Potentials of an Interactive 360°-Panoramic-Video-Based Virtual Reality Learning Application for Chemistry Students

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Abstract. Chemistry experiments in higher education are resource-intensive, requiring substantial materials, supervision, and laboratory time, yet they remain essential for hands-on learning. Immersive learning platforms integrating 360° video, virtual reality, and gamification offer a promising approach to addressing these challenges by enabling repeated practice and increasing student engagement.

We developed an immersive digital laboratory (IDL) incorporating 360° video and gamification elements for two physical chemistry experiments. We applied the human-centered gamification process, which considers user experience evaluation standards for designing successful gamified products.

This paper reports on the evaluation of the IDL using a mixed-methods approach, combining quantitative and qualitative data. We assessed 12 user needs, experiences, and improvement areas among students enrolled in physical chemistry courses. Results indicate overall positive evaluations, particularly regarding reusability and content quality. Qualitative findings emphasize the system's immersiveness and interactivity. Students reported improved preparation for practical tests and enhanced understanding of experimental procedures. Identified improvement areas include higher image quality and greater opportunities for free exploration. Beyond physical chemistry, the IDL approach demonstrates potential for broader application in higher education.

Keywords: User Experience · UX · Learner Experience · LX · Gamification · Virtual Reality · VR · E-Learning · Higher Education · Chemistry · Immersive Learning

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1 Introduction

Practical experiments in higher education chemistry often involve complex procedures, expensive materials, and supervision by educators. Additionally, it is essential to provide students access to expensive equipment while offering them the opportunity to practice their learning [6]. For these reasons, they are typically conducted just once per course, even though repetition could deepen the learning experience.

To address these challenges, research has shown that higher education may utilize 360° virtual reality (VR) videos to offer students a way to explore innovative practices in areas such as biology and surgery [23] to *e.g.,* repeat practices. In addition, the immersion of VR can enhance the learning experience [23], and gamification is known to improve motivation and increase engagement [14] by using game elements in a non-game context [7].

Hence, we developed digital content for practical courses in physical chemistry with two immersive digital laboratories (IDLs) using 360° video technology (including audio) and gamification (Fig. 1). Thereby, allowing chemistry students in higher education to prepare for practical experiments and to repeat these experiments as often as needed. To ensure a well-founded gamification concept, we applied the human-centred gamification process (HCGP) [27]. It considers the human-centered design process, which includes user experience (UX) assessment, to design a system that meets user needs [10].

Fig. 1. Example view of the 360° immersive digital laboratory for chemical students.

This paper presents the evaluation of two IDLs with nine students from the physical chemistry course at University of Applied Sciences Emden/Leer, Germany. Additionally, we investigated the IDL potential for other application areas with 25 STEM students from the same institution. We collected quantitative and qualitative data regarding 12 user needs to gain insight into the students' learning experiences. We also assessed their impressions and gathered improvement proposals. The qualitative data analysis, using thematic analysis, revealed a focus on the theme of technology. From these insights, we determined the potential of gamified virtual reality applications in higher education physical chemistry courses.

The paper is structured as follows: Sect. 2 presents definitions and an overview of the current status of immersive learning platform development. Section 3 introduces our methodology, IDL development, and the user study. Section 4 presents the results, which we discuss in Sect. 5. We close with the conclusion and prospects in Sect. 6.

2 Background and Related Work

Immersive learning platforms, such as 360° video or virtual reality (VR), increase engagement [4,23]. While 360° video is an omnidirectional format that enables viewers to look in any direction during playback [23], virtual reality is a 3D virtual environment that allows users to engage in immersive and more realistic experiences [4].

The human-centered gamification process (HCGP) provides guidelines and tools for developing context-specific gamification applications [27]. It considers the standardized human-centered design process [10], which includes a mandatory user experience (UX) assessment for the product evaluation to meet user needs. UX is a holistic concept that encompasses the user's impression of the interaction within the context of use before, during, and after use [10]. Learner experience (LX) includes experiences that enhance understanding and develop knowledge and skills [15]. User-centered assessment typically focuses on self-reported measures, employing quantitative, qualitative, or mixed-methods approaches. A mixed-methods approach combines quantitative and qualitative approaches to obtain more valuable results [16].

Thematic analysis is a flexible and valuable research tool for providing detailed and rich qualitative data analysis. It is *"a method for identifying, analyzing, and reporting patterns (themes) within data"*. It does not focus on quantification, as the analysis unit (theme) includes more than just a code word [2]. Thematic analysis is a widely used method for qualitative analysis in psychology [2] and is established in UX [13] and LX research [1].

Technical areas, such as computer and natural sciences, are particularly popular fields of application for VR and gamification [18,25]. For example, a review of 12 studies focusing on 360° video and VR in learning environments was conducted. The studies covered a range of subjects, including business, biology, and surgery students. The review examined aspects such as the effectiveness of 360° video compared to 2D video and the effectiveness of an immersive VR simulator combined with 360° video. The review found evidence of increased engagement and attentiveness with 360° video and significantly more enjoyment when using VR [23].

Another review analyzed applications that utilize VR and gamification in higher education. Most related work is found in computer science, followed by medical education and the natural sciences [18]. A common application scenario is the support of learning scenarios. For example, [20,21,24,25] all aim to teach computer science related topics like binary trees, stacks, and ques, or object-oriented programming. However, a common objective of related studies is also the increase in motivation [26] or engagement [3,19].

One study examined the use of VR to train students in the field of biopharmaceutical engineering, offering an immersive simulation of real-world scenarios. The participants who provided feedback highlighted the benefits of learning through the 3D-VR environment and being able to repeat lessons [6].

Although VR and 360° video have been shown to increase engagement and motivation in various educational domains, their application in chemistry laboratory settings remains limited. In particular, the combination of immersive VR with gamification for physical chemistry experiments has not yet been explored and evaluated [18].

3 Methodology

We aim to investigate how students in physical chemistry use immersive training. To that end, we evaluate two immersive digital laboratories (IDLs) using 360° video technology. We assess the degree to which the IDL fulfills various user needs and gather impressions and suggestions for improvement. We aim to answer two research questions (RQs):

RQ1: To what extent does a 360° interactive learning application fulfill the user needs of students in physical chemistry courses?
RQ2: What are students' impressions when using a gamified immersive digital lab to practice physical chemistry experiments?

RQ1 assesses the user needs of students in physical chemistry courses when using IDL applications. RQ2 aims to gain insight into the students' impressions to identify pitfalls and improvement proposals. To address these questions, two experiments are evaluated with students who either actively conduct the experiment, have recently completed it, or are enrolled in STEM programs. STEM students were additionally invited to evaluate the IDLs, as the number of relevant students at the institution is relatively low. We employ a mixed-methods approach (quantitative and qualitative) to evaluate the IDLs, assessing both UX and LX. We apply thematic analysis [2] to analyze the qualitative data. The following provides a description of the IDLs' development and the methods used in our study.

3.1 Immersive Digital Lab Development

We developed an application tailored to our specific use case by applying the Human-Centred Gamification Process (HCGP) [27] to achieve successful gamification. Table 1presents each HCGP step and our respective actions. We identified the user needs (see Table 2) in the first step and then used them as a foundation

Table 1. The operationalization of the HCGP applied in this project

Step of the HCGP	Action taken
1. Explored user motivation	(1) Conducted a mixed-methods user study, including interviews and surveys with higher education students, to identify user needs (see Table 2). (2) Developed personas based on the findings
2. Defined organizational goals	Developed a business canvas model
3. Analyzed market environment	Conducted a systematic literature review of similar studies [18]
4. Defined system requirements	Determined whether our tool (paneoVR) fulfills all requirements and identified necessary improvements
5. Customized gamification codebook	Selected appropriate game elements from the gamification codebook based on the defined scenarios
6. Bridged theory and practice	(1) Built user journeys for the defined scenarios. (2) Refined the user journeys to align with the technical constraints of paneoVR and the project's time restrictions
7. Created gamified prototype	(1) Created a prototype in paneoVR. (2) Filmed the 360° video material. (3) Finalized the prototype in paneoVR by integrating the videos into the developed prototypes
8. Evaluated gamified solution	Evaluated whether user needs are fulfilled by the gamified prototype (Sect. 3.2)

Table 2. User needs with short descriptions

User need	Description	Ref
Technical quality	Error-free, high technical standard	*
Content quality	Actual data, well-prepared and interesting, up to date	[22], *
Modernity/Innovation	Novel and original system design, creative modern didactics	[22], *
Usability	Goal-oriented, effective, efficient, and satisfying	[11]
Practice-oriented learning	Practical experience, realistic scenarios, applicable to real-life contexts	*
Sustainable learning	Reliable and trustworthy data, continuous and long-term learning effect	[22], *
Self-determined learning	Control of interaction, students decide where, when, and what to learn	[22], *
Appropriate complexity	Giving the students a challenge without it being overwhelming	*
Entertainment/Fun factor	Fun of use, exciting and stimulating	[22]
Interactivity	Engaging, interactive elements, controllable interactions	*
Reusability	Allows and supports repeated use, repetition gives advantages	*
Overall impression	Overall assessment, e.g., like or dislike	[22]

*Identified user need, see research protocol [17].

to develop the IDLs. We evaluated the fulfillment of these needs in the final step. More details on the user needs are provided in the research protocol [17].

Table 3 presents the game elements applied and their integration into the IDLs. We selected them based on the list of game elements in the HCGP gamification codebook [27] and described the implementation of each as suggested by experts [9]. We carefully selected each game element according to the identified user needs (see Table 2). Due to the constraints of 360° filming, we omitted the option for free exploration within the user interface (UI).

The IDLs are based on the following two experiments of the physical chemistry course: PC1 is the titration process used to determine the concentration of an unknown solution by comparing it with a known solution, and PC16 is an experiment to determine the dissociation constant of acetic acid and the limiting conductivity of sodium chloride. We filmed these experiments in the lab environment, with the instructor conducting them. We then structured the video material (including audio) for integration into the IDL using the PaneoVR tool, a VR authoring tool developed at University of Applied Sciences Emden/Leer and Bielefeld University, both located in Germany.

Table 3. Applied game elements in the final IDLs

Game element	Description	Relevant user needs
Game environment	The IDLs are placed in an interactive VR environment to create a game-like atmosphere	Entertainment, innovation, interactivity, technical quality
Goals	The students have one overall goal: to complete the experiment by the end	Appropriate complexity, practice-oriented learning, sustainable learning
Challenge	The students are challenged multiple times during the experiments with short quizzes and decision points	Appropriate complexity, entertainment, interactivity, self-determined learning, sustainable learning
Feedback	After each quiz or decision point, the students receive immediate feedback from the virtual instructor on whether their answer was correct	Content quality, sustainable learning, usability
Interactivity	The students can always look around in the VR environment, interact with UI elements such as quizzes, and repeat or stop the videos	Entertainment, interactivity, innovation, practice-oriented learning, reusability, self-determined learning, sustainable learning, technical quality, usability
Multimodality	The students can choose to conduct the IDLs in VR or via a web browser.	Self-determined learning, technical quality, usability

3.2 User Study

Due to time constraints and the pool of potential participants being limited by the size of the physical chemistry course (only five active and a few former students available), we opted for a simplified user study to evaluate the IDLs, collecting both quantitative and qualitative data. This involved a user test with observation and a think-aloud approach. Each participant had to test one of the two IDLs, randomly chosen by the test conductor. Ultimately, both IDLs were tested by the same number of participants to test the general concept. Participants could choose to test the IDL using the VR headset or the web browser. If they chose the VR headset, they could get a quick introduction to VR mechanics. After the user test, the participants completed a questionnaire about their positive, negative, and overall experiences as well as improvement proposals. We chose 12 aspects based on the identified user needs (see Table 2), usability [11], and the UEQ+ recommendations for learning applications [22].

The questionnaire begins with demographic data, followed by 12 questions, one for each user need. Each question includes a five-star rating scale (one star = terrible, five stars = excellent) and the option to add positive and negative free-text comments. The numerical values provide a quick overview of each aspect, while the comments offer more detailed insights. Finally, we asked: *Would you use the application, and if so, for what?* We followed this with four questions about the most positive and negative impressions and most desired improvements. It ends with the request to provide their *Reason for choosing VR/web browser*. We chose Google Forms to implement the questionnaire in German. It was pre-tested by research team members and took about 15 min to complete. The questionnaire is available in the research protocol [17].

We conducted the user study between April and May 2025 with nine students from the physical chemistry course at University of Applied Sciences Emden/Leer, Germany. The responsible lab research assistant recruited the participants from students who were enrolled in the relevant course or had recently completed it. We analyzed $N = 9$ female ($n = 3$) and male ($n = 6$) participants with an average age of 23.8 years ($SD = 8.6$). They were students in their second ($n = 8$) or third semester ($n = 1$) of Sustainable Process Technology ($n = 4$) or Biotechnology ($n = 5$). Some used the VR headset ($n = 6$), while others used the web browser ($n = 3$).

As no further chemistry students were available, we extended the sample to include students from STEM disciplines. To ensure the relevance of our findings, we repeated the same user study in October 2025 with $N = 25$ STEM students from the same institution. This second study aimed to examine whether the tendencies observed among the nine chemistry students would generalize to a broader target group. The STEM sample consists of $n = 8$ female and $n = 17$ male participants with an average age of 23.6 years ($SD = 4.1$). All participants selected the VR versions of the IDLs.

4 Results

This section presents our results addressing the two RQs on user needs (RQ1) and the participants' impressions (RQ2) when using IDLs. To answer RQ2, we applied thematic analysis [2] to the qualitative data derived from the free-text responses to the final four questionnaire items. All quotes used are available in their original German language in the research protocol [17].

4.1 Fulfillment of the User Needs (RQ1)

Our participants were required to rate each user need. In addition, they could make a positive comment, a negative comment, both, or neither. Table 4 presents the quantitative results of the IDL ratings and comments of the participants ($N = 9$) for each user need in descending order, starting with the highest total score. For each participant, column R contains the ratings (one star = terrible, five stars = excellent), while columns Po and Ne indicate whether the participant made a positive or negative comment, respectively (marked by an “x”). The total number of ratings and comments for each user need is given on the right. The last row sums the ratings and comments for each participant and in total. Among our participants, reusability ($R = 43$) was rated highest, followed by content quality ($R = 42$), usability ($R = 41$), and appropriate complexity ($R = 40$).

Figure 2 shows the mean ratings for STEM students ($N = 25$) for each user need category. They also confirm the generally positive impression (with average ratings above three for all user needs), but overall responded somewhat more critically. The STEM students rated six categories below 4 on average, with interactivity ($r = 3.44$) being the lowest.

Regarding the positive and negative comments for each user need among the participants ($N = 9$), content quality ($Po = 6$) received the highest number of positive comments, followed by appropriate complexity, interactivity, and entertainment/fun factor ($Po = 5$ each). It follows modernity/innovation, self-determined learning, technical quality ($Ne = 4$ each), and all other user needs with three or fewer positive comments. Sustainable learning is the only one with-

Table 4. Ratings and comments from participants for each user need

User need	P1			P2			P3			P4			P5			P6			P7			P8			P9			Total		
	R	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*	*R*	*Po*	*Ne*
Reusability	5	x	-	5	-	-	5	-	-	4	x	x	5	-	-	5	x	-	5	-	-	4	-	-	5	-	-	**43**	**3**	**1**
Content quality	4	x	x	5	-	-	5	-	-	4	x	x	5	x	-	5	x	-	5	x	-	4	-	-	5	x	-	**42**	**6**	**2**
Usability	5	-	-	5	-	-	5	-	-	4	x	x	4	x	x	5	x	-	4	-	x	4	-	-	5	-	-	**41**	**3**	**3**
Appropriate complexity	5	x	-	5	-	-	5	-	-	3	x	x	5	x	-	4	-	x	5	x	-	4	-	-	4	x	x	**40**	**5**	**3**
Interactivity	4	x	x	4	-	-	5	-	-	3	x	x	5	x	-	5	-	-	5	x	-	3	-	-	5	x	-	**39**	**5**	**2**
Modernity/Innovation	4	x	x	4	x	x	5	-	-	5	x	x	4	-	-	5	x	-	5	-	-	4	-	-	3	-	x	**39**	**4**	**4**
Practice-oriented learning	5	-	-	5	-	-	5	-	-	3	-	x	5	x	-	5	x	-	4	-	x	3	-	-	4	-	-	**39**	**2**	**2**
Self-determined learning	4	-	-	4	-	-	5	-	-	2	x	x	5	x	-	5	x	-	4	x	-	3	-	-	5	-	-	**37**	**4**	**1**
Overall impression	4	x	x	4	-	-	5	-	-	4	x	x	4	x	-	4	-	-	4	-	-	4	-	-	4	-	x	**37**	**3**	**3**
Technical quality	3	x	x	4	x	x	5	-	-	4	x	x	4	x	x	4	-	x	4	-	x	4	-	-	5	-	-	**37**	**4**	**6**
Entertainment/Fun factor	3	x	x	5	-	-	5	x	-	5	x	x	4	-	-	5	-	-	3	x	x	2	-	-	4	x	-	**36**	**5**	**3**
Sustainable learning	4	-	-	5	-	-	3	-	x	2	-	x	4	-	-	4	-	-	5	-	-	4	-	-	4	-	-	**35**	**0**	**2**
$\sum$	**50**	**8**	**6**	**55**	**2**	**2**	**58**	**1**	**1**	**43**	**10**	**12**	**54**	**8**	**2**	**56**	**6**	**2**	**53**	**5**	**4**	**43**	**0**	**0**	**53**	**4**	**3**	**465**	**44**	**32**

R = rating, Po = positive, Ne = negative, (x) = comment, and (-) = no comment.

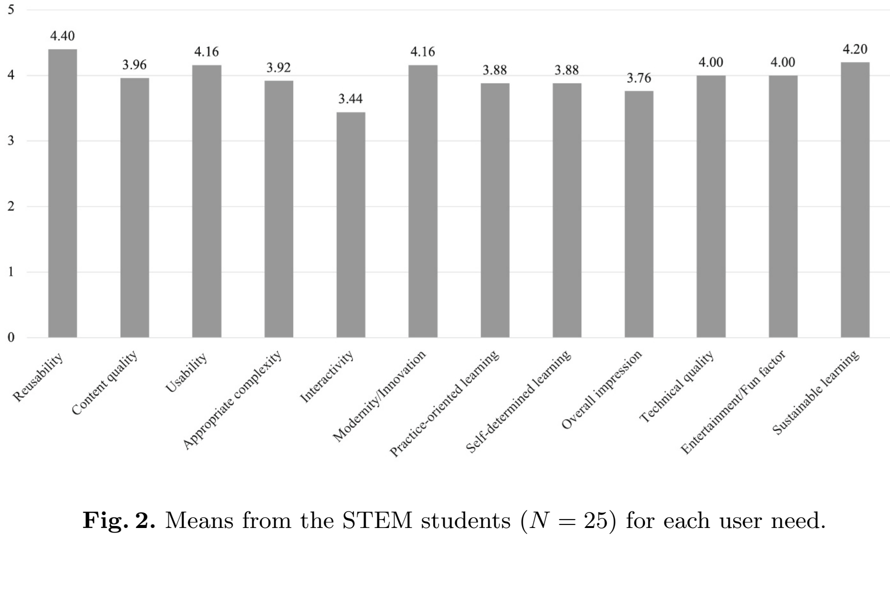

Fig. 2. Means from the STEM students ($N = 25$) for each user need.

out a positive comment ($Pe = 0$). P1, P4–P7, and P9 gave positive comments regarding content quality, noting that the explanations and content-related questions contributed to better understanding during the experiment. P1 stated: "*The experiment's procedure is presented clearly and simply, and the content-related questions help to understand the experiment.*" P1, P4, P5, P7, and P9 provided positive feedback regarding appropriate complexity, particularly regarding traceability, saying that the questions were not too complex. P7 stated: "*The questions are not very complex and are well explained.*" P1, P4, P5, P7, and P9 also positively commented on interactivity ($Po = 5$). They highlighted the questions available during the experiment to encourage participation. P5 stated: "*The questions are thought-provoking but not too complicated, so the viewer is motivated to participate.*" The participants also commented positively on modernity/innovation ($Po = 4$) (e.g., progress compared to classic videos), technical quality ($Po = 4$) (e.g., 360° view and functionality), usability ($Po = 3$) (e.g., UI ease of use), and practice-oriented learning ($Po = 2$) (e.g., excellent test preparation, application-oriented, suitable theoretical and practical reference). In contrast, technical quality ($Ne = 6$) received the most negative comments, followed by modernity/innovation ($Ne = 4$). It follows modernity/innovation ($Ne = 4$) and all other user needs with three or fewer negative comments. P1, P2, and P4–P7 had negative things to say about the technical quality, criticizing the image quality (e.g., flickering image sections) and the functionality, positions, and sizes of the UI elements (e.g., buttons). P2 stated: "*The video quality could be even better so that you can see in the experiment (1), for example, the gas and the liquid.*" P7 mentioned: "*The fields e.g. for question 4 are not always in the same place, which is a bit confusing [sic].*"

In summary, the ratings of the user needs are primarily favorable. Reusability ($R = 43$) received the highest rating, while sustainable learning ($R = 35$) received the lowest rating. Content quality received the most positive comments, and technical quality received the most negative comments.

4.2 Impressions and Recommendations (RQ2)

To answer RQ2, we asked the participants ($N = 9$) about their usage, experiences, and ideas for improvement when using the IDLs. All but one of them said they would use the application. In the following, we present the results of the thematic analysis. We did not apply the thematic analysis to the qualitative data from STEM students because they were not the intended target group for the application in physical chemistry.

Table 5 displays the identified themes and sub-themes, along with descriptions and example quotes. For each theme and sub-theme, we count the number of codes and the number of participants who mentioned it (columns four and five). Thus, we can measure the prevalence of themes and sub-themes separately (see Table 5), which does not necessarily indicate their importance [2].

Each sub-theme provides a concise quote example in the third column, and the total number of quotes belonging to this sub-theme in the last column. The accumulated quote numbers of the sub-themes result in the total number

Table 5. Themes and sub-themes of the final four questions ($N = 9$)

Theme Sub-themes	Description	Example quote	No	P
Technology	IDL technological aspects	–	**21**	**8**
UX	Usability aspects (e.g., interface)	**P8:** "Questions and illustrations were shifted, sometimes on the right or left side [sic]"	7	4
Interactivity	Content manipulation ability	**P1:** "A lot more interactive than a video [sic]"	6	3
Image quality	Visual quality (e.g., sharpness)	**P3:** "Sometimes the image was somewhat blurry [sic]"	5	5
Immersiveness	Engagement in VR	**P1:** "VR [...] feels somewhat 'more real' [sic]"	3	3
Content	IDL educational materials	–	**9**	**6**
Material	Material quality (e.g., clarity)	**P7:** "The explanations for incorrect responses [sic]"	6	5
Understanding	Lab activity comprehension	**P6:** "The experiment became quickly understandable [sic]"	3	2
Feelings	Feelings about IDL content	–	**8**	**5**
Curiosity	Interest in 360° video/VR	**P4:** "VR, [...] no experience existed yet [sic]"	6	4
Fear	Apprehension about tests	**P6:** "[...] videos become accessible for all experiments, so the 'fear' of performing them is further reduced [sic]"	1	1
Health	VR headset health concerns	**P5:** "I used the web browser because the VR version would likely have caused dizziness [sic]"	1	1
Usefulness	Value for chemistry education	–	**7**	**7**
Preparation	Lab task preparation utility	**P9:** "Yes, for preparation for any experiments [sic]"	6	6
Practicality	Learning support	**P1:** "Yes, among other things for training people [sic]"	1	1

No = number of codes, P = number of participants who mentioned the theme or sub-theme

of quotes for each theme. The theme and sub-theme are sorted by number of quotes.

The most frequently mentioned theme is *technology*, with the sub-themes *UX*, *interactivity*, *image quality*, and *immersiveness. UX* encompasses usability aspects related to the UI and content presentation in 360° video. Several participants reported inconsistent placement (e.g., questions and visual elements) in the IDL, which led to disorientation. For example, P5 stated: "*Partially, applications were in the corner and not immediately visible, so that one had to first orient oneself in the room [sic]*", which highlights challenges with element placement in the IDL user interface. Additionally, P7 noted, "*That not all videos were recorded from the same spot and that the click fields are not always in the same places. [sic].*" Another aspect is ease of use; e.g., P8 and P9 preferred the web application over the VR headset, as they perceived it as more familiar and easier to handle. *Interactivity* is the degree to which users can actively engage with the technology (e.g., to change the course of the experiment to get more information). The participants reported that IDLs' interactivity made them more engaging than 2D videos, but they also wanted more opportunities for interaction. For example, P1 stated, "*An apparently independent experiment execution, in which one is guided. [sic]*". P2 noted, "*I would wish to be able to conduct the experiment myself online after it has been explained [sic].*" *Image quality* includes visual aspects of the IDLs' video content. Our participants described the IDLs as having blurred images and small elements that were illegible. *Immersiveness* received positive feedback, with participants stating that the VR experience was more realistic than 2D video and helped to minimize environmental distractions.

Content was mentioned nine times and by six participants. It includes the sub-themes *material* and *understanding. Material* refers to the perceived quality and content of the IDL learning material. P7 highlighted the quality of the learning material, and P6 appreciated the comprehensibility of the content. P5 answered whether he would use the IDL: "*Yes, additionally as a supplement in the Moodle course after the lesson and the tests have been completed [sic].*" Five participants mentioned *feelings*. This includes the sub-theme *curiosity,* which refers to interest in using the VR headset. Some participants were motivated by having never used a VR headset before, while others valued applying modern technology in a practical context. P3 stated: *"The VR experience itself [sic]"* as a positive aspect of the IDL. Sub-theme fear refers to fear about test situations, and health refers to feelings of dizziness when applying a VR headset. We identified the theme of usefulness mentioned seven times by the participants, which refers to the perceived value of the IDL's content in supporting practical learning outcomes for physical chemistry. We divided it into preparation and practicality. In summary, *technology* is the central theme. Feedback was positive for the learning material but negative for the sub-themes *UX* and *image quality.*

5 Discussion

The IDLs are rated remarkably positively overall (RQ1), which illustrates the participants' positive perception of LX. Eight out of our nine of the participants said they would use the IDLs. This satisfaction is reflected in the high user need ratings, which are very close to each other (see Table 4). Our participants expressed motivation to use the IDLs for practice-oriented learning and to perform appropriately complex tasks within a modern, interactive, and easy-to-use simulation. These aspects were also mentioned in the free-text responses (RQ2). Thematic analysis revealed that *technology* is a key theme. The participants are eager to try new technology and emphasize *interactivity* and *immersiveness.* They also value comprehensible learning material that prepares them well for the experiments, which is highlighted by the *content* and *usefulness* themes (see Table 5).

Preferred game elements (see Table 3) include elements such as multimodality and interactivity. Six participants chose VR (Game Environment), and three chose the web app. Moreover, the STEM students ($N = 25$) all chose the VR application. The user needs appropriate complexity and interactivity both received high scores and positive feedback (see Table 4). This suggests that the IDLs' immersiveness enhances the clarity of complex tasks regardless of the platform used.

Technical quality received the most negative comments (see Table 4). It corresponds to the identified theme *technology*, where the *UX* and *image quality* are especially criticized (see Table 5). We see great potential for IDLs, as six participants expressed substantial approval for using them in physical chemistry. Two even mentioned potential in other areas, with P3 noting the possibility for "*virtual experiments*" and P4 suggesting use "*for space technology (Space Lab)* *experiments with high risk.*" Almost all participants were highly motivated to apply the IDLs, indicated by usefulness (for lab preparation) and feelings (emotions when using IDLs) (see Table 5). Technical quality and UX were suggested as areas of improvement for IDLs. This is due to problems with the 360° video design (e.g., inconsistent point of view), which disrupted user engagement. Our participants also expressed a desire for more modernity and innovation (e.g., 2D vs. 360°/VR app) and interactivity (e.g., independent experiment execution).

We align with the literature by demonstrating that a motivating environment with 360° videos and interactivity [4] and appropriate learning material [8] are essential features for immersive learning applications. In addition, curiosity drives interest in using VR headsets [23]. However, aspects such as image transition [12] and UI elements [5] can pose difficulties when creating digital lab applications.

Although our study is limited to a small number of participants ($N = 9$) and two tested experiments, it provides noteworthy quantitative and qualitative findings to evaluate our explored IDLs. The findings from the additional target group, STEM students ($N = 25$), also provide compelling support for the study's results and highlight the potential of IDL in STEM, which represents a substantial application area [18,25].

The evaluation also provides valuable insights to identify strengths and weaknesses, which can aid in future IDL development. Our study did not examine data separately for each platform, so it is not possible to make a comparison between VR headset and web browser use.

In summary, our participants expressed very positive impressions of the IDLs, which indicates successful LX. Thus, we see great potential for chemistry experiments and other high-risk areas. Technical quality (e.g., enhanced video design) and interactivity (e.g., free exploration) are suggested areas of improvement.

6 Conclusion and Future Work

We examined two newly implemented 360° VR interactive learning applications with students in higher education physical chemistry courses. We evaluated the gamified immersive digital lab (IDL) applications based on 12 user needs, collecting both quantitative and qualitative data on our participants' experiences and their proposed improvements.

We have consistently positive ratings for most of our user needs. Thematic analysis of the free-text responses emphasized the central theme of *technology*, especially *interactivity* and *immersiveness*. Our findings suggest that the IDLs enhance LX, increase engagement with the learning material, and prepare students for real-life lab exams. The students desire improved image quality and game elements for free exploration. The use of novel technologies, such as 360° video and VR, is well-received and arouses curiosity.

The results indicate that integrating IDLs into the learning experience of physical chemistry students increases their engagement with the learning material and helps them better prepare for real laboratory experiments in their courses. The use of novel technologies such as 360° video and virtual reality was generally well received and stimulated students' curiosity. However, some challenges emerged, including technical issues, limited image quality, and a lack of interactivity with the learning content.

In future work, we aim to evaluate the IDLs with a larger sample size and complementary to real academic courses. We want to investigate how using IDLs with a VR headset differs from using it in a web browser. The IDLs should also have improved image quality and interactivity. Furthermore, we see potential to apply them to other courses, such as biology, informatics, social work, health care, or media technology. The latter application area highlighted by the additional examination of the $N = 25$ STEM students, who indicate substantial potential for IDL application in STEM.

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References

1. Apeah-Kubi, D.: Interactive learning for impact: game-based learning in social work education. J. Teach. Soc. Work, 1–19 (2 2025). https://doi.org/10.1080/08841233.2025.2469565
2. Braun, V., Clarke, V.: Using thematic analysis in psychology. Qual. Res. Psychol. **3**(2), 77–101 (2006). https://doi.org/10.1191/1478088706qp063oa
3. Cecotti, H., Callaghan, M., Foucher, B., Joslain, S.: Serious game for medical imaging in fully immersive virtual reality. In: 2021 IEEE International Conference on Engineering, Technology & Education (TALE), pp. 615–621. IEEE (2021). https://doi.org/10.1109/TALE52509.2021.9678721
4. Chen, J., Fu, Z., Liu, H., Wang, J.: Effectiveness of virtual reality on learning engagement. Int. J. Web-Based Learn. Teach. Technol. **19**, 1–14 (2023). https://doi.org/10.4018/IJWLTT.334849
5. Chen, M.X., Hu, H., Yao, R., Qiu, L., Li, D.: A survey on the design of virtual reality interaction interfaces. Sensors **24**(19) (2024). https://doi.org/10.3390/s24196204
6. Chen, Q., et al.: Immersive virtual reality training of bioreactor operations. In: TALE, pp. 873–878. IEEE (2020). https://doi.org/10.1109/TALE48869.2020.9368468
7. Deterding, S., Dixon, D., Khaled, R., Nacke, L.E.: From game design elements to gamefulness: Defining 'gamification'. MindTrek **2011** (2011)
8. Fowler, C.: Virtual reality and learning: where is the pedagogy? BJET **46**(2), 412–422 (2015). https://doi.org/10.1111/bjet.12135
9. Hallifax, S., Altmeyer, M., Kölln, K., Rauschenberger, M., Nacke, L.E.: From points to progression: a scoping review of game elements in gamification research with a content analysis of 280 research papers. Proc. ACM Hum.-Comput. Interact. **7**(CHI PLAY) (2023). https://doi.org/10.1145/3611048

10. ISO 9241-210:2019: Ergonomics of human-system interaction - part 210: Human-centred design for interactive systems. Technical report, ISO (2019)
11. ISO9241-11:2018: Ergonomics of human-system interaction - part 11: Usability: Definitions and concepts. Technical report, ISO (2018)
12. Jumani, S.H., Aslam, M., Jamil, M.H., Kim, H.G., Kim, J.G.: Quality of experience that matters in gaming graphics: how to blend image processing and virtual reality. Electronics **13**(15) (2024). https://doi.org/10.3390/electronics13152998
13. Kashfi, P., Nilsson, A., Feldt, R.: Integrating user experience practices into software development processes: implications of the UX characteristics. PeerJ Comput. Sci. **3**, e130 (2017). https://doi.org/10.7717/peerj-cs.130
14. Seaborn, K., Fels, D.I.: Gamification in theory and action: a survey. Int. J. Hum. Comput. Stud. **74**, 14–31 (2015). https://doi.org/10.1016/j.ijhcs.2014.09.006
15. LaRocco, D.J., Fanelli, L.L.: Universal Design for Learning for Clinical Educators, pp. 389–411. IGI Global Scientific Publishing (2021). https://doi.org/10.4018/978-1-7998-7106-4.ch020
16. McKim, C.A.: The value of mixed methods research: a mixed methods study. J. Mixed Methods Res. **11**(2), 202–222 (2017). https://doi.org/10.1177/1558689815607096
17. Nagel, K., Pastoor, L., Klein, A.M., Rauschenberger, M., Pfeiffer, T.: Protocol for potentials of an interactive non-linear 360°-panoramic-video-based virtual reality learning application for chemistry students (2026). https://www.researchgate.net/publication/400620973_Protocol_for_Potentials_of_an_Interactive_Non-Linear_360-Panoramic-Video-based_Virtual_Reality_Learning_Application_for_Chemistry_Students
18. Nagel, K., Rauschenberger, M.: The use of gamification and virtual reality in higher education: a literature review. In: 8th International GamiFIN Conference 2024 (GamiFIN 2024), Ruka, Finland (2024)
19. Nicola, S., Virag, I.: VR medical gamification for training and education. In: Hayn, D., Schreier, G. (eds.) Health Informatics Meets eHealth. Studies in Health Technology and Informatics, pp. 97–103. IOS Press, Amsterdam and Washington DC, (2017)
20. Rajeev, S., Sharma, S.: Educational game-theme based instructional module for teaching introductory programming. In: IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society. IEEE (2018). https://doi.org/10.1109/iecon.2018.8592835
21. Rajeev, S., Sharma, S., Sahu, A.: Game theme based instructional module to teach binary trees data structure. In: Proceedings of ISCA 26th International Conference on Software Engineering and Data Engineering 2017, pp. 13–18 (2017). https://sharadonly.github.io/papers/19.pdf
22. Schrepp, M., Thomaschewski, J.: Design and validation of a framework for the creation of user experience questionnaires. IJIMAI **5**, 88–95 (2019). https://doi.org/10.9781/ijimai.2019.06.006
23. Snelson, C., Hsu, Y.C.: Educational 360-degree videos in virtual reality. TechTrends **64**(1), 1–14 (2019). https://doi.org/10.1007/s11528-019-00474-3
24. Stigall, J., Sharma, S.: Usability and learning effectiveness of game-themed instructional (GTI) module for teaching stacks and queues. SoutheastCon **2018**, 1–6 (2018)
25. Sunday, K., Wong, S.Y., Samson, B.O., Sanusi, I.T.: Investigating the effect of Imikode virtual reality game in enhancing object oriented programming concepts among university students in Nigeria. Educ. Inf. Technol. **27**(5), 6819–6845 (2022). https://doi.org/10.1007/s10639-022-10886-z

26. Theethum, T., Arpornrat, A., Vittayakorn, S.: Thinkercise: an educational VR game for python programming. In: 2021 18th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), pp. 439–442. IEEE (2021). https://doi.org/10.1109/ECTI-CON51831.2021.9454730
27. Thomas, A., Bader, F., Thomaschewski, J., Rauschenberger, M.: Integrating gamification: The human-centered gamification process. In: 17th International Conference on Web Information Systems and Technology, pp. 430–435. INSTICC (2021). https://doi.org/10.13140/RG.2.2.22625.02403