluation. Regarding student learning diversity, the module helps educators identify needs in processing speed, learning preferences, attention, pace/autonomy, language, and digital confidence, and how to address them with practical examples. It then shows how to embed these practices into the three implementation scenarios: group work, self-paced use, and remote learning; using VHEalthLab features to personalize inquiry without sacrificing rigor. An applied case and an "interactive task" guide educators to design an inclusive, IBL-aligned VHEalthLab session tailored to their class context.

4. Aim and objectives of this thesis

The aim of this thesis is to explore and evaluate educators' perceptions and experiences with the VHEalthLab online toolkit and VLs as digital learning activities designed to complement and support laboratory-based Biology teaching across HE and secondary education contexts. The study examines how educators who are involved in Biology education across HE and secondary contexts, including pre-service and in-service educators, perceive the use of VLs and their accompanying pedagogical materials, focusing on perceived usability, pedagogical value, and support of IBL, with the aim of extending laboratory instruction beyond the physical laboratory environment.

In addition, the thesis investigates specifically educators' intention to use the VHEalthLab online toolkit and VLs in future teaching practice and investigates exploratory associations between intention to use and key perceived related factors such as clarity, pedagogical guidance, learning design, usability, and IBL support. By combining descriptive quantitative findings with qualitative insights from focus group discussions conducted across four European countries, the study seeks to provide an integrated understanding of the factors that shape the

acceptance, pedagogical value, and adoption potential of the VHEalthLab online toolkit and VLs across diverse educational contexts. More specifically, the thesis aims to:

1. Evaluate educators' perceptions of the VHEalthLab online toolkit and VLs in terms of usability, navigation, multimedia quality, pedagogical value, and support for IBL
2. Explore educators' intention to use the VHEalthLab online toolkit and VLs and investigate exploratory relationships between intention to use and key perceived factors
3. Analyse qualitative data from focus group discussions conducted in four European countries to identify perceived benefits, challenges, contextual factors, and pedagogical implications related to the interaction with the VHEalthLab online toolkit and VLs
4. Provide an integrated understanding of the conditions that influence pedagogical value, acceptance, and potential adoption of the VHEalthLab online toolkit and VLs
5. Conduct a comparative cross-country analysis that highlights how institutional, pedagogical, and cultural factors shape educators' experiences and perceptions of the VHEalthLab online toolkit and VLs adoption

In the long term, the findings aim to inform the design of transferable and sustainable digital educational initiatives that support IBL and contribute to the development of digital and scientific competences for current and future health professionals within a rapidly evolving, data-driven healthcare landscape.

4.1. Research questions

The study is guided by the following research questions:

RQ1. How do educators perceive the usability, navigation, multimedia quality, and overall pedagogical value of VLs in laboratory-based biology teaching?

RQ2. To what extent do educators perceive the VLs as supporting IBL and their integration into teaching practice?

RQ3. What is educators' intention to use VLs in future teaching contexts?

RQ4. Which perceived factors (e.g. clarity, pedagogical guidance, usability, IBL support etc.) are exploratorily associated with educators' intention to use the VLs?

RQ5. What benefits, challenges, and contextual factors do educators identify through focus group discussions regarding the use and implementation of VLs in?

RQ6. How do educators' experiences and perceptions of VLs vary across participating countries, and what shared themes and contextual particularities emerge from the qualitative cross-country analysis?

5. Methods

5.1. Research design and context of the study

The pilot implementation of VHEalthLab was carried out within the framework of the VHEalthLab European research project, providing an authentic implementation setting, ensuring that educators' responses were grounded in actual use rather than hypothetical evaluation. Implementation and validation activities were conducted in four participating countries acting as pilot sites (1) Cyprus, led by the University of Nicosia (UNIC), (2) Greece, led by Aristotle University of Thessaloniki (AUTH), (3) Spain, led by Universidade de Santiago de Compostela (USC) and (4) Romania, led by Ascendia.

This study adopted a mixed-methods research design, combining quantitative and qualitative approaches to provide a comprehensive evaluation of the VHEalthLab online toolkit during its implementation. The design was exploratory, descriptive, and evaluative in nature, aiming to capture both measurable trends in educators' perceptions and deeper insights into their experiences, challenges, and contextual practices. A sequential explanatory strategy was employed. Quantitative data were initially collected through structured questionnaires administered to educators who participated in the implementation to systematically assess their perceptions related to usability, pedagogical value, and readiness for VLs adoption and implementation. Subsequently, qualitative data was gathered through focus group discussions in each participating country, allowing for in-depth exploration and interpretation of the quantitative findings and for the identification of contextual factors that may not have been captured through quantitative instruments alone. Finally, the cross-country nature of the study enabled a comparative perspective, not through statistical comparison, but through thematic and interpretive analysis. This approach made it possible to identify common patterns across countries as well as country-specific particularities related to pedagogical culture, institutional conditions, and digital readiness, thereby enriching the evaluation of the VHEalthLab online toolkit and its potential for broader European HE adoption.

Given the exploratory nature of the study and its focus on perceived usability, pedagogical value, and intention to use, the inclusion of educators with diverse professional backgrounds provided a broader perspective on how VLs may be perceived and adopted across different educational pathways.

5.2. Participants

5.2.1. Overall participants sample

Participants of the study were educators involved in Biology education across different educational levels, including HE and secondary education. Both pre-service and in-service educators were included, to capture a broad range of professional experiences, teaching roles, and levels of familiarity with digital educational tools and VLs. A total of *70 educators* from four European countries—Cyprus, Greece, Spain, and Romania—participated in the pilot implementation and evaluation of the VHEalthLab online toolkit.

From this broader group, *25 educators* participated in follow-up focus group discussions conducted in the four (4) participating countries. These participants were purposefully selected from among those who had participated in the pilot implementation, with the aim of ensuring representation of different educational contexts, professional roles, and levels of teaching experience.

5.2.2. Participant characteristics and demographic considerations

Participation criteria were defined at project level and included educators involved in Biology teaching in HE or secondary education. Participants were invited to take part through institutional networks and project partner channels in each participating country, following the ethical guidelines of the VHEalthLab project.

Although the project-level guidelines encouraged the involvement of both HE biology educators and secondary education biology teachers, the final composition of participants varied across countries due to institutional contexts, availability, and national implementation strategies. As a result, the study sample includes educators at different stages of their professional trajectory, including in-service HE and secondary educators, as well as pre-service secondary science teachers. This heterogeneity reflects the authentic and practice-oriented nature of the VHEalthLab pilot implementation and was treated as a contextual characteristic rather than a limitation of the study design. Additionally, no detailed demographic data was collected. This decision was taken at project level to facilitate data collection, reduce participant burden, and ensure compliance with data protection and ethical requirements (GDPR) across different national contexts. While this limits the possibility of analysing differences based on individual characteristics, it does not compromise the core evaluative aims of the study, which focus on educators' perceptions of the pedagogical and technological aspects of the VHEalthLab VLs and online toolkit.

5.3. Data collection instruments

5.3.1. Quantitative evaluation tools

Quantitative data was collected through two project-designed questionnaires developed to systematically capture educators' perceptions of the platform's pedagogical and technological characteristics and its potential for integration into teaching practice. Both questionnaires were completed after participants had engaged with the online toolkit, including the VLs and corresponding pedagogical materials.

The **first questionnaire** assessed overall educators' perceptions of the pedagogical guidelines and instructional module of the VHEalthLab online toolkit, focusing on clarity and usability of instructions, perceived usefulness for teaching practice, support for IBL, and consideration of inclusive teaching aspects (e.g. gender inclusion and diverse learning needs). Educators' intention to use the pedagogical materials was particularly examined. The **second questionnaire** evaluated educators' experiences with the VLs activities themselves, examining platform usability and navigation, pedagogical effectiveness and alignment with IBL, role in relation to face-to-face laboratory teaching, supporting learning features, and intention to use VLs in future teaching contexts.

Both questionnaires employed five-point Likert scales (1 = strongly disagree to 5 = strongly agree) to allow for descriptive quantitative analysis and comparison across participants and countries. The estimated completion time for each questionnaire was approximately 10 minutes, ensuring feasibility within the project's pilot implementation timeline and minimizing participants' burden.

5.3.2. Qualitative evaluation tools

Qualitative data were collected through four (4) focus groups, conducted separately in each participating country. Across all countries, focus groups were semi-structured ensuring cross-country comparability. The primary aim of the focus groups was to elicit educators' experiences with the platform, identify perceived benefits and barriers, and capture contextual and institutional factors influencing the adoption and integration of the VHEalthLab online toolkit. The focus groups were guided by a semi-structured discussion guide consisting of predefined questions designed to facilitate dialogue around key aspects of participants' experiences with the platform, including usability, perceived benefits, challenges, and suggested improvements. These predefined questions ensured consistency across focus groups and supported comparability between countries, while also allowing participants to elaborate on issues they

considered important. Conducting separate focus groups per country allowed participants to discuss their experiences within a shared national and institutional context, while also enabling a subsequent comparative analysis across countries. To support participation across countries the focus groups were held in the languages of implementation in each partner country.

The full questionnaires, including all items and response scales, as well as the focus group guide are provided in Annexes A and B.

5.4. Procedure

A common data collection procedure was followed across all four participating countries to ensure methodological consistency and comparability of findings. Initially, educators participated in an introductory session, during which the objectives of the VHEalthLab project, the structure of the online toolkit, and the intended pedagogical use of the VLs were presented. Following that, participants were given access to the VHEalthLab online toolkit and were encouraged to interact with the platform, explore the VLs, and engage with the accompanying pedagogical guidelines and instructional materials. Finally, participants completed the two questionnaires, which captured their perceptions of the pedagogical materials, the VLs, and the overall usability and educational value of the toolkit.

Subsequently, focus group discussions were conducted with a subset of participants in each country. The focus groups took place after the completion of the questionnaires, allowing participants to reflect on their experiences and elaborate on issues that emerged during the quantitative evaluation. Across all countries, focus groups followed a semi-structured format and were facilitated by project partners. Most focus groups were conducted online, apart from the focus group in Spain, which was held face-to-face. The discussions were recorded, transcribed, and analysed as part of the qualitative component of the study.

5.5. Data analysis

Quantitative data was analysed using descriptive and correlational statistics in Microsoft Excel. Given the exploratory and evaluative nature of the study, as well as the absence of pre-intervention measures and demographic variables, the analysis focused on identifying overall trends in educators' perceptions rather than testing causal relationships. Due to unequal participation rates across countries and relatively small national subsamples, analyses were conducted on the aggregated dataset (N = 70) to ensure more stable and interpretable results.

To enhance analytical clarity, questionnaire items were grouped into thematic categories reflecting key dimensions of the VHEalthLab toolkit, including usability, pedagogical value,

IBL, learning design, inclusion strategies, and intention to use. Internal consistency reliability for multi-item themes was examined using Cronbach's alpha prior to further analysis. Descriptive statistics (means and standard deviations) were calculated at both item and theme levels. In addition, Pearson correlation analyses (two-tailed) were conducted to explore associations between educators' intention to use (single-item measures in each questionnaire) and the corresponding thematic dimensions. Statistical significance was interpreted at the $p < .001$ level.

Qualitative data derived from focus group discussions were analysed using a thematic, inductive, descriptive analysis. The analysis followed a comparative process in which responses were examined within each country and then across countries to identify recurring patterns, perceived benefits, challenges, and contextual factors related to the implementation of the VHEalthLab online toolkit and VLs. Rather than applying a fully inductive coding framework, the analysis was guided by the study's research questions allowing themes to emerge within these analytical categories. Cross-country comparison was conducted to identify both shared themes and context-specific variations.

Qualitative data from the focus group discussions were analysed following an inductive thematic coding process, involving preparing and categorizing data, ongoing revision, and reporting themes (Thomas, 2006). All focus groups were audio-recorded and transcribed verbatim prior to analysis. The analysis involved successive stages of familiarisation with data, coding, and theme development. An initial set of codes was generated by systematically examining participants' statements and was subsequently refined through an iterative process. The coding followed a combined deductive and inductive approach: deductive codes were informed by the predefined focus group themes, while inductive coding allowed additional themes to emerge from the data.

5.6. Ethical considerations

The study was conducted in full compliance with ethical research standards and the General Data Protection Regulation (GDPR). Ethical approval was obtained from the Research Ethics and Deontology Committee of the Aristotle University of Thessaloniki (Approval No. 145792/2024). Participation was entirely voluntary, and data was collected anonymously to ensure confidentiality of responses.

6. Research findings

6.1. Quantitative data

6.1.1. Internal consistency reliability (Cronbach's alpha)

Prior to the main analyses, the internal consistency reliability of the questionnaire themes was examined using Cronbach's alpha. Reliability analysis was conducted for all multi-item themes across both questionnaires.

As far as questionnaire evaluating the pedagogical guidelines and the modules of the VHEalthLab online toolkit is concerned, results indicated acceptable to good internal consistency for most themes. Themes consisting of four items demonstrated good reliability, while slightly lower alpha values were observed for themes comprising two items, which is expected and acceptable in exploratory educational research. More specifically, the Clarity & Accessibility theme and Inclusion Strategies theme showed good reliability (α = .79, α = .76), while the Pedagogical Guidance & IBL theme demonstrated very good internal consistency (α = .84) (Table 6.1). These results support the use of theme-level composite scores in subsequent descriptive and correlational analyses.

Table 6.1 Internal consistency reliability for Questionnaire 1 themes.

Questionnaire	Theme	Number of items	Cronbach's α
Questionnaire 1	Theme 1: Clarity & Accessibility	2	0.79
Questionnaire 1	Theme 2: Pedagogical Guidance & IBL	4	0.84
Questionnaire 1	Theme 3: Inclusion Strategies	2	0.76

Internal consistency reliability for the themes of the questionnaire exploring perceptions of the VLs demonstrated acceptable to good internal consistency. The Usability, Clarity and Platform Functionality theme showed good reliability (α = .78), while the Pedagogical Value and Inquiry-Based Learning theme demonstrated very good internal consistency (α = .86). The Learning Design, Resources and Assessment theme yielded acceptable reliability (α = .75). The Inclusion Strategies theme also showed acceptable internal consistency (α = .75), despite consisting of two items. The Adoption and Intention to Use theme demonstrated lower but acceptable reliability (α = .61), which is considered adequate in exploratory studies with a limited number of items (Table 6.2).

Table 6.2 Internal consistency reliability for Questionnaire 2 themes.

Questionnaire	Theme	Number of items	Cronbach's α
Questionnaire 2	Theme 1: Usability, Clarity & Platform Functionality	4	0.78
Questionnaire 2	Theme 2: Pedagogical Value & Inquiry-Based Learning	3	0.86
Questionnaire 2	Theme 3: Learning Design, Resources & Assessment	3	0.75
Questionnaire 2	Theme 4: Inclusion Strategies	2	0.75
Questionnaire 2	Theme 5: Adoption and Intention to Use	3	0.61

6.1.2. Evaluation of the pedagogical guidelines and the modules of VHEalthLab online toolkit

The analysis focuses on overall descriptive statistics (Mean and Standard Deviation) to capture participants' perceptions of the modules and the pedagogical guidelines of the online VHEalthLab online toolkit. Due to unequal and relatively small sample sizes across participating countries, country-level quantitative comparisons were not conducted. Overall, the findings indicate consistently positive evaluations across all items, with mean scores exceeding 4.0 in most cases, suggesting a high level of agreement among participants (Table 6.3-6.4).

Theme 1: Clarity and Accessibility

Items related to clarity and accessibility (Theme 1) received the highest ratings overall. Participants strongly agreed that the instructions, descriptions, and language used in Modules and the pedagogical guidelines were clear and easy to understand (M = 4.44, SD = 0.77), and that necessary information could be located quickly (M = 4.32, SD = 0.84). At the theme level, Theme 1 achieved the highest mean score (M = 4.39, SD = 0.74), highlighting the effectiveness of the materials in supporting user navigation and comprehension.

Theme 2: Pedagogical Guidance and Inquiry-Based Learning

Theme 2, which focused on pedagogical guidance and IBL approach, was also positively evaluated. Participants perceived Modules as useful for meeting their learning and teaching needs (M = 4.32, SD = 0.98) and reported that the pedagogical guidelines enhanced their understanding of how to use VHEalthLab online toolkit across different educational contexts (M = 4.01, SD = 0.98). The theme-level mean (M = 4.10, SD = 0.78) suggests that the modules effectively communicate pedagogical principles and practical strategies for implementing VLs through IBL.

Theme 3: Inclusion Strategies

Items related to inclusion strategies (Theme 3) also received positive evaluations, though with slightly lower mean scores compared to other themes. Participants agreed that the pedagogical guidelines provided useful strategies for addressing both the gender gap in STEM education (M = 4.11, SD = 0.96) and diverse learning needs (M = 4.15, SD = 0.86). At the theme level, Theme 3 yielded a mean score of M = 3.92 (SD = 0.82), indicating overall agreement, while also suggesting potential scope for further strengthening explicit inclusion-related guidance.

Theme 4: Adoption and Intention to Use

Participants expressed a strong intention to use the pedagogical guidelines and Modules to support the implementation of VHealthLab (M = 4.07, SD = 1.01). This finding indicates a generally positive disposition toward future adoption, although the slightly higher standard deviation suggests some variability in participants' readiness or contextual feasibility.

Table 6.3. Descriptive statistics for Questionnaire 1 (Item level).

Item	Statement	Theme	Mean (M)	SD
Q1	The instructions, descriptions, and language used in Modules and the pedagogical guidelines were clear, appropriate, and easy to understand.	Theme 1: Clarity & Accessibility	4,44	0,77
Q2	I was able to locate the necessary information quickly while working through the Module and the pedagogical guidelines.		4,32	0,84
Q3	The Modules were useful in meeting my teaching needs.	Theme 2: Pedagogical Guidance & IBL	4,32	0,98
Q4	The pedagogical guidelines and the Modules enriched my understanding of how to use VHEalthLab in different contexts.		4,01	0,98
Q5	Modules provided practical guidance on implementing VHEalthLab using an IBL approach.		4,01	0,89
Q6	The IBL approach used in Modules effectively illustrates how VLs can be applied for active learning in various teaching situations.		4,11	0,95
Q7	The pedagogical guidelines and Modules provide useful strategies for addressing the gender gap in STEM education using VLs.	Theme 3: Inclusion Strategies	4,11	0,96
Q8	The pedagogical guidelines and Modules provide useful strategies for addressing diverse learning needs in STEM education using VLs.		4,15	0,86
Q9	I would like to use the pedagogical guidelines and Modules to support the implementation of VHEalthLab.	Theme 4: Adoption and Intention to Use	4,07	1,01

Table 6.4. Descriptive statistics for Questionnaire 1 (theme level).

Theme	Items	Mean (M)	SD
Theme 1: Clarity & Accessibility	Q1–Q2	4,39	0,74
Theme 2: Pedagogical Guidance & IBL	Q3–Q6	4,09	0,78
Theme 3: Inclusion Strategies	Q7–Q8	3,92	0,82
Theme 4: Adoption and Intention to Use	Q9	4,07	1,01

6.1.3. Evaluation of the VLs

The second questionnaire examined participants' perceptions of the VLs included in the VHEalthLab online toolkit. As with the first questionnaire, descriptive statistics were used to summarize overall trends (Table 6.5-6.6).

Theme 1: Usability, Clarity, and Platform Functionality

Theme 1 achieved the highest overall evaluation among the VLs themes (M = 4.22, SD = 0.70). Participants reported that the platform was easy and intuitive to navigate (M = 4.40, SD = 0.76), that instructions and language were clear (M = 4.24, SD = 0.89), and that the platform functioned effectively in supporting interaction (M = 4.11, SD = 0.97). These findings suggest that the technical and usability aspects of the platform did not present barriers to engagement with the VLs.

Theme 2: Pedagogical Value and IBL

Theme 2, which addressed pedagogical value and IBL, received moderately positive evaluations (M = 3.87, SD = 0.87). While participants acknowledged the usefulness of VHEalthLab for teaching health and science-related topics using IBL (M = 4.07, SD = 0.83), slightly lower scores were observed for perceived usefulness in meeting learning/teaching needs (M = 3.65, SD = 1.12) and for promoting scientific inquiry practices (M = 3.88, SD = 1.00). These results suggest that although the pedagogical potential of the VLs is recognized, participants may require additional scaffolding or experience to fully leverage inquiry-based practices.

Theme 3: Learning Design, Resources, and Assessment

Theme 3 received positive evaluations overall (M = 4.01, SD = 0.77). Participants valued the clear structure of the VLs and their alignment with learning goals (M = 4.21, SD = 0.86), as well as the contribution of video tutorials to clarifying key concepts (M = 4.08, SD = 0.91). The final quizzes were perceived as moderately effective in supporting self-assessment (M = 3.74, SD = 1.05), indicating room for further refinement of assessment components.

Theme 4: Inclusion Strategies

Theme 4 yielded the lowest mean scores across the VLs evaluation (M = 3.35, SD = 1.08). While some participants agreed that the VLs considered diverse educational contexts and learners (M = 3.50, SD = 1.21), perceptions of explicit gender inclusion were more mixed (M = 3.20, SD = 1.21). The relatively high standard deviations suggest variability in how inclusion strategies were perceived, possibly reflecting differences in participants' backgrounds or expectations.

Theme 5: Adoption and Intention to Use

Theme 5 examined participants' views on adoption and the role of VLs in relation to traditional laboratories. Participants expressed a strong intention to implement VHEalthLab in their teaching contexts (M = 4.02, SD = 0.86). However, a clear distinction emerged between replacement and complementarity. While participants largely disagreed with the idea that VHealthLab could replace face-to-face laboratories (M = 2.05, SD = 1.28), they strongly agreed that it could serve as a suitable complement to traditional laboratory activities (M = 4.22, SD = 0.74). This finding underscores the perception of VLs as enhancing rather than substituting hands-on laboratory experiences.

Table 6.5. Descriptive statistics for Questionnaire 2 (Item level).

Item	Statement	Theme	Mean (M)	SD
Q1	I found it easy and intuitive to navigate the online course space for the VL.	Theme 1: Usability, Clarity & Platform Functionality	4,4	0,76
Q2	The instructions, descriptions, and language used in the VL were clear, appropriate, and easy to understand.		4,24	0,89
Q3	I was able to locate the necessary information quickly while working through the VL.		4,14	0,99
Q4	The platform functioned effectively and supported my interaction with the VL.		4,11	0,97
Q5	The VL was useful in meeting my learning/teaching needs.	Theme 2: Pedagogical Value & Inquiry-Based Learning	3,65	1,12
Q6	I've found VHEalthLab to be a useful tool for teaching health and science-related topics using IBL.		4,07	0,83
Q7	VHEalthLab can promote scientific practices such as inquiry.		3,88	1,00
Q8	The final quizzes included in the VL effectively helped me to assess my understanding of the topic.	Theme 3: Learning Design, Resources & Assessment	3,74	1,05
Q9	The video tutorials helped me clarify key concepts and enhanced my overall learning experience.		4,08	0,91
Q10	The VL followed a clear structure that guided me through the activities and aligned them with specific learning goals.		4,21	0,86
Q11	The VL explicitly addressed aspects of gender inclusion.	Theme 4: Inclusion Strategies	3,2	1,21
Q12	The VL considered the needs of diverse educational contexts and learners.		3,5	1,21
Q13	I would consider implementing VHEalthLab in my teaching context.	Theme 5: Adoption and Intention to Use	4,02	0,86
Q14	VHEalthLab can replace a face-to-face laboratory.		2,05	1,28
Q15	VHEalthLab can be used as a suitable complement to face-to-face laboratories.		4,22	0,74

Table 6.6. Descriptive statistics for Questionnaire 2 (theme level).

Theme	Items	Mean (M)	SD
Theme 1: Usability, Clarity & Platform Functionality	Q1–Q4	4,22	0,70
Theme 2: Pedagogical Value & Inquiry-Based Learning	Q5–Q7	3,87	0,87
Theme 3: Learning Design, Resources & Assessment	Q8–Q10	4,01	0,77
Theme 4: Inclusion Strategies	Q11–Q12	3,35	1,08
Theme 5: Adoption and Intention to Use	Q13-Q14	3,43	0,74

6.1.4. Correlation analysis

To explore the factors associated with educators' intention to adopt the pedagogical framework (i.e., the pedagogical guidelines and Modules), Pearson correlation analyses were conducted using Item 9 ("I would like to use the pedagogical guidelines and Modules to support the implementation of VHEalthLab") as the dependent reference variable (Table 6.7).

The results indicated statistically significant positive correlations between intention to use and all examined themes. A moderate positive correlation was observed between intention to use and Theme 1 (Clarity & Accessibility) ($r = .52$, $p < .001$), suggesting that clearer structure and accessible materials are associated with stronger adoption intentions. A strong positive correlation emerged between intention to use and Theme 2 (Pedagogical Value & Inquiry-Based Learning) ($r = .67$, $p < .001$), indicating that educators who perceived higher pedagogical value and stronger alignment with IBL were substantially more likely to express willingness to adopt the framework.

Similarly, Theme 3 (Inclusion Strategies) demonstrated a moderate positive correlation with intention to use ($r = .47$, $p < .001$). Overall, the findings suggest that perceived pedagogical value—particularly alignment with IBL principles—is the strongest factor associated with educators' intention to adopt the pedagogical framework. Theme 4 Adoption and Intention to Use was excluded from the correlation analysis, due to the fact that it is comprised of one item.

Table 6.7. Pearson correlations between Adoption and Intention to Use of Pedagogical guidelines and Modules and Themes.

Theme	r	t	p-value	N
Theme 1: Clarity & Accessibility	0,52	5,06	<0,001	70
Theme 2: Pedagogical Guidance & IBL	0,67	7,44	<0,001	70
Theme 3: Inclusion Strategies	0,47	4,39	<0,001	70

All correlations significant at $p < .001$.

To examine factors associated with educators' intention to adopt VHEalthLab and VLs in specific as a technological tool, Pearson correlation analyses were conducted using Item 13 ("I would consider implementing VHEalthLab in my teaching context") as the reference variable (Table 6.8).

The findings revealed statistically significant positive correlations between intention to use and all examined themes. A moderate correlation was found between intention to adopt and Theme 1 (Usability, Clarity & Platform Functionality) ($r = .43$, $p < .001$), indicating that positive usability perceptions are linked to stronger implementation intentions. A stronger positive association was observed with Theme 2 (Pedagogical Value & IBL) ($r = .60$, $p < .001$), highlighting the importance of perceived pedagogical relevance in shaping adoption decisions.

Theme 3 (Learning Design, Resources & Assessment) demonstrated a strong positive correlation ($r = .68$, $p < .001$), suggesting that well-structured learning design and supportive resources substantially influence educators' willingness to integrate the VLs. Notably, the strongest correlation was identified between intention to use and Theme 4 (Inclusion Strategies) ($r = .70$, $p < .001$). This finding indicates that educators who perceived the VLs as inclusive and responsive to diverse educational contexts were significantly more likely to express adoption intentions.

Overall, the results suggest that pedagogical design quality and inclusion-related perceptions are key drivers of technological adoption in this context.

Table 6.8. Pearson correlations between Adoption and Intention to Use of VLs and Themes.

Theme	r	t	p-value	N
Theme 1: Usability, Clarity & Platform Functionality	0,43	4,34	<0,001	70
Theme 2: Pedagogical Value & Inquiry-Based Learning	0,60	6,11	<0,001	70
Theme 3: Learning Design, Resources & Assessment	0,68	7,59	<0,001	70
Theme 4: Inclusion Strategies	0,70	8,04	<0,001	70

All correlations significant at $p < .001$.

6.2. Qualitative data

6.2.1. Analytical approach

The analysis followed a thematic, descriptive approach. While focus group discussions were guided by predefined questions, themes were derived inductively from the data. Across all four

focus groups, a common set of five themes emerged, *Theme 1. Navigation & Interface Usability, Theme 2. Multimedia Quality, Theme 3. Assessment and Feedback, Theme 4. Pedagogical Value of VLs and Theme 5. Pedagogical Guidelines and Modules.* These themes were subsequently used as an organizing framework for within-country reporting and cross-country comparison.

6.2.2. Within-country findings

6.2.2.1. Greece

Theme 1. Navigation & Interface Usability

Participants found the platform well-structured and visually appealing, with smooth interaction, large readable text and high-quality images. They emphasized that the organization and content of information were useful and no negative comments were made regarding usability.

Theme 2. Multimedia Quality

The educational videos and multimedia materials were perceived as very well-developed, adding strong value to the learning experience. Most importantly, all of them were impressed and enthusiastic and emphasized the quality of these resources, which they felt contributed strongly to the learning process. They suggested that further material of this kind could be added to enrich the experience even more. Another suggestion concerned incorporating advanced analytics: for example, capturing an image and then processing it with sophisticated AI tools for deeper analysis, especially at the observation level.

Theme 3. Assessment and Feedback

Participants, overall, highly appreciated the assessment features at the end of modules. The tools were considered highly relevant and helpful both for teaching and for students' learning. However, one area for improvement concerned feedback: participants suggested that corrective feedback should explicitly reintroduce the correct information to ensure better understanding and learning retention.

Theme 4. Pedagogical value of VLs

A strong consensus emerged across participants that VLs cannot replace real laboratory work, but they can serve as highly valuable supportive tools. They allow students to study more complex information at home, interact with them asynchronously, and then focus on practical tasks in class. Participants compared this approach favorably to their own experiences of learning, for example, with the microscope, saying the digital method was clearer, more instructive, and more supportive when combined with hands-on practice. Asynchronous learning opportunities were described as particularly important, since even textbooks often fail

to represent lab processes adequately. VLs were seen as excellent tools that should be incorporated into the curriculum rather than treated with skepticism. They were thought to enhance the introduction of concepts, provide checkpoints for understanding and could even be used as homework activities.

The discussion highlighted the need for VLs to be integrated into curricula, particularly in cases where existing equipment cannot support all students. For instance, in molecular biology classes with over 120 students, where time and equipment availability are limited. VLs could enrich the educational process in these situations. Participants also expressed interest in seeing more up-to-date and modern topics and equipment incorporated in the upcoming VLs. They said they would be even more impressed if, alongside classical material, students could be exposed to content that they would otherwise never have the chance to see in class. For example, while traditional microscopes are already sufficiently covered, introducing advanced or rare instruments would add significant value.

Theme 5. Pedagogical Guidelines and Modules

Participants recognized and agreed that VLs could be more beneficial for teaching more complex subjects. Especially, for some thematics that even though the information and representation in books is considered sufficient. Suggested improvements included providing additional references for deeper study, though these should remain aligned with the course's central focus. Finally, participants suggested enhancing gender inclusivity by referencing women scientists or by portraying instructors in roles that reflect greater diversity, for instance, featuring female professors.

6.2.2.2. Cyprus

Theme 1. Navigation & Usability

Participants generally described navigation as easy and intuitive, highlighting a clear step-by-step flow that supported novice users without being overwhelming. However, several navigation frictions were reported, including hidden buttons (e.g. a "plus" button below the visible area) and small fonts. Occasional drag-and-drop glitches were also mentioned, slowing down progress.

Theme 2. Multimedia Quality

Visual elements and multimedia resources were positively perceived and considered engaging. At the same time, they suggested improvements such as larger and sharper images, narrated videos, clearer labels, and caption options. These enhancements were viewed as particularly

important for learners with specific needs (e.g. dyslexia) and for those preferring content in Greek.

Theme 3. Assessment and Feedback

Quizzes embedded throughout the VLs were generally well received, especially when they allowed retries and provided immediate explanations. In addition, the automatic issuance of certificates upon completion was perceived by some participants as limiting time for reflection, although others viewed certificates as motivating.

Theme 4. Pedagogical value of VLs

Participants consistently viewed VLs as safe and flexible supplements to, but not replacements for, wet laboratory work. They emphasized their usefulness in contexts where equipment is limited or where microscopic details are difficult to observe in physical settings. Given tightly scheduled class periods and national syllabi, participants stressed the importance of explicit links between VL content and curriculum outcomes, as well as short orientation sessions for both teachers and students to support effective integration.

Theme 5. Pedagogical Guidelines and Modules

The Pedagogical Guide and Modules were perceived as ready-to-use and directly applicable to teaching practice. Participants highlighted that the provided storylines, guiding questions, and visual assets reduced lesson-planning time and supported structured implementation. The step-by-step guidance was seen as particularly helpful for educators with limited prior experience in VLs. Participants emphasized that any future enhancements (e.g. richer media, virtual reality views, AI-assisted support) should rely on free and open-access tools to ensure inclusiveness and broad applicability.

6.2.2.3. Romania

Theme 1. Navigation & Usability

Educators described the platform as intuitive and logically structured, supporting smooth navigation during lesson use. While overall usability was positively evaluated, some participants noted that navigation could be streamlined further in specific labs, such as Light Microscopy, where usability lagged slightly.

Theme 2. Multimedia Quality

Multimedia resources were considered effective in supporting understanding of abstract concepts, such as microscopy procedures and stages of cell division. The combination of visual materials and structured content helped bridge theory and practice, particularly in the absence of physical laboratory access.

Theme 3. Assessment & Feedback

Assessment design emerged as a key area for improvement. Participants requested clearer and more varied formative assessment activities, alongside immediate and explanatory feedback to support learning and reflection. The absence of detailed feedback explaining incorrect responses was seen as limiting the educational value of assessment components.

Theme 4. Pedagogical Value of VLs

VLs were viewed as having strong practical classroom utility, particularly in reducing risks and costs associated with wet-lab work. Participants emphasized their value in supporting inquiry-based learning through clear scaffolding and structured guidance. The labs were seen as especially helpful in making abstract biological processes more tangible and accessible to learners across different educational levels.

Theme 5. Pedagogical Guidelines and Modules

Modules and Pedagogical Guidelines were highly valued for their step-by-step structure and alignment with IBL principles. Participants highlighted the need for stronger curriculum alignment, including explicit mapping to national syllabi, age-appropriate variants, and differentiated difficulty levels. Additional support materials were suggested, such as glossaries of scientific terms, printable resources, and low-bandwidth alternatives, to enhance clarity, accessibility, and inclusive implementation.

6.2.2.4. Spain

Theme 1. Navigation and Usability

Overall, participants described the navigation of the platform as ‘easy’ and ‘intuitive’, although some noted difficulty in finding Module 1 within the platform. In terms of the experience navigating the lab case, the avatar figure was controversial, as some found it supportive during the activity, but others found it simply an unnecessary addition, such as a ‘continue’ button, and criticised its appearance.

Theme 2. Multimedia Quality

Participants appreciated the organisation and appearance of the course. The avatar was criticised for its unrealistic physical appearance. They recommended a real scientist if possible. One student mentioned the moving gif of the puzzle piece as a potential distraction for students with concentration problems. The videos and images were well appreciated, although more interaction in the lab activity and being able to observe the parts of the microscope more closely were recommended.

Theme 3. Assessment and Feedback

During the laboratory activity, the dialogues between learners and the teacher were appreciated as they provide a realistic context for learners. It was also appreciated that failing an option was an opportunity to learn, with no pressure to finish. As for the final assessment, it was recommended to indicate the correct option in case of failing the answer, as well as to indicate where in the theory they could find the necessary information to understand it. All students agreed that more interactivity with the platform would be positive, although as support material for a face-to-face laboratory practice, it is very good, it saves time and possible material costs.

Theme 4. **Pedagogical Value of VLs**

All participants considered virtual laboratories as safe and flexible complements - never complete substitutes - for physical laboratories. They consider them particularly useful in environments where equipment is scarce or microscopic details are difficult to observe. The inclusion of how to address the gender gap as a teacher is appreciated in the guide. Including a forum is considered key for the teacher to be aware of students' needs and developments. The pedagogical guide and the module were considered very useful for first-time teachers, especially for including examples and step-by-step instructions on how to implement the online platform in different learning contexts. Some considered the guide too long; however, others considered it comprehensive and well-structured. It was recommended to view the module first and then the pedagogical guidelines if you want to go deeper.

Theme 5. Pedagogical Guidelines and Modules

Participants considered both the guide and the module useful and complementary, with a preference for consulting the module first and using the guide for further reference. Although the length of the guide was initially perceived as intimidating, it was later described as enjoyable and easy to follow due to its clear structure and practical examples. The materials were seen as particularly valuable for first-time educators, supporting them in class design and implementation. Contextualized examples were appreciated, including guidance on identifying and addressing the gender gap. Overall, participants agreed that prior educators' training is necessary for the use of VLs and that the materials provided sufficiently support this need. Some participants noted content overlap between the guide and the module and suggested a clearer distinction between theory and practice, with the module becoming more practical. Additional examples and references to the digital divide were also suggested. As general feedback, some participants noted that for students facing challenges, time isn't the only constraint; providing clear, step-by-step instructions within activities can be especially beneficial for students with special educational needs. Gradual educators' training pace, combined with using VLs as a complement to hands-on practice, emerged as the most effective

approach. Finally, the value of a forum to facilitate communication among students and educators was highlighted.

6.2.3. Cross-country thematic synthesis

A thematic comparative analysis was conducted to identify recurring patterns and contextual variations across countries. Through iterative comparison of within-country themes, three higher-order analytical dimensions emerged inductively: (a) Acceptance, referring to educators' overall perceptions of usability and pedagogical value; (b) Integration, capturing the conditions and requirements for embedding the VLs within national curricula and classroom practice; and (c) Scalability, reflecting considerations related to sustainability, feedback mechanisms, educator preparedness, and broader institutional adoption. Table 6.9 synthesizes the cross-country findings according to these three dimensions.

The cross-country comparative analysis revealed a high degree of convergence in educators' overall acceptance of the VHEalthLab VLs. Across Greece, Cyprus, Romania, and Spain, participants consistently described the platform as intuitive, clearly structured, and pedagogically coherent. The step-by-step design and alignment IBL principles were widely recognised as strengths that facilitated both understanding and instructional implementation. Importantly, in all contexts, virtual laboratories were positioned as complementary tools rather than substitutes for physical laboratory practice, reinforcing their perceived pedagogical legitimacy.

Beyond baseline acceptance, differences became more visible at the level of educational integration. While educators across countries acknowledged the pedagogical value of VLs, the conditions required for their effective classroom incorporation varied. In Cyprus and Romania, strong emphasis was placed on curriculum alignment, time constraints, and structured differentiation, reflecting systemic and institutional considerations. In Greece, participants highlighted opportunities for technological enrichment and innovation, including the incorporation of more advanced instrumentation and expanded multimedia scenarios. In Spain, discussions focused more explicitly on interactivity, accessibility, and inclusive design features, including multilingual support and step-by-step scaffolding for diverse learners. These variations suggest that although acceptance is stable across contexts, integration priorities are shaped by national curricula, institutional readiness, and pedagogical traditions.

At the level of scalability, recurring themes emerged regarding assessment functionality, feedback mechanisms, and educator preparedness. Across all countries, participants identified formative assessment and explanatory feedback as areas requiring enhancement. The request

for clearer corrective guidance, multiple attempts, and stronger scaffolding indicates that long-term sustainability of VLs implementation depends not only on usability, but on deeper pedagogical refinement. Additionally, the perceived need for prior teacher orientation or structured pedagogical guidance highlights that scalability is closely linked to professional development support.

Table 6.9. Cross-country comparative synthesis structured by Acceptance, Integration, and Scalability.

Dimension	Cross-country Convergence	Contextual Differentiation	Implications for Broader Adoption
Acceptance	High perceived usability; clear structure; strong IBL alignment; VLs viewed as complementary to traditional labs	Minor navigation/interface nuances (e.g., avatar design, hidden buttons, lab-specific usability variations)	Core platform design is transferable across contexts with limited structural adaptation
Integration	Recognised pedagogical value in supporting conceptual understanding and preparation for lab work	Cyprus & Romania: curriculum alignment and differentiation; Greece: innovation and technological enrichment; Spain: interactivity and inclusive design	Local curriculum mapping and adaptive design features are necessary for effective embedding
Scalability	Broad willingness to use VLs in future teaching; appreciation of pedagogical guide	Shared request for stronger formative assessment and explanatory feedback; need for educator orientation; accessibility refinements	Sustainable scaling requires enhanced feedback systems, structured teacher support, and inclusive access mechanisms

Overall, the cross-country findings indicate high acceptance and perceived pedagogical value of the VHEalthLab online toolkit, coupled with context-specific expectations regarding usability refinement, assessment feedback, curricular alignment, and inclusivity. The comparative analysis suggests that scalability across European contexts is feasible, provided that adaptive refinements address local curriculum structures, accessibility standards, and varying levels of digital readiness. Rather than reflecting fundamentally different attitudes toward virtual laboratories, cross-national differences primarily concern implementation conditions and optimisation priorities. This indicates a stable foundation for broader adoption, with contextual customisation serving as the key factor for sustainable integration into higher education and secondary biology teaching.

7. Conclusions

7.1. Pedagogical value and technology acceptance

The results of this study indicate that the perceptions of educators of the VHEalthLab online toolkit and its VLs are, to a large extent, pedagogically driven and not purely technology driven. When analyzed in the context of the IBL framework, the perceptions of educators are largely driven by their perceptions of the VLs and the degree to which these VLs are perceived to support authentic inquiry processes. The findings indicate that the perceptions of educators are driven by the degree to which the online toolkit is perceived to provide clarity in terms of structure and pedagogical support. This is particularly important when analyzed in the context of an IBL-oriented framework. IBL environments are not necessarily effective merely because they are explored. The effectiveness of such environments is largely dependent on the degree to which they are scaffolded to support processes of questioning, hypothesis development, investigation, and evidence-based reasoning (Lazonder & Harmsen, 2016).

However, results also show a complex understanding of support in inquiry. On one hand, educators recognize the inquiry-supportive qualities of VLs. On the other hand, their assessments show that they consider digital inquiry environments to need pedagogical support. This is consistent with studies that have found that IBSE is most successful when it is supported by carefully designed phases of engagement, investigation, and reflection (Pedaste et al., 2015; De Jong et al., 2013). In this way, VLs seem to be regarded as pedagogically interesting tools whose value lies in their careful integration into teaching practice.

When findings are further interpreted considering the scope of the technology theory lens, namely TAM, they reveal interesting aspects regarding the educators' perceptions of the VLs and potential underlying factors for their intention to use them. While participants acknowledged the usefulness of VHEalthLab for teaching health and science-related topics using IBL, slightly lower scores were observed for perceived usefulness in meeting teaching needs and for promoting scientific inquiry practices. These results suggest that although the pedagogical potential of the VLs is recognized, participants may require additional scaffolding or experience to fully leverage inquiry-based practices. This is in alignment with literature underscoring the importance of offering professional development opportunities to educators (Kolil & Achuthan, 2024;).

TAM theory assumes that the adoption of technology is mediated by Perceived Usefulness and Perceived Ease of Use, which in turn influence Behavioural Intention. In the current study, it seems that educators' intention to use the VHEalthLab toolkit is more related to its

pedagogical relevance than to its usability features. Although usability and comprehensibility are necessary conditions for the adoption of VLs, these factors are not sufficient for their adoption and educators' intention to use VLs is closely related to their perceived pedagogical relevance and their alignment with the principles of scientific inquiry and educators' instructional goals. This finding could be in a degree consistent with the theoretical assumption of TAM, which assumes that Perceived Usefulness is a stronger predictor of intention than Perceived Ease of Use in the adoption of technology (Davis, 1989). This study aligns with existing literature (Hitlal, 2023; Yazici & Nakıboğlu, 2024), which underscores that a strong positive perception of a technology' usefulness is crucial for its successful acceptance and integration in educational contexts. However, when educators consider the use and integration of VLs a stronger correlation emerges, related to the "pedagogical value", aligning with findings from other research (Shambare & Jita, 2025; Ngiruwonsanga et al., 2026; Asare et al., 2023).

Lastly, one particularly relevant discovery relates to the way in which educators view VLs in relation to more traditional face-to-face laboratory environments. Rather than viewing VLs as replacements, most educators view VLs as complementary to face-to-face environments. Thus, VLs adoption potential is likely to be greatest when digital tools are seen as supporting rather than disrupting existing laboratory practices. In the context of IBL theory, this makes sense as IBL has its roots in experiential engagement with the world. Physical laboratories provide a tactile, bodily, and social aspect to the experience of inquiry (Gormally et al., 2011). VLs, on the other hand, provide an extension of the experience of inquiry beyond the boundaries of time, space, and safety (Lazonder & Harmsen, 2016; García-Carmona, 2020). The view of VLs as complementary to face-to-face environments reflects a hybrid model of the experience of inquiry. VLs are not viewed as replacing the experience of hands-on investigation but as extending and enriching it. This is in alignment with previous literature supporting the complementarity of VLs (Makransky et al., 2016; Sypsas & Kalles, 2018; Griffin et al., 2025).

7.2. Intention of use and the role of perceived factors

One of the main goals of this research was to examine the factors related to the intention of educators to use the VHEalthLab toolkit and the VLs. The results of the correlation analysis are of great importance for the interpretation of this goal as they show that the intention of educators to use the pedagogical framework and VLs is not random but is systematically influenced by a set of interrelated perceptions. Two different correlations were explored; one investigating specific factors associated with educators' intention to adopt the pedagogical framework of VHEalthLab (i.e., the pedagogical guidelines and Modules), and another examining factors

associated with educators' intention to adopt VHEalthLab and VLs in specific as a technological tool.

Notably, regarding the adoption of the pedagogical framework of VHEalthLab highest correlations were found between intention to use and the pedagogical value-related dimensions. This indicates that the primary motivation for adoption is pedagogically grounded and educators will be more inclined to adopt VHEalthLab and its pedagogical framework if they view them as adding value to inquiry processes, supporting learning objectives, and providing a coherent meaningful, well-structured content. This result empirically confirms the assumptions of the TAM, according to which the intention to use is influenced by cognitive evaluations of usefulness and ease of use (Davis, 1989).

On the other hand, correlations conducted exploring factors associated with educators' intention to adopt VHEalthLab and VLs in specific as a technological tool led to different results. Although positive associations were observed with Pedagogical Value & IBL and Learning Design, Resources & Assessment, the strongest correlation was identified between Intention to Use and Inclusion Strategies. This finding indicates that educators who perceived the VLs as inclusive and responsive to diverse educational contexts were significantly more likely to express adoption intentions. In this sense, the construct of inclusion is found to significantly influence external factors in consideration of behavioral intention, supporting modern understandings of the socio-pedagogical nature of technology adoption in education. While the TAM has been extensively extended with variables such as self-efficacy (Scherer et al., 2019), subjective norms (Venkatesh & Davis, 2000) and trust (Mustofa et al., 2025). Extending the technology acceptance model: The role of subjective norms, ethics, and trust in AI tool adoption among students. *Computers and Education: Artificial Intelligence*, *8*, 100379., the explicit incorporation of *inclusion* as a distinct construct remains largely unexplored in the literature. Therefore, it could be assumed that this finding extends the traditional TAM model into consideration of context-sensitive and equity-based factors considering diverse student groups and educational contexts.

On the whole, these correlational results contribute to the strength of the integrated analytical framework applied in the research study. These results reveal the multidimensional nature of behavioral intention, in which a range of factors—technological, pedagogical, inquirying, and inclusive—contribute to a comprehensive understanding of the construct of adoption as a multidimensional construct in consideration of both the IBL framework and the TAM model.

7.3. Cross-country qualitative discussion: acceptance, integration, and scalability

The cross-country qualitative synthesis enabled the designation of deeper insights into the ways in which educators in Greece, Cyprus, Romania, and Spain consider and position the VHEalthLab online toolkit and VLs in terms of teaching practice. Rather than indicating that there are fundamental differences in terms of attitudes, the comparative approach suggests that there is a base level of common perceptions that is complemented by context-dependent factors. The discussion is organized in terms of three higher-order dimensions that were inductively derived from the data: *Acceptance*, *Integration*, and *Scalability*.

7.3.1. Acceptance: a shared pedagogical legitimacy

In all four countries, educators demonstrated high levels of acceptance of the VLs. The platform was found to be intuitive, clear in structure, and pedagogically sound. Most importantly, the acceptance of the VLs was not based on technical merits but was linked to the platform's usefulness in teaching. The participants were unanimous in their perception that VLs are useful adjuncts to physical labs, especially in the context of preparation, conceptualization, and asynchronous work.

A few minor usability issues were raised in several of the countries in terms of navigating the platform's interface, but these did not impact the overall perception of the platform in any negative manner. Rather, these were considered to be minor improvements that did not impact the platform's fundamental structure. The similarity in perceptions indicates that the fundamental principles of the platform's design can be transferred across any educational system without having to make fundamental changes to the platform's design.

7.3.2. Integration: context shapes implementation priorities

Although this was largely consistent across the board, there was clearer differentiation in terms of integration into the national context.

In Cyprus and Romania, there was an emphasis on curriculum alignment, syllabus constraints, and differentiation in terms of age and ability groups. The discussion clearly demonstrated an awareness of the systemic implications of the VL activities in terms of the need to map these activities against the national curriculum. In Greece, there was more emphasis in terms of innovation/enrichment. The discussion centered around the need to expand the platform in terms of more advanced scientific equipment, new topics, and improvements in

multimedia functionality. Moreover, it clearly moved away from alignment to the opportunities that VLs offered in terms of innovation/enrichment of the curriculum. In Spain, there was stronger discussion in terms of interactivity, accessibility, and inclusive design. Considerations were given to multilinguality, step-by-step approaches, and the role of communication tools in facilitating diverse learners. It seems that the integration discussion is context-dependent in terms of curriculum structures, institutional flexibility, and pedagogical culture. However, there was no evidence of resistance in any of these groups.

7.3.3. Scalability: Sustainability Depends on Pedagogical Refinement

For all countries, scalability was seen as being very much tied to the design of the assessment, the quality of feedback, and teacher readiness. While the value of the current assessment components was appreciated, the theme of needing better corrective feedback and explanatory guidance kept recurring.

Another theme that was very much in common was educator orientation. Even in situations where the educational guide was appreciated, the need for systematic teacher orientation would make it easier to use more confidently and consistently. This implies that sustainability is not just about the usability of the platform but also about the professional development that accompanies it. Inclusivity was another aspect of scalability that came to the forefront. Recommendations for gender inclusion, accessibility modifications, differentiated materials, and low-bandwidth options suggest that scalability is not just about technical scaling but also about embedding into pedagogy.

7.3.4. Final conclusions and future steps

Overall, this cross-country analysis thus illustrates the high and constant level of acceptance of the VHEaltHLab online toolkit and VLs across different contexts in Europe. The variation between countries is mainly in the conditions for implementation and optimization, and not in the level of acceptance of the concept of virtual laboratories. The acceptance is based on pedagogical considerations, the integration is context-dependent, and scaling is dependent on the enhancement of feedback and teachers' support.

The VHEalthLab project has clearly shown that VLs hold a tremendous potential for transforming STEM and health education in European educational systems. With the creation of open access, inclusive, and pedagogically sound VLs, the VHEalthLab project has contributed to the development and enhancement of digital competence, IBL and access to quality practical experiences without any geographical, socioeconomic, linguistic, and physical

constraints. The significance of combining digital innovation and inclusive education to allow all learners was also emphasized, especially for those derived from less privileged groups, to fully participate in digital education ecosystems that are emerging across Europe.

The results of the transnational analysis have pointed out the opportunities and challenges linked to large-scale VLs integration. While there is a rising enthusiasm for digital experimentation and virtual learning, there are significant disparities in infrastructure, educators, and policy frameworks that hinder large-scale and consistent integration across Europe. These realities highlight the necessity for continued investment and policy work, as well as developing a capacity building strategy to address these needs and create a conducive environment for large-scale and sustainable Virtual Laboratories integration. Looking ahead, the future development of VLs will necessitate continued cooperation between institutions of higher education, ministries, technology companies, accreditation agencies, and European funding sources. Continued research will be necessary to better understand the impact of VLs on learning outcomes, motivation, skill acquisition, and employability. Advances in artificial intelligence, immersive simulation, multilingualization, and personalized learning environments provide exciting areas of future development for the expansion of VLs offerings. Ensuring that these developments remain accessible, inclusive, and educationally sound will be critical to their success.

In conclusion, the VHEalthLab project lays the groundwork for the next stage of digital transformation in the field of higher education. With the continued development of the Virtual Laboratory, the further development of educators, the development of the infrastructure, and the inclusion of the Virtual Laboratories in national and European policy strategies, Europe will continue to move closer to the goal of a more inclusive, resilient, and future-ready education system. The progress created with the VHEalthLab will be the beginning, not the end, of the next stage of innovation.

8. Limitations and further considerations

Although the implementation of the VHEalthLab online toolkit across countries was effective in producing valuable insights, some limitations need to be considered while analyzing the results. Firstly, the differences in the implementation period for the tool and the development process of the tool itself meant that not all participants were exposed to the same level of refinement. For instance, some laboratories may not have been fully translated at the time of the experiment, which could have impacted the perception of the tool. Secondly, the differences in participant profiles and sample sizes from each country, as well as the voluntary nature of

the experiment, may have created self-selection biases. Moreover, the results were mainly based on self-reported data from participants through questionnaires and focus groups, which only represented short-term perceptions rather than long-term effects in the classroom. Variations in curriculum design, institutional environments, technology availability, as well as the languages in which the tool was implemented, may have impacted the user experience. Finally, although VHEalthLab follows a guided inquiry model to support IBL, educators indicated a preference for more open-ended exploration, underscoring the ongoing pedagogical balance between guidance and the need for student autonomy in inquiry-based learning. These limitations highlight the need for future research to investigate the longitudinal integration of VHEalthLab in the classroom, student learning outcomes, and adaptation to different educational systems.

Declaration on the Use of Artificial Intelligence

I hereby declare that generative artificial intelligence (AI) tools were used exclusively for language correction and stylistic refinement of text originally written by the author. Specifically, ChatGPT (OpenAI, GPT-4 model) was utilized to improve grammar, clarity, coherence, and overall linguistic quality. All conceptual development, research design, analysis, interpretation of results, and scholarly contributions presented in this thesis are entirely the author's own original work and intellectual responsibility.

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Annexes

Annex A

Evaluation of the Pedagogical guidelines and the Modules

A. On a scale from 1 (strongly disagree) to 5 (strongly agree), please indicate your level of agreement in the following statements:

	Items	**1- Strongly disagree**	**2 - Disagree**	**3 - Neither agree or disagree**	**4 - Agree**	**5 - Strongly agree**
1	The instructions, descriptions, and language used in Modules and the pedagogical guidelines were clear, appropriate, and easy to understand.					
2	I was able to locate the necessary information quickly while working through the Modules and the pedagogical guidelines.					
3	The Modules were useful in meeting my teaching needs.					
4	The pedagogical guidelines and the Modules enriched my					

	understanding of how to use VHealthLab in different contexts.					
5	Modules provided practical guidance on implementing VHealthLab using an IBL approach.					
6	The IBL approach used in Modules effectively illustrates how VLs can be applied for active learning in various teaching situations.					
7	The pedagogical guidelines and Modules provide useful strategies for addressing the gender gap in STEM education using VLs.					
8	The pedagogical guidelines and Modules provide useful strategies for addressing diverse learning needs in STEM education using VLs.					
9	I would like to use the pedagogical guidelines and Modules to support the implementation of VHEalthLab.					

Evaluation of the VLs

B. On a scale from 1 (strongly disagree) to 5 (strongly agree), please indicate your level of agreement in the following statements:

	Items	**1- Strongly disagree**	**2 - Disagree**	**3 - Neither agree or disagree**	**4 - Agree**	**5 - Strongly agree**
1	I found it easy and intuitive to navigate the online course space for the VL.					
2	The instructions, descriptions, and language used in the VL were clear, appropriate, and easy to understand.					
3	I was able to locate the necessary information					

	quickly while working through the VL.					
4	The platform functioned effectively and supported my interaction with the VL.					
5	The VL was useful in meeting my learning/teaching needs.					
6	I've found VHEalthLab to be a useful tool for teaching health and science-related topics using IBL.					
7	VHEalthLab can promote scientific practices such as inquiry.					
8	The final quizzes included in the VL effectively helped me to assess my understanding of the topic.					
9	The video tutorials helped me clarify key concepts and enhanced my overall learning experience.					
10	The VL followed a clear structure that guided me through the activities and aligned them with specific learning goals.					
11	The VL explicitly addressed aspects of gender inclusion.					
12	The VL considered the needs of diverse educational contexts and learners.					
13	I would consider implementing VHEalthLab in my teaching context.					
14	VHEalthLab can replace a face-to-face laboratory.					

15	VHEalthLab can be used as a suitable complement to face-to-face laboratories.					

1. Please select the aspects below where you encountered difficulties during the course. Select all that apply.
   - Virtual Labs (VLs)
   - Previous experience with similar courses
   - Assessment – Quizzes
   - Language
   - Video-tutorials
   - Gender inclusion aspects
   - Understanding of course materials
   - Technical difficulties (e.g., platform issues)
   - Lack of interactive elements
   - Time management and course pacing

2. To what extent do you think the pedagogical guidelines and the Module 1 promote IBL? Please justify your answer.

3. What improvements would you suggest for the pedagogical guidelines and the Module 1? Which aspects did you find most useful?

Annex B

Focus group guide questions

1. Navigation Experience

- How easy was it to navigate the online course platform? Was the navigation intuitive?
- What aspects of the navigation were easy or difficult to use? Could you provide specific examples of features that either facilitated or hindered your experience?

2. Likes and Dislikes

- What features of the online course did you find most appealing, and why?
- Were there any features that you found least appealing, and why?
- Can you give examples of particular elements that contributed positively or negatively to your experience?

3. Suggested Improvements

- If you could make changes to the online course platform, what would you modify?
- How would these changes improve the overall user experience and the effectiveness of the course? Please provide specific suggestions.

4. Evaluation of Course Tools

- How would you assess the effectiveness of the various tools in the course (e.g., virtual labs, quizzes, presentations)?
- Did you find these tools relevant and helpful for your teaching and the students' learning?
- Could you provide constructive feedback on how these tools could be improved or better utilized?

5. Benefits of Using the E-Learning Platform

- What do you see as the main benefits of using this online course compared to traditional classroom learning?
- How has the course impacted your teaching practices or helped you achieve your educational goals?
- How has the online course influenced your students' engagement, collaboration, and overall learning experience? Can you provide specific examples?

6. Benefits of Using Virtual Labs

- What are the advantages of incorporating virtual labs into the course curriculum?
- How have the open access virtual labs enhanced your teaching and reinforced course concepts?
- How have the virtual labs contributed to improving your students' understanding, practical skills, and retention of course material? Could you provide any specific examples of this?

6. Additional Comments

- Is there anything else you'd like to share about your experience with the online course?
- Are there any aspects of the course that we haven’t addressed, but you think are important for future improvements?