Evaluating the Impact of User and Learning Experience in Three Cultural Heritage VR Applications

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Abstract

Many existing Virtual Reality (VR) applications in the Digital Cultural Heritage (DCH) domain are for education purposes. As educational VR DCH experiences become more prevalent, it becomes increasingly important to understand the user and learner experience of such installations. This work reports on a user study (n=30) evaluating three educational VR DCH experiences using three existing User experience (UX) evaluation methodologies from related fields and three learning evaluation methodologies. A total of 31 participants were recruited for the experiment, resulting in a dataset of 30 valid records. Our research seeks to explore the relationship between UX and Learning experience (LX), and their impact on learning in VR DCH experiences. Our results suggest that UX and LX in educational VR DCH experiences can influence certain aspects of learning, such as retention, concentration, motivation, and flexibility. Additionally, specific aspects of the educational VR DCH experience captured evidence by three existing UX evaluation and three learning evaluation methodologies are identified. These include instrumental aspects (ease of use, learnability, efficiency, etc.), stimulation of new experiences, the role of interactions, immersion in VR DCH contexts and flexibility of learning pace and using learning materials.

CCS Concepts

• **Human-centered computing → User studies**.

Keywords

User experience, user study, Learner experience, Digital Cultural Heritage, Virtual Reality, Learning experience

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1 Introduction

The field of Digital Cultural Heritage (DCH) is continuously integrating cutting-edge technologies, such as Extended Reality (XR), to provide digital access to cultural heritage, especially when physical access is restricted [1]. According to Fast [43], XR—including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR)—has been utilised in various ways to offer users novel and sensory experiences by combining real and digital content [1, 3, 10, 35]. Incorporating VR technologies into educational DCH experiences opens a new dimension of learning, enabling users to explore and engage with content in immersive ways [10, 29]. This depth of learning demonstrates the potential and value of VR applications in the DCH learning context. Games designed with educational objectives (serious games) are considered effective tools for learning cultural content in an engaging manner [39]. By incorporating game mechanics and interactivity into non-game contexts and scenarios, static content can be transformed into serious games within the Cultural Heritage (CH) [39]. In recent years, researchers take advantage of the affordances of digital technologies and gaming technologies, broadening the scope of gaming in culture game field across various genres used in real-life applications [22]. Specifically, VR-based serious games can teach cultural awareness, historical reconstruction, and heritage consciousness in a highly immersive and engaging manner [25, 26, 41]. While different from traditional games, many existing educational VR DCH applications are like serious games in employing the language of games: exploring 3D environments, immersive virtual experiences, and interacting with objects within these environments, can be characterized as a form of "game practice".

However, VR applications rely on VR headsets to display content, requiring developers to consider various user experience factors.

User experience (UX) can be understood as inherently dynamic, given a person's ever changing internal and emotional state, the characteristics of the designed system and differences in the circumstances during and after an interaction with designed systems [21]. Learner experience refers to the subjective perceptions, emotions, and interactions that a learner has during the learning process, as a simulation of UX [36]. While Learning experience(LX) in this study also includes the actual process and outcome of learning[2]. VR technology has enhanced the presentation of cultural heritage content, resulting in improved learner engagement and learning experience [3, 23]. Interactions with the designed systems shape learners' perceived usability and usefulness of technology in achieving learning goals [17]. At the same time, learners experience various emotions during learning in technology-rich environments[12]. The emotional components of interactions influence learning efficacy, including engagement and higher-order thinking. But technologies with challenging interactions may create negative emotions, which can hinder meaningful learning [38].

Hence, understanding the relationship between user and learner experience and learning impacts is essential for developing VR DCH applications with educational values. The research questions to frame this work are as follows:

Table 1: Search results.

Database	Keywords	Results
ACM	[[All: "virtual reality"] OR [All: "vr"]] AND [[All: "cultural heritage"] AND [[All: "education"] OR [All: "learning"]] AND [All: "user experience"] AND [All: "user study"]]	[10, 15] [23, 35]
Science Direct	("Virtual Reality" OR "VR") AND ("cultural heritage") AND ("education" OR "learning") AND ("user experience") AND ("user study")	/
IEEE	("Abstract": "Virtual Reality" OR "Abstract": "VR") AND ("All Metadata": "cultural heritage") AND ("All Metadata": "education" OR "All Metadata": "learning") AND ("All Metadata": "user experience") AND ("All Metadata": "user study")	[3][32–34]
MDPI	("Virtual Reality" OR "VR") AND ("cultural heritage") AND ("education" OR "learning") AND ("user experience") AND ("user study")	[29, 37]
Springer Link	("Virtual Reality" OR "VR") AND "cultural heritage" AND ("education" OR "learning") AND "user experience" AND "user study"	[16]

(1) How does User experience and Learning experience impact learning in VR DCH?
(2) What aspects of educational VR DCH experience do existing UX and learning evaluation methodologies successfully capture evidence for?

2 Related Works

As part of prior work [24] we conducted a literature survey across five academic databases: ACM Digital Library, Science Direct, IEEE Xplore, MDPI, and Springer Link to better understand this space. Our aim was to pinpoint exemplary instances of educational VR DCH applications, the evaluated aspects of UX, and the specific UX evaluation methodologies employed. We filtered the low-participation articles after full-text reading by employing selected search strings (see in Table. 1), excluding the books, chapters and proceedings, and excluding irrelevant titles and abstracts. The inclusion criteria were as follows: more than 30 participants for quantitative research, more than 5 participants for qualitative research, and both conditions had to be met for mixed research. This data selection produced 11 papers (see Table. 1).

2.1 Educational VR DCH Applications

The primary feature of educational VR DCH applications in this field is reproducing the past. The cultural heritage learning resources of the educational VR DCH Application are presented in various ways. Three typical trends of VR DCH applications with educational impacts were identified: visualizing digital reconstruction and information of the past [3, 10, 29, 37], providing tangible and intangible heritage learning resources through the establishment of virtual museums or exhibitions[15, 23], and involving storytelling in heritage sites or cultural communities[33–35]. In addition, compared to traditional learning methods, VR is used to optimize visual effects and enhance learning motivation[16, 32]. From all these cases, we can see that VR technologies provide opportunities for learners to interact with historical content in dynamic and interactive ways, which causes complicated UX needs.

2.2 UX Evaluation in Educational VR DCH Experiences

Regarding the multi-faceted feature of UX, Hassenzahl and Tractinsky identified four crucial facets of UX [14]: **"The instrumental"** refers to user-centred analysis and evaluation of how well interactive products or systems achieve expected behavioural goals in work settings, such as usability test. **"Beyond the instrumental"** addresses human needs beyond the instrumental, pays attention to hedonic aspects, such as stimulation, identification and evocation. **"Emotion and affect"** pertains to understanding the role of affect as an antecedent, a consequence and a mediator of technology use. Rather than focusing on positive emotions, preventing frustration and dissatisfaction is always a core objective, even from the most cognitively driven perspective on HCI. **"The experiential"** emphasizes situatedness and temporality of technology use, which holds that "experience" is a composite of diverse components unfolding over a period, with a clear beginning and end.

They believe the narrow focus on interactive products as tools does not capture technology use's variety and emerging aspects. UX researchers approach the interactions between users and technology from various perspectives, each sharing some ideas and arguments with the others[14]. We can use these facets to understand current UX approaches in educational VR DCH fields.

2.2.1 UX Evaluation Trends. UX evaluation in educational VR DCH experiences focuses on various UX facets. Our analysis shows comparable attention to two primary perspectives: "instrumental" and "beyond the instrumental", with six studies investigating both, as well as "emotion and affect" simultaneously [10, 15, 23, 29, 35, 37]. Only one study used the User Experience Questionnaire (UEQ) for evaluating the experience design [34], indicating a need for more evidence from "the experiential" perspective. This gap calls for further research to explore potential compromises or alternative approaches in this area.

In terms of instrumental aspects, the focus is on system usability, such as ease of use [10, 29, 35], usefulness [35, 37], and dependability [34], each evaluated based on specific needs. Beyond instrumental aspects, typical evaluation focuses include immersion [15, 29], engagement [23, 29, 33], and learning effectiveness [3, 10, 16]. Additionally, positive emotions during learning have been noted [10, 29, 37].

2.2.2 Existing UX Evaluation Methods . Different UX evaluation methods can guide product development and address real user needs at each stage [14]. We see some examples of using different evaluation methods:questionnaires [3, 10, 15, 16, 23, 29, 29, 32, 34, 35, 37], interviews[10, 23, 33, 37], observations[10], and objective methods (e.g., mEEG)[23].

Classic UX methods have been utilized to evaluate VR DCH applications with educational impacts. For instance, the System Usability Scale (SUS) focuses on instrumental aspects [15], while the UEQ, which assesses pairs of contrasting attributes, successfully evaluated four UX facets of educational VR DCH experiences [34]. However, these methods lack comprehensive coverage of all UX aspects researchers aim to measure, such as immersion, presence, and VR sickness. Consequently, other existing specific UX methods [10, 15, 23] or bespoke methods [15, 29, 32] have been adopted.

Unfortunately, an integrated UX evaluation framework or model specifically designed for educational VR DCH experiences has yet to be found in current research. Methods from other relevant fields, like DCH, are discussed in Section 2.2.3 to address this gap.

2.2.3 DCH UX Evaluation Methods. Given the diversity of UX evaluation methods, research into integrated UX evaluation methods in relevant fields has been conducted. Two additional methods, Othman's The Museum Experience Scale (MES) and Multimedia Guide Scale (MMGS) [30], and an evaluation of UX aspects applied to virtual museums (VMUXE) [11], are believed to have the potential to map out UX for VR DCH experiences.

Gockel [11] asserts that "communicating" culture through technology is more of an epistemological challenge than a technological one. They incorporated Hassenzahl's concept of "stimulation" [13] to assess personal development by offering new, interesting, or exciting content, functionality, presentation, or interaction styles. VMUXE, designed for evaluating virtual experiences in digital museums, includes a questionnaire combining elements from the UEQ and multiple-choice questions, along with semi-structured interviews based on responses. This mixed-method approach establishes evaluation criteria and quality parameters for the DCH domain.

MES and MMGS contain two scales measure visitors' and multimedia guide experiences in cultural contexts. MES emphasizes knowledge and learning experiences, assessing the knowledge/learning gained from exhibitions and exhibits. Multiple studies have used these models to evaluate UX in XR heritage environments [18, 28].

2.3 Learning Evaluation in Educational VR DCH Experiences

2.3.1 Learning Evaluation Trends. Regarding evaluations for learning, researchers have primarily focused on three attributes — learning and cognitive stimulation[10, 32], emotions when interacting with learning materials[10, 15, 32, 37], and learning effectiveness[3, 10, 15, 16]. For knowledge acquisition, questionnaires and interviews are commonly used to evaluate how users understand a given subject[10], by assessing their knowledge before and after their experiences, and then comparing the two sets of results. In our review scope, no cases were singled out for specific evaluation with an emphasis on the learning experience.

2.3.2 LX and Learning Evaluation Methods. Although many studies in the field of education recognize the importance of the teacher's perspective in learning assessment, this study will primarily focus on single learner' perspectives. The following three methods are considered to have potential in evaluating VR DCH learning.

Kirkpatrick's model (KM) is a classic learner assessment method[19, 20], comprising of four levels: Reaction, Learning, Behavior, and Results - with each level building upon the previous one. Poriki et al. [31] successfully applied this model in the assessment of DCH serious games, demonstrating its credibility within XR DCH learning evaluation. In our upcoming experiment, we will adopt the questionnaire design from this study.

The contextual model of learning (CML) was proposed by Falk and Dierking [8, 9], it offers a theoretical framework for evaluating learning in the cultural heritage context. It emphasizes eight factors influencing contextual learning, categorized into Personal, Sociocultural, and Physical contexts, providing a valuable perspective for evaluation. We will adopt the questionnaire and interview design from one of Falk's experimental study[7] based on this model.

The four-dimensional framework for designing and evaluating immersive learning experiences in virtual worlds (4DF) was developed[5, 6] based on previous work by de Freitas and Oliver [4], focuses on digital technologies to provide learners with immersive contexts. Proven by two cases [5, 6], this framework offers valuable insights for learning cultural heritage in immersive contexts.

3 Methodology

To evaluate the educational impact of UX, LX and learning efficacy in VR DCH, we conducted an experiment using three VR DCH experiences and a mixed methods approach to gathering data on UX, LX, and efficacy. The following methodology was taken through, and approved by, university ethics committee.

3.1 Participants Recruitment

For this user study, participants were required to be over 18 years old, capable of providing informed consent, and not experiencing hearing or visual impairments. Recruitment was conducted through forums related to XR, cultural heritage, education, and local contacts in a games design degree program. Snowball sampling was also used, with participants recommending others.

The study initially gathered 31 respondents, with one participant withdrawing midway, resulting in 30 valid responses. These included 10 female, 20 male, and 1 individual who identified as another gender. The majority of them were native English speakers. Age-wise, 19 participants were between 18 and 24 years old, 5 were between 25 and 34, and 6 were between 35 and 44. In terms of professional background, 60% of participants worked in Technology and Engineering, 33.33% were in Creative Arts and Communication, with only a few in Business, Management, or Social and Human Services. Regarding education, most participants were either in college (14) or held a master's degree (6), with the rest evenly distributed across high school, bachelor's, and doctoral degrees.

Participants reported similar levels of self-assessed ICT skills across all applications, with an average rating of 3.87 out of 5 (SD = 0.860). Thirteen participants had prior XR experience, with four using VR devices 2-5 times per week and one using them daily. Very few had prior experience with educational VR DCH applications. Participants were randomly assigned to one of three applications, resulting in 10 user data sets per application. Participants were asked to rate their intentions to learn and use the application prior to the experience, responding to items related to Motivation and Expectation (e.g., intentions to learn, expectations of enjoyment) and Prior Interest (in cultural heritage content, VR applications, and educational VR applications). Application three had the highest motivation to learn (Mean = 4.5) and Application one had the highest expectation of enjoyment (Mean = 5.1). Interest in educational VR applications was consistently high across all three applications (Mean $\approx$ 4.9–5.0)

3.2 Materials

3.2.1 Educational VR DCH Applications. Following the typical trends of VR DCH experience identified in the literature review (section 2.1), three VR experiences which create interactive, immersive 3D environments, were chosen as testing materials for this user study:

The first is the Antarctic Heritage Trust[40], includes a guided virtual tour of Sir Edmund Hillary's Antarctic hut with a storytelling narrator, allows users to learn about the hut's layout, functions, and the team's missions. The flexibility of this experience is low, but users can interact with objects while the narrator provides information through audio, videos, or highlighting the recreations in the context. An HTC Vive was used to display this experience.

The second one is the School House Virtual Museum with tangible user interfaces [15], which is a virtual museum presents a curated collection in three storylines: Kosovo in former Yugoslavia, Civil Resistance, and Schoolhouse. The narrative is event-based and non-chronological. Learning materials are presented through text, images, videos, and other archival materials, which allows users choose them freely. This experiment used the desk mode and the virtual museum was ported to Oculus Quest 2 VR headset.

Hadrian's Villa Reborn [42] is another virtual tour that allows users to explore the Stadium Garden at Hadrian's Villa, where they can learn about the emperor's private banquets, the Roman elite's ambulatio habits, and the intricate design of the rooms, providing deeper insights into Hadrian's story. Unlike the first application, this experience allows users to teleport to any location and access audio and text to learn at their own pace. For this study, we used an HTC Vive to display the recreated virtual world.

3.2.2 Questionnaires and Interviews . Three user experience evaluation methods were introduced to this experiment. The UEQ[27], considered capable of assessing the overall user experience, will be used alongside two other DCH UX evaluation methods—MES and MMGS[30]—and VMUXE[11] to capture evidence for UX in educational VR DCH. MES, MMGS, and VMUXE are also considered valuable for providing insights from a cultural perspective. In addition, Three learning evaluation methods identified in section 2.3.2 are adopted to serve as a lens to understand users' LX and the educational impact from VR DCH experiences. To ensure a fair evaluation of these methods, the questions in the questionnaires and interviews remained consistent with the original works [6, 7, 11, 20, 27, 30, 31]. As our applications advocates for single user, aspects related to pedagogic in the 4DF[5, 6] and Socio-cultural in the CML[8, 9] will be excluded. The study employs a mixed methodology to gather quantitative and qualitative data. Questions from the adopted methods are organized into pre- and post-experience questionnaires and interviews, aligning with chronological sequences in the original literature. Additionally, one more bespoke question about learning outcome is included in the post-experience interview: *Can you identify the particular parts of this experience that helped you acquire this knowledge? What aspects were especially effective in facilitating your understanding?*. See Table.2 for details on questionnaire and interview design. By adopting a range of methods for evaluating UX and LX we also hope to gather evidence towards answering research question two on the coverage of these methods.

3.3 Procedure

The experiment took approximately 75 minutes to run. The procedure began with participants receiving an information sheet to review prior to attending the session. Upon arrival, they were greeted and asked to sign a participant agreement form. Participants then completed a pre-experience questionnaire, which collected demographic information and assessed their prior experiences. An audio-recorded interview followed, featuring one question to gauge their prior knowledge of the specific cultural heritage content they would encounter in the following educational VR DCH experience. Participants were invited to engage with one of three selected applications for a duration of no less than 10 minutes and no more than 20 minutes. After completing the experience, they filled out a post-experience survey consist of UX and LX questionnaires. The experiment concluded with an audio-recorded semi-structured interview, which covered UX evaluation, LX evaluation, and provided evidence of knowledge acquisition.

4 Results and Discussion

Following the successful execution of the above methodology (n=30) our data was analysed to answer our two research questions using a mixture of quantitative methods on numerical data, and qualitative coding (single coder, lead author).

4.1 The Relationships Between UX and LX

To ensure internal consistency, scale reliability was assessed for both the post-experience UX and LX questionnaires using Cronbach's α. Item-total correlations were analyzed to identify items that demonstrated weaker coherence within their respective UX

Table 2: Design of questionnaires and interviews.

Pre-experience Questionnaire		Reference
1-4	Basic demographic data	/
5	ICT skills	4DF's Learner Specific
6	Prior experiences	4DF's Learner Specific & CML's Personal Context
7	Motivation and expectation, Prior knowledge and interest	CML's Personal Context
Pre-experience Interview		**Reference**
1	Prior experiences	CML's Personal Context
Post-experience Questionnaire		**Reference**
1-26	Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation and Novelty	UEQ & VMUXE's rating questions
27-31	Utility, Learnability, Efficiency and Stimulation	VMUXE's choice questions
32-68	Cultural and Multimedia guide experience	MES & MMGS
69	User's enjoyment	4DF's Learner Specific
70	Choice and control of materials	CML's Personal Context
71	Navigation of the system	CML's Physical Context
73-75, 77-78	Learning Motivation, Needs, Effort, Usefulness and Understanding assist	KM's Reaction, Learning and Behavior
76, 79-80	Knowledge acquisition, Intention and Recommendation	KM's Learning, Behavior and Result & 4DF's Learner Specific
Post-experience Interview		**Reference**
1-5	Utility, Learnability, Efficiency and Stimulation	VMUXE
6-8	Learning experience	4DF's Learner Specific, Representation and Context
9	Post-experience knowledge	CML's Personal Context
10	Bespoke question	/

or LX questionnaires. Pearson's product-moment correlation was used to calculate the relationships between the scales. Additionally, we also explored the relationship between UX and LX through qualitative analysis results.

Table 3: Pearson r correlations of questionnaire scores (N=30, **p<0.01).

	UEQ	MES_MMGS	KM	4DF	CML
UEQ	1	.780**	.807**	.803**	.734**
MES_MMGS	.780**	1	.811**	.818**	.815**
KM	.807**	.811**	1	.929**	.625**
4DF	.803**	.818**	.929**	1	.688**
CML	.734**	.815**	.625**	.688**	1

**Correlation is significant at the 0.01 level (2-tailed).

4.1.1 Scale Reliability. The collected data was analyzed to assess the reliability of both the UX Questionnaire—which included the UEQ, VMUXE, and MES & MMGS scales—and the LX Questionnaire, encompassing the KM, 4DF and CML models.

For the UX questionnaire, internal consistency was evaluated using Cronbach's α, yielding a high reliability score of 0.94 across 63 items. This indicates that the items are strongly correlated, suggesting they measure the same underlying UX construct, which is indicative of excellent reliability. Similarly, the LX questionnaire demonstrated good internal consistency, with a Cronbach's α of 0.898 for its 11 items. This result suggests that the items within the LX questionnaire are well-aligned, reliably capturing core learning experience constructs such as appeal and motivation, learner satisfaction, and the effectiveness of educational interventions.

4.1.2 UX/LX Scales Correlations. Overall, there were high positive correlations between the pairs of the UX evaluation questionnaires (the UEQ, incuding VMUXE, MES & MMGS) and LX evaluation questionnaires (the KM, 4DF and CML scales),as shown in the Table3. There was a strong positive correlation between the UEQ (including VMUXE rating scales) and both the KM and 4DF models, with $r = 0.807$ and $r = 0.803$, respectively.The KM evaluates training effectiveness, while 4DF assesses immersive learning experiences. These strong correlations suggest that VR DCH UX quality positively impacts LX and outcomes - as we might expect measures of UX and LX are closely aligned. The correlation with the CML scale was slightly weaker, at $r = 0.734$, though still significant. This might be due to the fact that the CML scale contains only two questions, addressing two specific contextual aspects: physical context (navigation) and personal context (the ability to choose different materials). For MES & MMGS, strong positive correlations were also found with the KM ($r = 0.811$), 4DF ($r = 0.818$), and CML ($r = 0.815$), indicating a close relationship with the learning models. Notably, compared to UEQ, MES & MMGS exhibited stronger associations with the learning evaluation results. This is likely because MES & MMGS focus on assessing the user's cultural experience and interactions with multimedia guides, elements that are more directly tied to the effectiveness of VR DCH applications in facilitating learning.

We further analyzed the correlation of CML's two specific questions, "choosing learning materials" and "navigation", with both UEQ and MES & MMGS. The results indicated that the ability to select desired learning materials during the experience was less strongly related to UX, with correlations of $r = 0.603$ for UEQ and $r = 0.699$ for MES & MMGS. This suggests that, in the context of VR DCH learning, whether the application help or hinder participants' ability to choose and view desired learning materials has a relatively low correlation with the overall UX and cultural experience.

From the qualitative analysis, we observe that the evaluation results of UX and LX differ, but there are notable overlaps. The data from 30 post-experience interviews of UX and LX evaluation is analyzed by a single coder. The inductive coding process started with broad initial codes such as "assist remembering" and "helpful interactions" and evolved into more refined themes, which were then applied to the entire data set to ensure overall fit of each area. The UX and LX evaluation results were individually coded to identify distinct features and potential overlaps, enabling a detailed comparison of the unique and shared elements between the two areas. These individual coding results are presented in the AppendixA.

From the themes identified for each area, we observe that UX evaluation explore how various factors of the application influence the entire experience and learning activities, while LX is more concerned with how users' learning activities going from different education perspectives (understanding, remembering, flexibility in learning et.al). Moreover, both the UX and LX evaluation results address aspects such as system usability, learning pace, and how these factors are influenced by the design of the application.

In the UX evaluation results, most users did not limit their feedback to the system or immersive experience alone but extended it to their learning activities. For instance, six users mentioned "Ease of use in navigation" in their UX feedback. They highlighted that certain features, such as well-designed navigation, draw attention to key areas, making it easier to locate and interact with important elements for learning. Users further elaborated on how the ease of navigation impacted their learning process: "Ease of use in navigation assists learners in finding information and focusing on learning materials" or "Ease of use in navigation reduces confusion in complex systems, which might otherwise cause distractions or lower learning efficiency."

Based on the coding results, the most frequently mentioned learning-related aspects in UX evaluation include concentration, understanding, learning efficiency, learning pace, learning motivation, and the use of learning materials. These aspects align closely with the key themes identified subsequently in LX evaluation. However, from the LX coding results, there is less direct evidence pointing toward UX-related aspects.

Overall, the quantitative analysis suggest a strong positive relationship between the UX and LX evaluation questionnaires, indicating that they may measure related dimensions or variables, both of which are closely linked to capture the evidence for users/learners educational VR DCH experiences. Additionally, the current UX evaluation interview shows a certain capability to capture partial aspects of the learning experience through qualitative analysis.

4.2 Learning Efficacy

4.2.1 Participants' Perceptions of Knowledge Acquisition. In post-experience LX Questionnaires, We combined similar questions in the 4DF with the KM's questionnaire to assess whether users' knowledge acquisition was increased by their own assessment. Also, it assess the effectiveness of using VR DCH applications in learning through five aspects: motivation, meeting learning needs, effort, learning usefulness, and assisting understanding.

Figure 1 displays the descriptive analysis of these six metrics. Application Three consistently outperforms the other applications across learning effectiveness, particularly in knowledge acquisition, motivation, meeting learning needs, usefulness, and assisting understanding. However, it also demonstrates the highest variability in some areas (e.g., learning needs and effort). Despite lagging slightly in most categories, Application One generally performs well, showing consistency. Application Two demonstrated comparatively lower effectiveness, potentially due to the greater cognitive effort required from users to acquire knowledge.

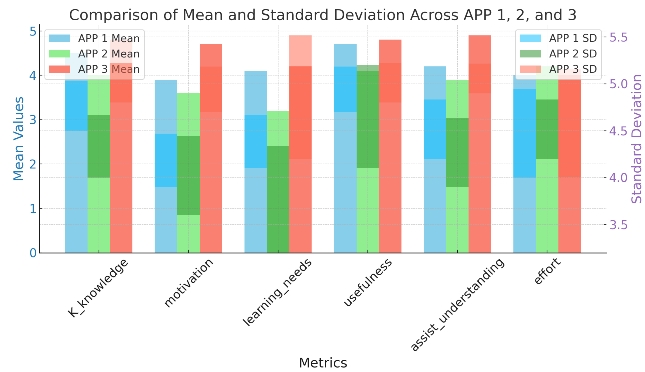

Figure 1: Descriptive Analysis of Three Applications

"Perceived knowledge acquisition" refers to the extent to which users feel they have gained knowledge or understanding through the experience. It reflects the their own assessment of how much they believe they have learned. We analyzed perceived knowledge acquisition's relationships with other variables based on the Pearson correlation coefficient, as show in Table4.

The correlation analysis demonstrates that perceived knowledge acquisition is significantly and positively associated with several key variables. The strongest relationships are with motivation $r = 0.711, p < 0.001$ and assisting understanding $r = 0.671, p < 0.001$, also, usefulness $r = 0.643, p < 0.001$ is moderately to strongly correlated with knowledge acquisition. Learning needs $r = 0.452, p = 0.012$ shows a moderate positive correlation. However, effort $r = 0.069, p = 0.718$ does not significantly relate to knowledge acquisition. This may suggests that while effort is typically considered a key factor in learning, other variables such as motivation and perceived usefulness may play a more substantial role. Therefore, more evidence is needed in future studies to better understand the role of effort and its potential interaction with other factors in influencing knowledge acquisition. Overall, these findings underscore the importance of motivation, usefulness, and support in understanding as critical factors in knowledge acquisition, while effort seems to play a lesser role.

4.2.2 Learning Outcomes Results. We recorded 30 pre- and 30 post-experience interviews, with 10 of each pre- and post-experience interview per application, totaling 60 interviews. Pre-experience interviews data revealed that all participants had no prior knowledge of the content. For analysing learning outcomes from post-experience interviews, a single coder coded the pieces of information from knowledge recall answers through whether the participants' answers were correct, whether they were general or detailed, and where the information was situated in the experience. For example: the colorful hut in Application One is very conspicuous in the snowstorm for the safety of the explorers, which is a specific piece of information situated at the beginning of the experience. Based on these initial codes, our inductive coding resulted in the identification of five themes on participant understanding, and by extension learning efficacy. **Specific Knowledge (SK):** Detailed, accurate information or in-depth understanding. **General Understanding (GU):** Basic or overall grasp of a concept, often with simple or broad

Table 4: Correlation Table for perceived knowledge acquisition and Other Variables

	knowledge	motivation	learning_needs	usefulness	assist_understanding	effort
knowledge	1	.711** <.001	.452* .012	.643** <.001	.671** <.001	.069 .718
N	30	30	30	30	30	30

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

answers. **Only Mention Keywords (OMK):** Responses that only include key terms without any elaboration or context. **Reflections (R):** Personal thoughts, insights, or evaluations about the learning experience or content. **Wrong Answers (WA):** Incorrect or inaccurate information provided.

Table 5 shows the themes, the number of participants whose answers aligned with each theme, and the frequency of recollections recalled by participants for each theme. Quotes are used to illustrate each theme, labeled with participant numbers.

Application One learning outcomes results Nine participants were able to recall specific and detailed knowledge, distributed across different parts of the experience. Application One, the most interactive application, allowing user interact with the tangible objects in VR environment, helped participants understand and remember relevant knowledge through these interactions:

"Like I said, the users actually interact with the content that they are learning about, so it makes it a lot easier to learn it because you can actually see and experience what they're talking about."[P5]

"I'll remember more with what I interacted with, like the videos and the binoculars."[P10]

Besides forming emotional connections with the cultural heritage they were observing, participants raised questions related to the learning content based on their contextual experiences. A common phenomenon observed was that they tried to resolve their doubts by exploring and observing the VR environment. A typical example:

"Yeah, I was looking around like, where's the bed? But I should assume the sleeping bag is, in that bag at the corner."[P6]

Table 5: Number of Participants and Frequency of Recollections in Specific Knowledge (SK), General Understanding (GU), Only Mention Keywords (OMK), Reflections (R) and Wrong Answers (WA) themes for three applications.

Theme	Number of Participants			Frequency		
	APP 1	APP 2	APP 3	APP 1	APP 2	APP 3
SK	9	5	5	25	14	14
GU	3	7	7	3	9	8
OMK	3	0	5	3	0	16
R	4	2	2	6	2	2
WA	0	1	1	0	1	1

Application Two learning outcomes results Application two presents the core information in a logical order. Half of the participants recalled specific knowledge from various parts of the experience. Most participants developed a general understanding of the concept of the "School House" and its contexts after the experience, which is largely based on the structure of the information presentation within the application. This is evidenced by the fact that five out of seven participants summarized the structure of the learning materials in their interviews. A typical example is:

"I remember it was about the first section was about Yugoslavia and how that broke down. And then it was about Kosovo under Serbia, about how those you know the harsh measures and things like that and the authoritarianism. And then it moved on to focusing on the school aspect, about how they set up their home schooling to get around the sanctions and things like that."[P16]

The UX results of Application Two revealed that system efficiency issues affected users' learning. Some participants experienced interruptions in focus or thinking due to delays or response issues:

"They (issues) were with the bottoms mainly. There was one part on the videos where I was trying to pause the video to like be able to read the text that was on there and It didn't feel like it responded. So I think I accidentally pressed it again and it went back, so I had to go back into it, through the video to get back to where I was. So it's mainly the buttons that were a bit funky."[P15]

When encountering system efficiency issues, more effort is required to handle them, which hinders the effectiveness of learning:

"I would say it might just be with my particular not version, but like this particular time of the buttons were tad bit finicky in terms of just actually like interacting with it with like my hands or like how it was scanned or whatever making it, just you know it took a lot more effort to push a button than I felt like it should have been to push a button sometimes. "[P11]

Application Three learning outcomes results The learning outcomes for Application Three in terms of SK and GU are almost identical to those of Application Two. However, the knowledge recalled by participants from it was focused on two specific areas inside the experience: the area where the king was seated and the statue area. Participants felt these visually impactful locations and immersion level aided their learning and memory retention:

"Just being in that particular room is enough to give you some insight and retention, for me at least... I think I won't forget that because it's there as a visual thing."[P21]

"The visuals and the maps are the main things because, I mean, usually when you learn, you don't feel like you are there. But I can clearly see, I mean when I'm describing that scene, I can clearly see the statues and the pond like I've been there." [P29]

Additionally, participants experienced Application Three mentioned keywords in their answers more frequently than those using the other two applications. This might be related to the placement of learning materials. For example, observing the surrounding environment helps extract fragmented information and remember keywords, but this often leads to a loss of attention to the narrator:

"Sometimes I do focus on what I'm looking at instead of listening to the audio. Sometimes I just go out of focus because I'm looking at the environment or when there's audio I have to listen." [P24]

"Sometimes I do get lost a bit with the words, but then I catch back up. Because I'd be focusing on what was around rather than what they were saying. But then I catch on." [P28]

4.3 Captured educational VR DCH Experiences

4.3.1 "the instrumental" Aspects. The "instrumental" aspects were evaluated through mixed methods. We categorized perspicuity, efficiency, and dependability aspects of UEQ and VMUXE scales, under instrumental aspects of UX evaluation. The MMGS scales tested the instrumental aspects of the guide, including usability, learnability, and quality of interaction.

The results indicate that users rated Application One the highest in terms of perspicuity (Mean=2.025), efficiency (Mean=1.450) and guide learnability (Mean=4.42), with minimal disagreement among participants. From the quantitative analysis results, most users were satisfied with the usability of Application One, which in turn facilitated specific learning aspects. For instance, the ease of use of the system and interface improved users' motivation and concentration during the learning process. In contrast, Application Two received the lowest efficiency score (Mean=0.575), users felt it required unnecessary effort to complete tasks. The system efficiency issues mainly stemmed from user interactions with the physical buttons, which were based on gesture tracking. Although physical buttons were used instead of a controller to create a new experience, users occasionally encountered problems when they moved. This movement caused a misalignment between the virtual buttons displayed in the headset and the actual positions of the physical buttons. As a result, users had to adjust their hand positions to "find" the correct button based on the virtual display, rather than relying on the physical location of the buttons. We also observed this issue in the UX quantitative analysis results: *"it took a lot more effort to push a button than I felt like it should have been to push a button sometimes."[P11]*

4.3.2 Other Three Aspects. The existing methods also captured the parts belongs to "beyond the instrumental", "emotion and affect" and "the experiential" of VR DCH experiences. MES provide evidence for "beyond the instrumental" through Engagement, Knowledge/Learning, and Meaningful Experience scales. Learning evaluation methods also align with the "beyond the instrumental", please refer to section 4.2.1. For the "emotion and affect", there is limited evidence, the 4DF question asked, "How much did you enjoy the experience?". When users respond to interview questions, they might mention their emotions, giving us a glimpse into their feelings. However, the data we gather lacks systematic depth. In the future, we are required to seek more evidence to better support this facet.

Among these aspects, stimulation, a significant hedonic quality in UX, plays a crucial role in VR DCH experience. The subjective experience of stimulation, as emphasized by VMUXE [11], is a 'driving power' for interaction and learning new skills and knowledge. Hassenzahl [13] proposed that this stimulation can be achieved by offering new, interesting, or exciting content, functionality, presentation, or interaction styles. The UEQ provides evidence in stimulation and novelty scales. Three applications scored similar level in these two scales in UEQ. The qualitative analysis results (A) provided more detailed evidence through five themes: New experience with using VR, New cultural experience, New DCH learning experience, Reflections and No new experience. The new VR experience, especially for first-time users, such as *"the aspect of being there isn't the real world has its own sort of charm"[P11]*, led to higher perceived stimulation. This was enhanced by the ease of use of the equipment, the visual elements, and the gesture tracking experience. Additionally, two other themes frequently mentioned as parts of stimulation were the new cultural experience (learning about unknown cultural heritage) and the new method of learning (using the VR DCH application). Our qualitative analysis suggests that participants who were able to recall specific knowledge also reported having one or more of these three types of new experiences. Another theme- Reflection, is more related to emotional connections to cultural heritage content— *"I do remember that they wanted to pioneer and like, instil pioneering spirit in other people and other stuff"[P9]*. However, users with prior VR experience might find it challenging to discover such stimulation. Thus, providing stimulating new experiences for these users is a crucial consideration for future educational VR DCH applications.

4.3.3 Pathways of Learning Impact From Experience. A single coder analyzed the data from 30 post-experience interviews to understand the learning impacts from the experience using VR DCH applications. The inductive coding process started with broad initial codes such as "assist remembering" and "helpful interactions" and evolved into more refined themes, which were then applied to the entire data set to ensure overall fit. Initially, the UX and LX evaluation results were individually coded to identify potential overlaps and distinct features, enabling a more detailed comparison of the unique and shared elements between the two areas. These results are presented in the Appendix and are not reported here for brevity. Following this, the coded results from both evaluations were organized and combined to provide a holistic view of the VR DCH learning, capturing insights from both the UX and LX perspectives.

Four typical themes were identified to explain learning aspects in the VR DCH experience(Table6). Quotes are used to illustrate each theme, labeled with participant numbers.

Understanding and Retention refers to the ability of learners to understand, remember and recall information or skills over time. From qualitative analysis results, understanding is related to diverse aspects, which including the design of the experience (application structure, interactions, recreations), learning materials settings (combination and balance of learning materials), flexibility (in choosing materials and controlling learning pace) and some UX attributes (immersion and interaction quality).

As previously explained in the learning efficacy results, it is evident in Application One's experience that useful interactions significantly aid users in remembering information and knowledge. On the other hand, useless or meaningless interactions can negatively impact users, such as causing disappointment and feel unnecessary:

Table 6: List of final themes

Theme	Sub Theme	Frequency	Participant number
Understanding and Retention	Easy for understanding the knowledge	19	P3, 4, 5, 6, 7, 8, 10, 11, 13, 14, 19, 20, 22, 24, 25, 26, 27, 28, 29
	Enhance remembering	5	P3, 7, 9, 10, 12
Concentration	Ability to maintain focused attention on learning content	12	P1, 5, 6, 7, 10, 12, 13, 16, 17, 20, 22, 29
	Distraction	10	P8, 9, 12, 14, 15, 16, 17, 20, 24, 28
Motivation and Engagement	Being motivated to learn	14	P1, 3, 4, 6, 7, 8, 9, 11, 12, 17, 18, 19, 21, 25
	Maintaining engagement in the context	6	P1, 4, 5, 9, 11, 20
Flexibility	Flexibility in choosing learning materials	15	P3, 4, 5, 6, 8, 9, 12, 13, 22, 23, 25, 26, 27, 28, 30
	Flexibility in controlling learning pace	14	P4, 5, 6, 8, 9, 12, 13, 14, 15, 17, 20, 26, 27, 29

"They made us turn on the mixer, but then nothing, nothing really happened."[P3]

"When I clicked on the mixer, it made a noise and it stayed for quite a while. It was interesting, but I kind of know what a mixer sounds like. I guess that's a little unnecessary."[P4]

In educational VR DCH experiences, immersion is another apparent factor impacting understanding and retention. Regardless of the three applications, the immersive reconstruction of heritage sites makes it easier for users to engage in the contexts and understand the learning content:*"I think it's very useful and helpful. Yeah. It can help us learn culture better and we can immersively go past the history to the exact area or something like that."[P29]*. Especially when the recreation itself is part of the information being presented, the visual stimuli help users remember the related information[P21] (see in the learning outcome analysis for Application Three (Section.4.2.2)).

Concentration In the context of VR for DCH learning, concentration involves maintaining focused attention on the immersive educational content, navigating the virtual environment, and interacting with learning materials without becoming distracted by extraneous elements. Multiple UX aspects are discovered to impact on learning concentration: Stimulation of new experience [P11], ease of use of the system [P13], learnability of the system [P6], engagement in VR context [P26]:

"And also just especially for people who haven't experienced XR or VR, the just the aspect of being there isn't the real world has its own sort of charm do it and that too also helps you to just become more engaged since it's, I don't know if that would wear off with time, like say, if you're doing this every day for school or something." [P11]

"it was very easy to focus on the content because again, the controls being so simple meant that you didn't have to think about it much, which let you focus a lot more on what you were being shown and it was displayed and shown in a very easy to understand and read way. And it was very well structured." [P13]

"it was very easy to learn and may made that I concentrate on listening to what was going on and looking around, and learning that sort of thing, with them to figure out pretty complex controls. " [P6]

"I think strengths maybe, since you're immersed in the In the 3D environment might be a bit easier to focus on the writing."[P26]

We found that interaction in educational VR DCH contexts is rich in meaning, stimulating learning behavior and providing entertainment, but it can also negatively impact concentration. During the learning process, users may occasionally get distracted, while exciting interactions related to the learning content can re-engage them effectively. Conversely, interactions, while engaging, can sometimes divert attention and interrupt the learning activities. These distractions, often stemming from the very interactions meant to enhance engagement, warrant careful consideration in optimizing the learning environment, which may led to mixed evaluations of the interaction among participants in Application One:

"...being able to hear what like the narrative said again would be useful, because sometimes I might like miss what they said and like interaction distracts it."[P1]

"I look out the window at the snow and that's like to me, I think that's just me distracting that little thing."[P5]

Meaningless interactions can cause negative emotions, such as disappointment and confusion. For example, Application One includes an interaction with a mixer to help users remember information about food preparation, but participants did not rate it highly: "That's a little unnecessary" [P4] and "Nothing really happened" [P3]. Quantitative data also showed that participants of Application One were not very satisfied with the interactions, particularly regarding interaction dependability and the quality of interactions with the guide, receiving the lowest scores among the three applications. While interaction can stimulate higher-order thinking [38], these complex findings highlight the critical need to balance interaction design when developing educational VR DCH applications.

Motivation and Engagement Motivation here refers to the user's desire to interact with the learning material. Although we allowed users to use the application for up to twenty minutes, not all participants were willing to continue learning for the full twenty minutes. In the VR DCH contexts, motivated learners are observed to be more likely to immerse themselves in the VR experience, actively participate in learning activities, and retain information more effectively:

"...inspire my motivation to learn it. I'd like to learn some new things and also new experience compared with other applications." [P18]

Stimulation of new experience enhance motivation:

"I definitely think within its current state now, especially if you're not familiar with it, it definitely helps to entice the learning, which is a lot more interesting that way. "[P11]

This stimulation primarily arises from the new experience of using VR devices for learning, which is different from traditional learning methods. From these perspectives, it is noted that the participants' motivation is closely related to whether the application they are using can stimulate new experiences.

The ease of use of systems also enhances motivation, especially at the initial stages of usage for those who have not had any XR experience before:

"There's just something that was really easy to get into it. So maybe that's what you do, find interest in. " [P17]

New technologies can bring about negative emotions[12], we found that it happens especially in the initial stages. Simple-to-operate applications can generate positive emotions and increase interest, as reflected by participants who found the system "really easy to get into", which helped them "find interest in" the application [P7]. An easy-to-use system allows learners to focus on content rather than interface issues. According to the UEQ and MMGS results, Application One received the highest feedback on ease of use and learnability. Participants had ample time to complete the experience, resulting in more diverse recollections and higher-level thinking. Participants' UX evaluation feedback of the three applications revealed that clear guidance, simple navigation, understandable user interfaces, and intuitive labels (e.g., highlights) reduce cognitive load and frustration, facilitating easier access to learning materials and better engagement in the learning environment. Additionally, usability issues were identified that could hinder user interaction and learning motivation. For example, in Application Two, delays in the response of tangible buttons made users feel less confident, participants rated lower efficiency scores (Mean=0.575) in the UEQ results. Systems that do not provide timely or informative feedback on user actions can leave users uncertain about the success of their actions. Clear and immediate feedback is essential for guiding users and reinforcing learning.

Useful interactions are also observed to enhance learner motivation. Application One allows users to interact with tangible items in the VR environment, making the experience enjoyable through entertaining interactions. These interactions are linked to learning material(e.g. if they pick up the menu on the table it triggers a video); after each interaction, a video or audio clip provides more information about an object. This engaging approach sustains and boosts users' motivation to learn -*"spend more time on the details and I want to know more things, more information" [P7].*

Engagement in educational VR DCH experiences is closely related to immersion and contextual learning. These three applications place users in realistic historical or heritage environments, enhancing learning focus and improving understanding and memory. This was most evident in Application Three, which received the most positive feedback for cultural engagement according to MES results. Qualitative analysis revealed that participants in Application Three were able to gather information from the context effectively through observation.

Engaged learners are more likely to be intrinsically motivated, meaning they are driven by an internal desire to learn rather than external rewards. This intrinsic motivation fosters a deeper commitment to the learning process. Engagement boosts learners' willingness to persist through challenges and difficulties, leading to a more sustained effort in learning activities; for example, when experiencing highly immersive applications, users may have questions while learning, and they will search for answers in the environment instead of giving up directly. Three participants in Application One observed the explorer's bedroom and concluded that "they might sleep in sleeping bags." This observation, made possible by immersion in the heritage site, did not increase their cognitive load but excited them. On the other hand, engaged learners are actively involved in the learning process, which helps maintain their attention and focus on the task at hand. This active participation can lead to better comprehension and retention of information.

Flexibility in VR DCH learning refers to user's adaptability. It involves creating flexible learning experiences that respond to diverse learning styles, paces, and goals. Evaluation results show that each user has unique learning needs, making it imperative for VR DCH experiences to deliver personalized learning that caters to these diverse needs. The qualitative data reveals that flexibility theme includes two aspects: learning materials and learning pace.

When users had the flexibility to select and control the learning materials that best suit their interests and needs, they would provide positive feedback. Application Two provide more flexibility to choose different materials, which enhances effective interactions with the system. Multiple users specifically mentioned this point for their beneficial learning, a typical example is: A participant pointed out application two have different options on images videos and text, *"sometimes and then I forget the stuff that I was reading before, but I think that the videos helped like to reassure the content that I read before."[P12]* This participant chose the suitable materials for themselves to overcome learning difficulties, and finally recalled correct detailed knowledge afterwards. The flexibility to choose and control learning materials not only affects the user and learning experience but also influences the ultimate learning outcomes.

Flexibility to select and control the learning materials also refers to free movement in VR contexts. This occurred more often in Applications One and Three, which offered virtual tour experiences. Recreations of the heritage sites themselves are the part of the learning materials, allowing users to engage more deeply, as one participant noted: *"being able to move around and get closer and inspect things easier "[P18].* Peoples observe environment and dig for deeper understandings.

Another way the system affects learners' learning efficacy is by allowing users to control the pace, enabling them to spend more time on challenging topics and move quickly through familiar material. Suitable learning pace are essential for learning activities, three participants using Application One reported that the reasonable pauses in the narrator's audio provided valuable time for learners to digest the knowledge. The following examples show the typical comments on the flexibility of learning pace for Application One (lower flexibility)[P9] and Three (higher flexibility)[P13]:

"The only weaknesses I'd say is maybe it's a narrative experience, you might not get to experience things at your own time and pace." [P9]

"It makes my brain a lot more receptive to it because I can go at my own pace."[P13]

In Applications Two and Three, users control their interaction with learning materials and decide where to allocate more time to achieve the desired learning effect. This personalized learning rhythm effectively alleviates stress and anxiety, fostering a more supportive and conducive learning environment.

5 Conclusion

This paper presents an experiment evaluating the experience and learning efficacy of three educational VR Digital Cultural Heritage applications. Revisiting the two research questions posed at the start of this study:

How does User experience and Learning experience impact learning in VR DCH?

The data analysis indicates a positive correlation between UX and LX, both of which jointly influence learning in VR DCH applications through four key aspects: understanding and retention, concentration, motivation and engagement, and flexibility. From UX perspective, a system that is easy to use allows learners to focus on the content rather than on interface issues. High system usability and ease of use enhance learning motivation and engagement, whereas low system efficiency reduces both motivation and concentration. Interaction plays a dual role: while it can provide enjoyment and help learners focus briefly, ineffective or overly simple interactions can have negative consequences, such as frustration or disappointment. In some cases, interactions may even lead to distractions, making it essential to evaluate both their relevance to the learning content and whether entertainment aspects might hinder learning effectiveness at certain stages.

Regarding learning efficacy, intrinsic motivation—driven by an internal desire to learn rather than external rewards—encourages deeper engagement in the learning process. This motivation is influenced by the perception of new experiences. Our findings suggest that learners who experienced more novel interactions also demonstrated better learning outcomes. Another critical factors highlighted by participants are the learning pace and the flexibility in using learning materials. They reported that unsuitable learning methods can detract from learning outcomes and efficiency. A clear example is Application One's fixed audio guide, which cannot be paused or replayed, causing learners to miss key content and only recall fragmented information rather than fully grasp the material.

What aspects of educational VR DCH experience do existing UX and learning evaluation methodologies successfully capture evidence for?

The results indicate that the existing evaluation methods used successfully captured experiences across Hassenzahl and Tractinsky's four UX facets. There was substantial evidence supporting "the instrumental" and "beyond the instrumental", and VMUXE qualitative data also supported "the experiential" facet through Stimulation section. However, for "emotion and affect", while some fragmented evidence exists, further research is required to better define and measure emotions within this context. Among them, "the instrumental" aspects were effectively captured by the UEQ, MES and MMGS ratings and VMUXE interview questions. The role of interactions and flexibility were strongly supported by evidence from both UX methodologies and Representation and Learner specific of 4DF. Moreover, UX and LX together encompass the evaluation of learning materials, as the VR environment not only represents the learning materials themselves but also serves as the interactive environment that facilitates learning.

Given that this study focused on three specific applications, the generalisability of the findings to other VR DCH learning applications requires further investigation. Additionally, the relatively short learning duration in this study limits our understanding of long-term learning processes, and future research should address these limitations by exploring phased learning and extended interactions.

References

[1] Mafkereseb Kassahun Bekele, Roberto Pierdicca, Emanuele Frontoni, Eva Savina Malinverni, and James Gain. 2018. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* 11, 2, Article 7 (mar 2018), 36 pages. https://doi.org/10.1145/3145534

[2] Keith Bowen, K Forssell, and Soren Rosier. 2020. Theories of change in learning experience (LX) design. *Learner and user experience research: An introduction for the field of learning design & technology. EdTech Books* (2020).

[3] Monica Clerici, Paolo Boffi, Pier Luca Lanzi, Lilia Coppola, Cristina Murone, and Alberto Gallace. 2022. One day in a Roman Domus: Human Factors and Educational Properties Involved in a Virtual Heritage Application. In *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct).* 692–697. https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00145

[4] Sara de Freitas and Martin Oliver. 2006. How can exploratory learning with games and simulations within the curriculum be most effectively evaluated? *Computers & Education* 46, 3 (2006), 249–264. https://doi.org/10.1016/j.compedu.2005.11.007 Virtual Learning?.

[5] S. de Freitas, G. Rebolledo-Mendez, F. Liarokapis, G. Magoulas, and A. Poulovassilis. 2009. Developing an Evaluation Methodology for Immersive Learning Experiences in a Virtual World. In *2009 Conference in Games and Virtual Worlds for Serious Applications.* 43–50. https://doi.org/10.1109/VS-GAMES.2009.41

[6] Sara De Freitas, Genaro Rebolledo-Mendez, Fotis Liarokapis, George Magoulas, and Alexandra Poulovassilis. 2010. Learning as immersive experiences: Using the four-dimensional framework for designing and evaluating immersive learning experiences in a virtual world. *British journal of educational technology* 41, 1 (2010), 69–85.

[7] John Falk and Martin Storksdieck. 2005. Using the contextual model of learning to understand visitor learning from a science center exhibition. *Science Education* 89, 5 (2005), 744–778. https://doi.org/10.1002/sce.20078 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/sce.20078

[8] John H Falk and Lynn D Dierking. 2000. Learning from museums. Walnut Creek.

[9] John H Falk and Lynn D Dierking. 2016. *The museum experience revisited.* Routledge.

[10] Xinyi Fu, Yaxin Zhu, Zhijing Xiao, Yingqing Xu, and Xiaojuan Ma. 2020. RestoreVR: Generating Embodied Knowledge and Situated Experience of Dunhuang Mural Conservation via Interactive Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>Honolulu</city>, <state>HI</state>, <country>USA</country>, </conf-loc>) *(CHI '20).* Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376673

[11] Bianca Gockel, Holger Graf, Alfonsina Pagano, Sofia Pescarin, and Joakim Eriksson. 2013. VMUXE. In *Design, User Experience, and Usability. Design Philosophy, Methods, and Tools,* Aaron Marcus (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 262–272.

[12] Arthur C. Graesser. 2020. Emotions are the experiential glue of learning environments in the 21st century. *Learning and Instruction* 70 (2020), 101212. https://doi.org/10.1016/j.learninstruc.2019.05.009 Understanding and measuring emotions in technology-rich learning environments.

[13] Marc Hassenzahl. 2018. *The Thing and I: Understanding the Relationship Between User and Product.* Springer International Publishing, Cham, 301–313. https://doi.org/10.1007/978-3-319-68213-6_19

[14] Marc Hassenzahl and Noam Tractinsky. 2006. User experience - a research agenda. *Behaviour & Information Technology* 25, 2 (2006), 91–97. https://doi.org/10.1080/01449290500330331 arXiv:https://doi.org/10.1080/01449290500330331

[15] Vedad Hulusic, Linda Gusia, Nita Luci, and Michael Smith. 2023. Tangible User Interfaces for Enhancing User Experience of Virtual Reality Cultural Heritage Applications for Utilization in Educational Environment. *J. Comput. Cult. Herit.* 16, 2, Article 38 (jun 2023), 24 pages. https://doi.org/10.1145/3593429

[16] Yan Jiang, Ruiliang Guo, Fenfen Ma, and Jinlong Shi. 2019. Cloth simulation for Chinese traditional costumes. *Multimedia Tools and Applications* 78 (2019), 5025–5050.

[17] Victor Kaptelinin and Bonnie Nardi. 2018. Activity Theory as a Framework for Human-Technology Interaction Research. *Mind, Culture, and Activity* 25, 1 (2018), 3–5. https://doi.org/10.1080/10749039.2017.1393089 arXiv:https://doi.org/10.1080/10749039.2017.1393089

[18] Mudassar Ali Khan, Sabahat Israr, Abeer S Almogren, Ikram Ud Din, Ahmad Almogren, and Joel JPC Rodrigues. 2021. Using augmented reality and deep learning to enhance Taxila Museum experience. *Journal of Real-Time Image Processing* 18 (2021), 321–332.

[19] Donald Kirkpatrick. 1996. Great ideas revisited. *Training & Development* 50, 1 (1996), 54–60.
[20] Donald Kirkpatrick and James Kirkpatrick. 2006. *Evaluating training programs: The four levels.* Berrett-Koehler Publishers.
[21] Markos Konstantakis and George Caridakis. 2020. Adding Culture to UX: UX Research Methodologies and Applications in Cultural Heritage. *J. Comput. Cult. Herit.* 13, 1, Article 4 (feb 2020), 17 pages. https://doi.org/10.1145/3354002
[22] George Lepouras, Ioanna Lykourentzou, and Antonios Liapis. 2021. Introduction to the Special Issue on "Culture Games". *J. Comput. Cult. Herit.* 14, 2, Article 11 (May 2021), 3 pages. https://doi.org/10.1145/3453690
[23] Yue Li, Eugene Ch'ng, and Sue Cobb. 2023. Factors Influencing Engagement in Hybrid Virtual and Augmented Reality. *ACM Trans. Comput.-Hum. Interact.* 30, 4, Article 65 (sep 2023), 27 pages. https://doi.org/10.1145/3589952
[24] Wenjun Liu, Charlie Hargood, Wen Tang, and Vedad Hulusic. 2023. User eXperience in educational eXtended Reality applications in the Cultural Heritage domain. In *Eurographics Workshop on Graphics and Cultural Heritage*, Alberto Bucciero, Bruno Fanini, Holger Graf, Sofia Pescarin, and Selma Rizvic (Eds.). The Eurographics Association. https://doi.org/10.2312/gch.20231184
[25] Yilin Liu, Yiming Lin, Rongkai Shi, Yiming Luo, and Hai-Ning Liang. 2021. RelicVR: A Virtual Reality Game for Active Exploration of Archaeological Relics. In *Extended Abstracts of the 2021 Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Austria) *(CHI PLAY '21)*. Association for Computing Machinery, New York, NY, USA, 326–332. https://doi.org/10.1145/3450337.3483507
[26] Zixiao Liu, Shuo Yan, Yu Lu, and Yuetong Zhao. 2022. Generating Embodied Storytelling and Interactive Experience of China Intangible Cultural Heritage "Hua'er" in Virtual Reality. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, Article 439, 7 pages. https://doi.org/10.1145/3491101.3519761
[27] Jörg Thomaschewski Martin Schrepp. 2020. *Handbook for the modular extension of the User Experience Questionnaire.* https://ueqplus.ueq-research.org/Material/UEQ+_Handbook_V2.pdf
[28] Xingbo Wei Letian Xie Lingyun Yu Ningning Xu, Yue Li and Hai-Ning Liang. 2024. CubeMuseum AR: A Tangible Augmented Reality Interface for Cultural Heritage Learning and Museum Gifting. *International Journal of Human–Computer Interaction* 40, 6 (2024), 1409–1437. https://doi.org/10.1080/10447318.2023.2171350 arXiv:https://doi.org/10.1080/10447318.2023.2171350
[29] Nicla Maria Notarangelo, Gilda Manfredi, and Gabriele Gilio. 2023. A Collaborative Virtual Walkthrough of Matera's Sassi Using Photogrammetric Reconstruction and Hand Gesture Navigation. *Journal of Imaging* 9, 4 (2023). https://doi.org/10.3390/jimaging9040088
[30] Mohd Kamal Othman, Helen Petrie, and Christopher Power. 2011. Engaging Visitors in Museums with Technology: Scales for the Measurement of Visitor and Multimedia Guide Experience. In *Human-Computer Interaction – INTERACT 2011*, Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 92–99.
[31] V Poriki, E Tse, K Panakoulias, E Toki, and J Pange. 2019. Digital games as tools for preserving and transmitting cultural and historical heritage: a case study. *ISCAR* (2019), 355–369.
[32] Laura Raya, José Jesús García-Rueda, Daniel López-Fernández, and Jesús Mayor. 2021. Virtual Reality Application for Fostering Interest in Art. *IEEE Computer Graphics and Applications* 41, 2 (2021), 106–113. https://doi.org/10.1109/MCG.2021.3055685
[33] Selma Rizvic, Dusanka Boskovic, Bojan Mijatovic, Ivona Ivkovic-Kihic, and Edo Škaljo. 2022. Learning about prehistory through interactive digital storytelling. In *2022 International Conference on Interactive Media, Smart Systems and Emerging Technologies (IMET)*. 1–4. https://doi.org/10.1109/IMET54801.2022.9929609
[34] Khyrina Airin Fariza Abu Samah, Mohd Nor Hajar Hasrol Jono, Al-Afiq Che Mohamad Zulkepli, Noor Afni Deraman, Shahadan Saad, Alya Geogiana Buja, and Lala Septem Riza. 2021. Immersive Virtual Reality in Preserving Historical Tourism. In *2021 IEEE 11th International Conference on System Engineering and Technology (ICSET)*. 234–239. https://doi.org/10.1109/ICSET53708.2021.9612577
[35] Elmedin Selmanović, Selma Rizvic, Carlo Harvey, Dusanka Boskovic, Vedad Hulusic, Malek Chahin, and Sanda Sljivo. 2020. Improving Accessibility to Intangible Cultural Heritage Preservation Using Virtual Reality. *J. Comput. Cult. Herit.* 13, 2, Article 13 (may 2020), 19 pages. https://doi.org/10.1145/3377143
[36] Lei Shi. 2014. Defining and Evaluating Learner Experience for Social Adaptive E-Learning. In *2014 Imperial College Computing Student Workshop (Open Access Series in Informatics (OASIcs), Vol. 43)*, Rumyana Neykova and Nicholas Ng (Eds.). Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl, Germany, 74–82. https://doi.org/10.4230/OASIcs.ICCSW.2014.74
[37] Po-Yuan Su, Peng-Wei Hsiao, and Kuo-Kuang Fan. 2023. Investigating the Relationship between Users' Behavioral Intentions and Learning Effects of VR System for Sustainable Tourism Development. *Sustainability* 15, 9 (2023). https://doi.org/10.3390/su15097277
[38] Andrew A Tawfik, Jessica Gatewood, Jaclyn J Gish-Lieberman, and Andrew J Hampton. 2022. Toward a definition of learning experience design. *Technology, Knowledge and Learning* 27, 1 (2022), 309–334.
[39] Anastasios Theodoropoulos and Angeliki Antoniou. 2022. VR Games in Cultural Heritage: A Systematic Review of the Emerging Fields of Virtual Reality and Culture Games. *Applied Sciences* 12, 17 (2022). https://doi.org/10.3390/app12178476
[40] Antarctic Heritage Trust. 2020. Antarctic Heritage Trust. https://store.steampowered.com/app/1193510/Antarctic_Heritage_Trust/. PC game.
[41] Sophia Vu, Daniel Cliburn, Jennifer Helgren, Joshua Salyers, Keely Canniff, Andrew Johnson, Mary Milliken, Tyler Reardon, Kyle Sabbatino, and Alicia Stephan. 2018. Recreating Little Manila through a Virtual Reality Serious Game. In *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)*. 1–4. https://doi.org/10.1109/DigitalHeritage.2018.8810082
[42] Flyover Zone. 2020. Hadrian's Villa Reborn: Stadium Garden. https://store.steampowered.com/app/1439360/Hadrians_Villa_Reborn_Stadium_Garden/. PC game.
[43] Åsa Fast-Berglund, Liang Gong, and Dan Li. 2018. Testing and validating Extended Reality (xR) technologies in manufacturing. *Procedia Manufacturing* 25 (2018), 31–38. https://doi.org/10.1016/j.promfg.2018.06.054 Proceedings of the 8th Swedish Production Symposium (SPS 2018).

A The List of UX/LX Coding Themes

UX Theme	Sub-theme	Counts	Participant number
Ease of use	Navigation; Ease of use in Navigation assist learner find information; Ease of use in navigation decreases the confusion in contexts with complex maps.	6	P4, P7, P10; P13, P20; P22
	Highlights assist ease of use in navigation	2	P7, P10
	Helps in concentration	2	P6, P13
	Ease of use in using triggers to interact with interface	2	P23, P28
	Ease of use improves learning efficiency	2	P23, P28
Learnability	Easy to learn the system enhances learning concentration	2	P13, P20
	Navigation	3	P22, P25, P30
Usability	Bad usability of hardware causes the distraction	2	P15, P17
Immersion and Engagement	Immediate immersion at the beginning enhances motivation and experience	1	P1
	Immersion enhances understanding; Immerse in XR contexts enhances understanding of text reading; Immersion of the context benefits learning.	5	P8, P11, P22, P26, P28
	High system efficiency enhances immersion	1	P5
	Visual aspects enhance engagement with information	1	P11
Navigation	Highlights assist ease of use in navigation	2	P7, P10
	Highlights or signs enhance the sense of safety in immersive contexts	1	P9
	Navigation; Ease of use in navigation assists learners in finding information; Ease of use in navigation decreases confusion in contexts with complex maps during learning	6	P4, P7, P10; P13, P20; P22
Movements	Lack of flexibility of movements decreases the experience	3	P4, P5, P6
	Free movement increases the flexibility of learning in detail	2	P26, P28
Learning materials	The balance of materials affects experience	1	P7
	Lack of flexibility of using materials causes distractions; Quick pacing of information display prevented user focus on learning	3	P8, P9; P14
	Efficiency of learning materials presentation affects experience, leads to negative emotions	2	P3, P9
	Balance of learning materials setting helps concentration	2	P1, P7
	Good learning resources display structure enhances understanding	1	P13
	Good structures and flows of learning materials improve learning efficiency	2	P17, P19
	Videos enhance concentration	1	P12
	Combination of different types of learning materials enhances learning experiences and efficacy	1	P24
	Informative layout: rich learning materials are fairly distributed across the map	1	P29
	Video is necessary	1	P30
	Fidelity of the images does not meet learning needs	1	P26
	3D Recreation of the environment improves presence	1	P28
	No highlight or tips leads to losing concentration	1	P22
Guide of application	No guide at the start causes confusion; the guide will improve ease of use	2	P21, P30
Learning paces	Reasonable pauses in audio help understanding; Reasonable learning paces assist in understanding	3	P10; P4, P6
	Flexibility of movement helps capture suitable learning paces	4	P4, P5, P6, P9
	Flexibility of learning pace enhances concentration	1	P29
	Control own learning pace by freely selecting maps	1	P29

Table 7: UX Themes

UX Theme	Sub-theme	Counts	Participant number
Interactions	Usefulness of interactions affects emotions and interrupts learning process	2	P4, P6
	Request interactions to enhance enjoyment	2	P1, P7
	Interactions with triggers (physical tools) enhance user's motivation; Interactions increase motivation	2	P6, P7
	Interactions to open relevant learning materials enhance learning motivation and positive emotions	3	P3, P6, P9
	Request useful interactions related to learning materials and information	4	P1, P3, P4, P7
	Interactions help user focus on the content	1	P10
	More effort in interaction reaction time (system efficiency) reduces user experience	3	P11, P13, P15
	Less interactions decrease learning efficiency	1	P27
Ease of learn at the beginning	Ease of learn helps beginners perform learning activities	2	P8, P9
	Ease of learn at the beginning helps users quickly concentrate on the content	1	P10
	Low learnability at the start causes negative emotions and inefficiency (need more time to familiarize with the application)	2	P22, P25
	Ease of use at the start facilitates motivation to learn	1	P17
VR headset	Heavy hardware affects experiences	1	P9
Design of steps and process	Too simple design of steps and process decreases motivation to learn and causes negative emotions (unsurprised, bored)	1	P7
	Design of steps and process is related to the structure of learning contents, affecting information acquisition	2	P6, P7
	Good design of steps and process helps foster a good learning pace, increasing concentration	1	P10
Design of XR contexts	Elements in XR contexts causing information barriers lead to distractions	4	P12, P15, P16, P20
Flexibility	Flexibility in movement (choosing learning materials) affects learning efficiency; Flexible learning pace enhances learning efficiency; Flexibility in movement helps control learning pace, improving efficiency	4	P3, P15, P20, P22
	Flexibility in choosing the material assists in controlling learning pace	1	P27
	High flexibility assists in controlling learning pace; Control own learning pace	3	P17, P26, P29
	Designs assisting in controlling learning pace are considered meeting the needs	2	P12, P17
	Low flexibility of learning pace has negative impacts on learning activities	1	P15
Nature of experience	The nature of the experience, "immersion," and "presence" facilitates motivation	1	P19
Accessibility of the information	Information (or learning materials) with low accessibility is considered unnecessary	4	P13, P14, P15, P19
	Information barriers cause distraction and confusion	1	P20
	Unnecessary steps to acquire information decrease learning efficiency	1	P19
	Usability affects accessibility of the information	1	P16
	Improving simultaneous accessibility of related information enhances attention	1	P13
Stability of the system	Instability of the system causes confusion	2	P11, P14
Distraction	Looking around leads to losing focus on audio	2	P24, P28

Table 8: UX Themes

UX Theme	Sub-theme	Counts	Participant number
New experience with using VR	Totally new VR experience with positive feedback	8	P2, P5, P8, P9, P16, P18, P20, P24
	Reflections on using XR applications in the future	1	P9
	Ease of use positively affects stimulation	1	P2
	Gesture experience (tangible interface)	1	P13
	Previous XR experience stimulates reflections on using XR for cultural heritage learning	1	P19
	Visual elements in cultural heritage	1	P26
New cultural experience	Motivation to learn more about cultural heritage after the session	1	P3
	New experience of knowing specific cultural heritage	6	P3, P6, P23, P25, P28, P30
	New cultural heritage presenting experience	3	P1, P5, P8
New cultural heritage learning experience	The new way of learning cultural heritage; Learning in VR contexts and listening to stories	11	P3, P7, P11, P12, P15, P17, P22, P25, P27, P28, P29
	The new way of learning increases engagement in cultural heritage learning	1	P11
	Inspires motivation	1	P25
	New experience of specific learning resources	2	P1, P6
	Boring learning content causes negative emotions	1	P18
	Information presentation methods	1	P29
No new experience	Users with previous experience with VR are less likely to experience novelty	4	P1, P3, P4, P10
	Ease of use of the system affects stimulation for users with previous XR experience	1	P10
	Low creativity of the experience decreases stimulation	2	P14, P15
	Boring elements (texts) decrease stimulation	1	P21
Reflections	Reflections on using this app this time	3	P21, P22, P26
	Reflections on using XR applications in the future	1	P9

Table 9: UX Themes

LX Theme	Sub-theme	Description	Counts	Participant Number
Understanding	Easy for understanding the knowledge	Application structure	1	P10
		Interactions with learning content make it easy to learn	2	P5, P13
		Visual elements and experience make learning easier	3	P5, P7, P13
		Visual elements and audio combine to assist in understanding	3	P24, P25, P29
		Recreations of the CH environment facilitate learning	2	P24, P25
		Flexibility in learning materials enhances understanding	1	P13
Flexibility in Movement	Flexibility in movement improves understanding	Need to observe objects from different angles in the virtual environment	1	P6
	Flexible learning pace helps understanding	Flexible learning pace helps users be more receptive to new knowledge	1	P13
Retention	Enhances remembering	Fun experience helps remembering through learning	1	P3
		Visual elements make it easier to remember than texts	1	P7
		Different types of learning materials reassure knowledge	1	P12
Captions	Captions will improve remembering	Need captions to improve remembering	1	P10
Unlimited Learning Time	Unlimited learning time will improve remembering	Need more time to remember a lot of information	1	P9
Concentration	Helps concentration	Application design helps avoid losing concentration	1	P10
		Engaging in the environment helps concentration	1	P5
		Immersed in virtual heritage environment helps focus on texts	1	P16
		Ease of use of the application improves concentration	1	P6
		Flexibility in learning materials enhances concentration	1	P13
		Interactions enhance concentration	1	P17
		New experience of using VR headset enhances concentration	1	P22
Concentration	Flexibility in movement improves understanding and concentration	Observing objects from different angles when the narrator is talking helps concentration	1	P6
Engagement	Immersed in the cultural heritage environment improves learning engagement		2	P4, P9
Learning Efficiency	Immersed in the VR environment and experiencing first-hand improves learning efficiency		1	P6
		Fixed learning pace increases time to learn, reducing efficiency	1	P8
		Well-structured and catalogued learning content enhances efficiency	1	P16

Table 10: LX Themes

LX Theme	Sub-theme	Description	Counts	Participant Number
Motivation	Using VR applications to improve CH learning motivation	Compared to traditional learning methods, VR experiences are more engaging and useful	6	P1, P4, P6, P8, P11, P18
		Visual stimulus improves learning motivation	1	P11
		Virtual cultural heritage contexts improve motivation	1	P12
		New experience of learning through VR enhances motivation	2	P18, P21
Emotional Connections	Recreations of the heritage site improve emotional connections		1	P9
Novelty	Compared to learning in a museum, this learning method is more novel and facilitates a new CH learning experience		1	P3
Emotions	Flexibility in movement reduces boredom		1	P6
Flexibility in Choosing Learning Materials	Providing flexibility in choosing learning materials enhances users' concentration and focus during learning		2	P12, P13
		Flexibility enhances understanding and makes learning easier	1	P13
		Different types of learning materials reassure knowledge	1	P12
		Enhance the ability to learn by utilizing various types of materials	1	P12
Flexibility in Learning Pace	Fixed learning pace increases time to learn, reducing efficiency		1	P8
		Flexible learning pace helps users learn at their own time and pace	1	P9
		Flexible learning pace helps users be more receptive to new knowledge	1	P13
		Flexibility in controlling the audio track (e.g., rewinding) assists understanding	1	P27
Flexibility in Movement	Flexibility in movement allows users to control their own learning pace		1	P27
		Observing objects from different angles in the virtual environment improves understanding and concentration	1	P6
		Being able to observe objects from different angles while the narrator is talking helps concentration	1	P6
Low Flexibility in Movement	Limited movement flexibility leads to missing details in the VR CH environment		2	P23, P30

Table 11: LX Themes

LX Theme	Sub-theme	Description	Counts	Participant Number
Learning Contents	Need more useful interaction to provide professional CH contents		1	P7
	Information quality and placement	Facilitate positive attitudes or satisfaction	3	P14, P15, P18
	More types of learning contents will improve learning engagement		1	P20
	More visual learning content will help understanding		2	P14, P19
	Need more details for deep learning	Meet different learning needs	1	P26
	Clear structure or categories		1	P14
Combining Text and Audio	Need combining text and audio to provide a comprehensive learning experience	A narrator is more effective than just text	1	P18
		Subtitles for the audio guide are needed to resolve any confusion	2	P27, P23
Storytelling	Add storytelling	Storytelling will improve learning experience more than description in a virtual tour	1	P29

Table 12: LX Themes