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Article

Should XR Applications Supplement or Replace History Excursions in Education?

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Abstract

Cultural heritages are important out-of-school learning sites in history lessons, but excursions are associated with high organizational effort for teachers. This article explores whether XR applications can replace or supplement school excursions. The Einhardsbasilika, a historical building in Michelstadt (Germany), serves as a case study. Building on the learning forms by Freericks et al., which are designed for the conceptualization of excursions, a VR application for location-independent exploration and an AR application for supporting on-site visits are developed and described. In a formative user study, 17- and 18-year-old students assessed the applications based on indicators that break down the learning forms by Freericks et al. into understandable indicators. This approach differs from previous studies, which typically compared only one XR application with a school excursion, without utilizing a unified didactic model. Our study, embedded within regular history lessons, concludes that XR applications should not fully replace excursions but can meaningfully complement them. Our results contribute to establishing a link between the game mechanics of an educational XR application and the learning forms by Freericks et al., providing practical recommendations for teachers on how to weigh up an excursion against XR applications.

1. Introduction

"The appeal of leaving the classroom and thus stepping out of the familiar school environment and everyday lessons is [...] strong. The wide range of learning opportunities outside of school relieves the pressure on one's lessons, providing an enriching addition that allows new motivation to be awakened in learners and gives them new inspiration." [1, p. 7]

Originally—in the sense of reform pedagogy—out-of-school learning was intended to evoke a connection to the reality of students' lives. If this dictum is consistently applied to today's digitalized society, the question arises as to what requirements an out-of-school learning site must meet today to have a place in the digital world of learners.

Freericks et al. [2] closely link out-of-school learning sites with experience orientation. Based on their findings, they derive four modern forms of learning [2, p. 13], which are given greater or lesser weight depending on the teaching objective. The choice is up to the teacher.

1. Explorative learning: Learners search for and transform information independently and construct knowledge through their activities.
2. Cooperative learning: Learners work or learn together in small groups towards a common goal. In addition to gaining knowledge, acquiring social and action skills plays an important role.
3. Hands-on learning/Holistic learning: In terms of teaching methods, this means learning that involves as many sensory channels as possible.
4. Self-directed learning: Learning takes place based on personal experience, in a self-determined and flexible way through situational learning opportunities.

1.1 The Einhardsbasilika as an Out-of-School Learning Site

The *Einhardsbasilika* in Steinbach (Figure 1), a district of Michelstadt in the German Odenwald, was built as a church in the 9th century. The three-nave and mostly single-storey basilica with a base area of 26 m × 26 m and an underground crypt is named after its builder *Einhard*. It is one of the best-preserved examples of Carolingian architecture in Germany. Over the centuries, the *Einhardsbasilika* has been used for various purposes, including a monastery, hospital, timber store, and museum, and has been rebuilt several times. Most of the original building substance has been preserved, which makes the *Einhardsbasilika* a valuable architectural monument. The building is listed as a cultural monument in the register of monuments of the Hesse State Office for the Preservation of Monuments. It is under the administration of the *Staatliche Schlösser und Gärten Hessen* (State Palaces and Gardens of Hesse) and is open to visitors from February to December. Information materials such as books and flyers are available in the nearby information center, and inside information boards focusing on the construction period. In addition, guided tours and audio guides are offered [3], [4]. The *Einhardsbasilika* has the potential to play an important role in local history lessons as an out-of-school learning site. However, it is mainly frequented by tourists, who are the main target group for the information material provided.

Figure 1. The *Einhardsbasilika* in Michelstadt, Germany [5].

1.2 Motivation and Structure of this Work

Freericks' forms of learning offer teachers guidance for planning a school excursion and enriching it with playful elements. However, preparing, implementing, and follow-up of an excursion is very time-consuming. In many cases, an excursion is only seen as a nice-to-have and cannot be integrated into the tightly scheduled timetable of students and teachers. Could a serious/educational game as an AR application simplify the implementation of an excursion or even move it completely into the classroom as a VR application? Could Freericks' forms of learning—actually intended as guidelines for a conventional excursion—also serve as guidelines for comparing an XR application with an excursion? This contribution explores these questions.

The following chapter provides a comprehensive overview of research in the context of school excursions and XR for cultural heritages. Chapter 3 introduces our self-developed VR and AR applications. Chapter 4 describes the practical implementation of the user study and Chapter 5 its results. The article concludes with a discussion and a conclusion.

2. Background

This chapter first describes the significance and challenges of traditional school excursions. It then discusses technical approaches and use cases of XR for cultural heritages. Section 2.3 describes didactic models for cultural heritages and XR applications and the following section presents the results of studies on the trade-off between a (school) excursion and XR applications. The chapter concludes with identifying knowledge gaps, deriving research questions, and describing the study design.

2.1 School Excursions

Traditional school lessons, especially history lessons, are often perceived by students as boring and lacking relevance to everyday life [6]. Out-of-school learning sites offer welcome opportunities to complement school lessons. Visiting and viewing a monument on-site offers in-depth possibilities for an affective-emotional approach to history. They present an opportunity to make history lessons more engaging and spark students' interest in history. In particular, dealing with regional history using existing historical buildings contributes to students' identity formation [7, p. 73].

The benefits of school excursions for students of all ages have been very well-researched [6]. However, preparing an excursion to an out-of-school learning site can be time-consuming. Many teachers shy away from the organizational hurdles, such as planning the journey, organizing the trip on-site, and dealing with questions of cost coverage. [6] pointed out that local heritage sites rarely fit into the given curriculum and must be sufficiently contextualized by a teacher as part of an excursion.

The concept of gamification offers an opportunity to teach content playfully, thereby motivating and activating students. Numerous studies on this exist, for example [8]. The spectrum ranges from integrating gamification elements into conventional lessons to the use of extensive serious games such as video games. Gamification is more important in museum education than in conventional history lessons at schools [9, p. 340].

2.2 XR for Cultural Heritages

[10] suggested that cultural heritage, in the classical sense of buildings, can be understood as a kind of geometric shell that can be flexibly enriched using immersive technologies. XR is understood as a collective term for augmented reality (AR), virtual reality (VR), and mixed reality (MR). These techniques can help to strengthen the relationship between cultural heritages and the visitor and bring a place to life [9, p. 340]. Platforms such as *Google Arts &*

Culture [11] aim to replace a museum visit. For this purpose, curator tools are provided with which the 3D cubature of a building and (panoramic) images can be enriched with further information. A virtual museum tour is usually realized as a web application for desktop PCs or mobile devices, sometimes also for specific XR hardware. A user can more or less independently visit individual locations in a selected area digitally. They often move through a building from a first-person perspective and can view exhibits, while text information, images, or videos are also displayed. Movement is often implemented by jumping between adjacent 360° panoramas. With the widespread availability of XR hardware, such virtual museum tours have become more sophisticated, increasingly incorporating serious gaming elements [12], [13]. During the coronavirus pandemic, when many museums were closed, virtual museum tours attracted particular attention [14]. There are now also frameworks specifically for use in school lessons [15].

Numerous examples of individually developed VR and AR applications for exploring cultural heritage sites exist [16, p. 432], addressing tourism and formal education. User studies investigate how users respond to the applications and whether learning objectives are more likely to be achieved with educational applications than with conventional, often analog teaching methods. Overall, these study results are very promising and demonstrate the advantages of using VR & AR [17]. In 2022, [18, p. 1] found 17 studies on the comparative use of VR and AR concerning learning achievements. However, these applications are related to museums and not to heritage sites in general. A comprehensive study concluded that AR applications are significantly more common in museum education than VR applications, as they enable a better fusion with the real environment than VR [18, p. 8]. [17] described AR as beneficial for school lessons, as it conveys abstract concepts vividly, which leads to increased student motivation and better learning progress. Systematic evaluations of various AR and VR applications for virtual museums can be found in [19] and for cultural heritages in [20, p. 373].

[21] have compiled various studies on headset-based XR in the cultural domain and concluded that 71% involved a VR application (MR: 20%, AR: 9%). There are also extensive considerations for individual forms of XR, for example by [22, p. 62] for VR systems. As technology advances, the question of the technical differences in the hardware available for VR & AR arises again and again. More recently, there have been examples of studies comparing different forms of XR for cultural heritages. One of the first were [23], who developed a multimodal VR/AR web application. [20, p. 373] examined various XR implementation options for their interaction, manipulability, ease of use, and other factors. [24] developed a VR application focusing on a specific period of modern Italian history and provided an environment with multiple points of interest (POIs). They also developed a corresponding smartphone application and concluded that smartphones offer a more user-friendly interface for accessing cultural heritage information than a VR headset.

2.3 Didactic Concepts relating to XR and Cultural Heritages

Following the rather technical look at XR for cultural heritages, the underlying didactic model will now be discussed. However, research in which XR applications for excursions to cultural heritages in formal education are related to a didactic model is scarce. In particular, there are no publications that refer to Freericks' four forms of learning. Only [10] mentioned four cognitive aims for VR applications (knowledge acquisition, critical thinking, rational reasoning, interpersonal communication), which roughly go in the direction of the learning forms formulated by Freericks et al. [2]. At least in theory, the aspect of collaboration has been considered. In this context, the concept of Computer-Supported Collaborative Learning (CSCL) is worth mentioning [25, p. 21].

[6] found that it is crucial to understand users' emotions, as these have a significant influence on the teaching-learning process. For an AR application for cultural heritage tourism, [26] referred to Kolb's Experiential Learning Cycle [27], a model for digital learning. It comprises

the following steps: concrete experience, reflective observation, abstract conceptualization, and active experimentation. [28] systematically reviewed didactic models for heritage education and concluded that heritage education processes revolve around four didactic models: context, content, the teacher role, and the learner role. However, these models are not linked to XR. The authors [29, p. 6] have identified the possibilities that different immersive reality technologies (AR, VR, augmented virtuality, and mixed reality) have for relationship, collaboration, and engagement. Their work represents a general, more technical approach. A holistic approach was taken by [25, p. 17], in which a single, extensive use case from the field of museum education was selected. Based on this, a comprehensive theory of instructional design, the so-called Mixed Reality Museum Co-Visit Theory, was developed [25, p. 158].

2.4 Comparing an Excursion with XR Applications

[30] presented their 'excursion-game' (an educational game, that is not XR-based), with which 10–13-year-old students should have more engagement during a visit to historical sites. [6] conducted a study to weigh up a visit to a museum against the use of a corresponding VR application. They focused on usability, learning outcomes, and emotional responses. The teachers' perspective was also taken into account concerning the organizational effort. They concluded that VR leads to more motivation but slightly fewer learning outcomes than a museum visit. [31] compared virtual field trips with 360° videos to a real field trip and analyzed attitude, perceived usefulness, inquiry, and involvement. Their study with 8–9-year-old students showed slight advantages of 360° videos over a real field trip. [32] conducted a study where participants visited a heritage site in Portugal via VR and compared the experience with an actual visit. The authors concluded that their VR application should be a supplement rather than a substitute for a 'real' travel (the focus was on tourism).

2.5 Knowledge Gaps

While the aforementioned studies have already provided a considerable amount of insight into the interplay between XR, school excursions, and didactic models, there are still unresolved aspects. The XR applications were mostly initiated by people who are close to a museum or cultural heritage institution but do not work at a school. We conclude from this that application concepts are needed that take the teacher's perspective more into account. The technical equipment in schools is often inadequate and the knowledge of software and hardware that is usually a prerequisite for XR is not guaranteed. To enable a teacher to plan the content and organization of lessons, a potential XR application should be reliable and flexible for different teaching settings. This flexibility could be achieved with the help of curator tools, with which a teacher can independently insert or adapt the teaching content of an XR application. If these requirements are not implemented, the question of the possible substitution of an excursion by an XR application in the stressful school day remains a theoretical one. Corresponding considerations were only taken up by a few authors such as [31]. A third alternative is completely ignored: dispensing with an excursion and XR application and instead approaching a cultural heritage exclusively using conventional teaching materials in the classroom.

While comparative studies on various forms of XR such as VR and AR do exist for museums, school excursions have so far only been compared with a single form of XR. In the few studies in which a school excursion was compared with an XR application as part of a user study, the XR application was intended for single use. In our view, a direct comparison should be performed using small groups, as this form is common in excursions. It is explicitly expressed in the learning form 'cooperative learning' according to Freericks et al.

In the case of smartphone AR applications, it becomes apparent that they usually contain POIs that are linked to the real world using QR codes. There are now solutions such as the AR software development kit (SDK) *Immersal*, which do not require QR codes for positioning and therefore do not restrict the user's freedom of movement as much.

Freericks' forms of learning are an independent didactic model relating to school excursions. As shown in Section 2.3, only rudimentary, more functional-technical didactic models exist for XR applications in formal education. To adequately compare an XR application with an excursion, we consider it important to base all of them on the same didactic model. Since the excursion is the 'benchmark', Freericks' model should be favored. The individual game mechanics and key aspects of an XR application could be assigned to the four forms of learning. In the evaluation, the assessments of the game mechanics could be related to their addressed forms of learning, making the application highly comparable with the real excursion. This approach has not yet been pursued by anyone, which in our view represents the largest knowledge gap alongside the other aspects described.

2.6 Research Questions

The evaluation of the studies mentioned in the previous sections was mostly carried out by surveying the learning success of students and their engagement. However, the four forms of learning according to Freericks et al. illustrate that the sought learning outcomes when visiting an out-of-school site are only one of many goals. The four forms (explorative learning, cooperative learning, hands-on learning/holistic learning, and self-directed learning) are much broader and, in our view, cannot be adequately characterized/evaluated using the term 'engagement'. The question therefore arises as to whether the conception and evaluation of a (serious gaming) XR application for an out-of-school site should rather be based on the forms of learning according to Freericks et al. These thoughts are the basis for our first research question:

- **RQ1:** To what extent can the game mechanics of a VR/AR application in formal education be traced back to the four didactic forms of learning according to Freericks et al.? Is it possible to derive suitable indicators from the learning forms that could later be used to evaluate the applications provided to the students?

In our view, it is crucial to establish suitable indicators that will enable the students to evaluate the applications. Instead of the didactically motivated and abstract forms of learning, the students should evaluate the site based on predefined indicators (e.g. 'exciting' or 'encourages discovery'). However, only a coherent derivation of indicators from the learning forms allows the students' answers to be related to the implementation of the learning forms and thus to the conception of the application(s). Assessing learning outcomes becomes a secondary concern, as the learning forms are more general and cannot be tested in the same way as explicit teaching material.

As elaborated in Section 2.5, there are no studies in which a school excursion is weighed against several forms of XR simultaneously in one study. On this basis, we formulate a second research question:

- **RQ2:** How do students and teachers view the supplement or even replacement of a historical school excursion with the (combined) use of a VR/AR application from a didactic and organizational perspective?

An extensive school excursion including a preparation and follow-up that may take place independently of each other in terms of time and location shows that the question "XR application or excursion?" would be too narrow. Therefore, based on RQ2, it should also be investigated whether a combination of a conventional excursion with a VR/AR application for preparation or follow-up would be useful.

2.7 Study Design

The *Einhardsbasilika* and its thematization in the history lessons at a school with 17- and 18-year-old students is the basis for addressing RQ1 and RQ2.

To answer RQ1, a VR application for location-independent exploration of the *Einhardsbasilika* and an AR application to support an on-site visit were developed. To enable students to compare the applications with an on-site excursion, the applications are deliberately kept basic and essentially depict the use cases that could be meaningfully implemented didactically during an on-site excursion (free exploration, group assignment, 'scavenger hunt'). Due to this adaptation, there was no need to develop a storyboard-led concept as in [9, p. 342]. The implemented game mechanics and other key aspects of the applications were then linked to the learning forms by Freericks et al. (Chapter 3) and appropriate indicators required in RQ1 were formulated (Section 4.1). With these, the students can characterize the *Einhardsbasilika* as an analog and digital excursion site, which makes it possible to evaluate/weigh up the XR applications.

To answer RQ2, the aim was to integrate the applications into a complete lesson, including preparation and follow-up. Our study has the character of a formative study with a comparatively small number of participants. While museums and operators of cultural heritage sites can conduct larger user studies (for example [17], in which 245 students were part of a study in a telecommunications museum over a whole year), this is not possible at a school: school excursions in history rarely take place. They are planned and conducted individually by a teacher for one class, i.e. around 20 students. On the other hand, the students can be accompanied for over 90 minutes, extensive feedback can be collected from them and the student-teacher interaction can be examined comprehensively.

However, it is impossible to test a VR application and an AR application and also carry out a school excursion for comparison within the scope of a 90-minute history lesson. More time cannot be granted due to the narrow curriculum of history taught as a school subject. For the user study, it was decided not to visit the *Einhardsbasilika*, but—as it can be assumed that many students at the local school are familiar with this building—to focus on integrating the VR application into the lessons. This means that the class is not split up like, for example, in the study by [6] where half of the class visited a museum and the other half took a virtual tour.

As our AR application is intended for use on-site, it can only be evaluated conceptually by the students. As they do not actively try out the AR application, unlike the VR application, we have to accept compromises when answering the research questions. However, the lesson facilitates all students to try out all planned teaching methods (VR application, AR application conceptually, worksheets) in practice and compare them individually in a concluding survey. This has not been done in previous studies like [8] and is a unique feature of our study.

3. Developed Applications

As part of a digitization project, the *Einhardsbasilika* was scanned with a drone. In addition, laser scanning was carried out inside. As a result, a 3D exterior model as well as a point cloud, and a 3D model of the interior were available. The walkable interior model represents the graphical environment of the VR application. The aim was also to combine the exterior and interior models. However, this was not possible because the 3D exterior model was calculated by the manufacturer-specific software of the drone used and the faces and vertices had interfering overlaps with the interior model which was processed using *Blender*. Therefore, the application primarily enables the basilica's interior to be explored. This also includes the underground crypt, which is accessible via a staircase on the outside of the basilica. For the AR application, only the geometric reference for tracking was required, without displaying the actual geometry of the basilica. The *Immersal Mapper* smartphone app was used to capture the geometry specifically for mobile AR tracking. Both applications were developed using the *Unity* game engine. Figure 2 shows the accessible areas (all rooms of the basilica and the surrounding grounds) in the VR application. The same areas can be explored on-site and therefore within the AR application.

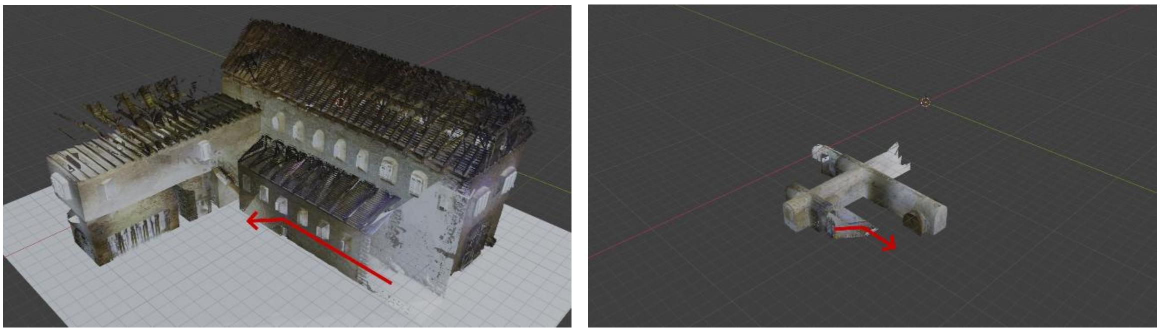

Figure 2. Left: Interior model of the *Einhardsbasilika* with textures projected onto the outside. The red arrow represents the staircase leading to the crypt. Right: The underground crypt.

As [18] found out, superimposing supplementary materials is the most common application design of XR applications in the field of cultural heritage. We also used this design principle and compiled learning content for the applications from the brochures available on-site and information from publicly accessible databases. The data basis for the preparation, follow-up, and implementation of an on-site excursion would be the same. On an excursion, after a short introduction, a teacher would divide the class into small groups and let them explore the basilica independently with a work assignment. This group work can also be achieved using the two applications, with one student operating the application and relying on the cooperation of the other group members.

The VR application was designed for the HTC Vive. At the school where the user study was conducted, corresponding VR stations are available. The AR application is intended to support an on-site visit and was designed for smartphones. This makes it a bring-your-own-device (BYOD) application. Figure 3 illustrates the concept of the VR and AR application.

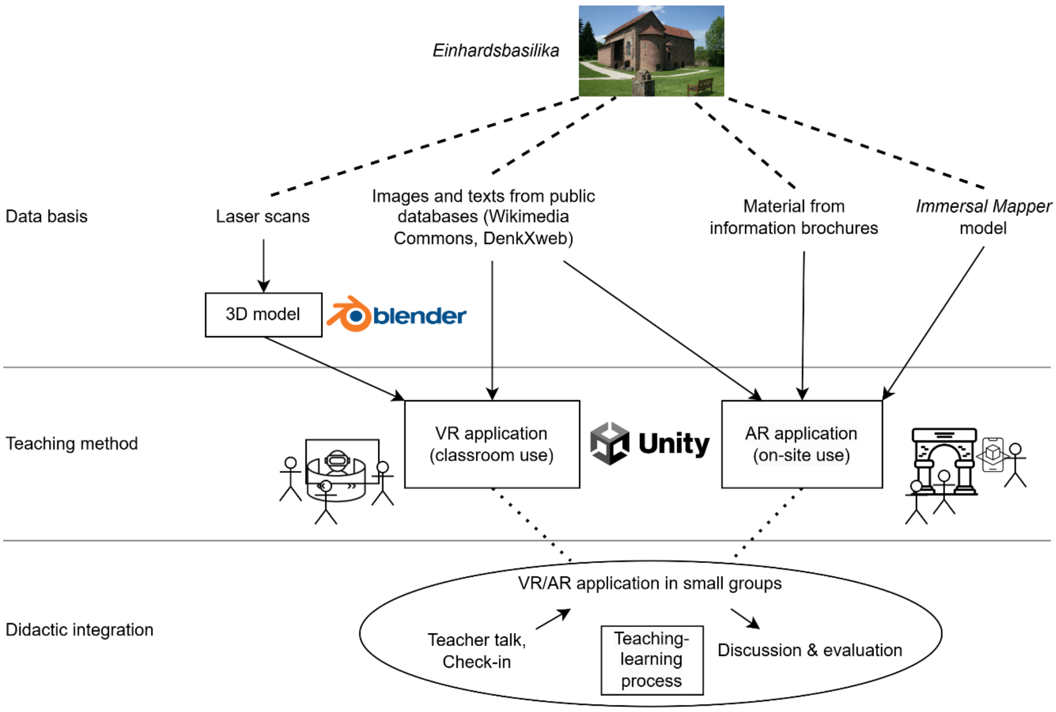

Figure 3. Concept of the VR and AR application.

The VR and AR applications are presented in the following sections. Their concept and game mechanics are listed in tabular form and—as far as possible—linked to the forms of learning according to Freericks et al. Afterward, key aspects of the applications and the gameplay are described.

3.1 VR Application

The VR application enables students to explore the *Einhardsbasilika* from any location. Table 1 provides an overview of the implemented game mechanics of the application. It shows that the application primarily reflects self-directed learning and explorative learning.

Table 1. Concept and game mechanics of the VR application.

Aspect	Category	Learning form according to Freericks et al.	Explanation
VR navigation	Game Mechanics	Explorative learning	The player can use the teleport function to move freely through all the rooms of the *Einhardsbasilika*, the crypt, and the grounds around the building.
Creating an information point (teacher)	Preparation	–	A teacher can arrange texts and images at freely selected locations within the application as so-called information points. Texts and images can be crawled from public databases or chosen from local files. A save file allows to save and load scenarios, meaning individually arranged sets of information points.
Interacting with information points	Game Mechanics	Explorative learning, Holistic learning	The player can grab, move, and scale texts and images using VR controllers.
To-do list	Game Mechanics	Self-directed learning	If a save file containing information points is loaded, their number and the number of information points already found are displayed.
'Game accomplished'	Game Mechanics	Self-directed learning	Once all information points have been found, a fireworks effect and the message "Tasks completed!" appear.
Creating an information point (student)	Game Mechanics	Self-directed learning	Students can also create new information points during the game, just like teachers.
Menus	UI	–	Menus, in the more specific sense, are only used for setting up an information point. The player interacts with them using the controllers. Texts can be entered using a virtual keyboard.
Group work	Didactic integration	Cooperative learning	If the application is used within a small group, one person can operate the application and the others can view what is happening on a monitor. Finding information points and viewing the texts and images requires the cooperation of all group members.

3.1.1 Curator tool

The technical basis of this VR application is a developed workflow with which building-related data is found using web crawling and automatically linked to the 3D model of a building [33]. A curator tool was developed for the application, which enables a teacher to enrich the interior model of the *Einhardsbasilika* already in VR mode with texts and images from freely accessible databases. Such immersive content creation tools can in principle also be aimed directly at students [34], which, for example, [8] have implemented with their 'History Maker VR' application. Based on the concept of web crawling, we finally included a web scraping option within the application.

Web scraping describes the process of retrieving specific information from the web. Here, a specific code tailored to the page to be searched is executed to ‘scrape’ the desired data from the web [35]. For the VR application, the *Beautiful Soup 4* web scraping library was used, cf. [36]. It contains functions for parsing HTML and XML documents as well as methods for iterating, searching, and modifying the given source code. It was investigated which websites contain easily retrievable and at the same time reliable building-related metadata about the *Einhardsbasilika*. The choice fell on *Wikimedia Commons* and *DenkXweb*.

Wikimedia Commons [37] is operated by the non-profit *Wikimedia Foundation* and is an online library with more than 100 million images, photos, videos, and audio files. *DenkXweb* [38] is a publicly accessible database from the Hesse State Office for the Preservation of Monuments. It contains detailed information on buildings and entire complexes of the state of Hesse, including the *Einhardsbasilika*. The mechanics for invoking the web scraping can be called up via a menu, which can be shown and hidden as a 3D object (Figure 4, left).

With the help of a drop-down menu and a text input field, all listed buildings from the *DenkXweb* database can be found and selected. All linked text and image data from *DenkXweb* and additionally those of the same building from *Wikimedia Commons* can then be found and loaded into the VR environment (Figure 4, right).

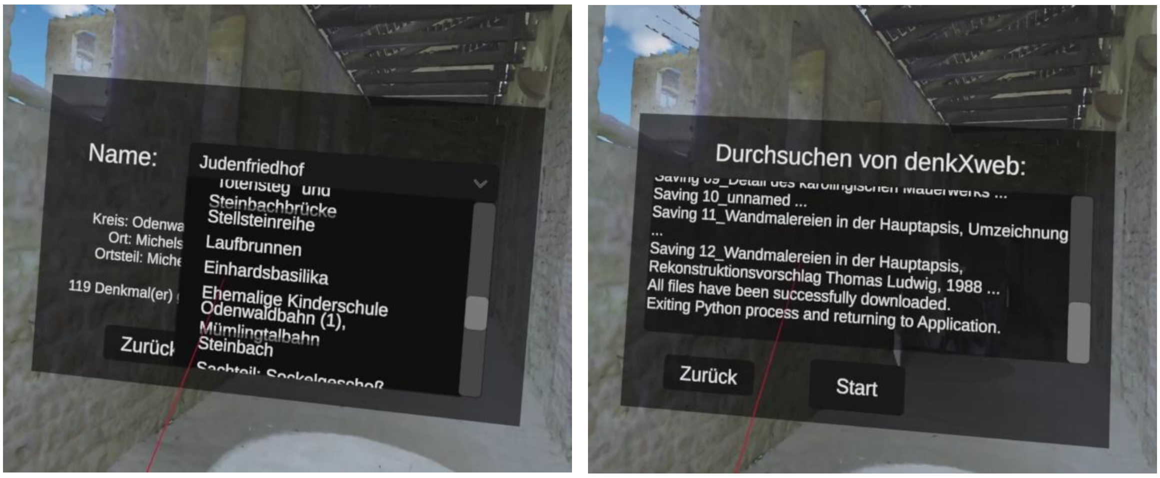

Figure 4. Left: Selecting a building listed in the *DenkXweb* database within the VR application (in detail: Searching for the *Einhardsbasilika* in all entries for the town of Michelstadt which belongs to the Odenwald district. 119 buildings were found). Right: Through web scraping, data from *DenkXweb* and *Wikimedia Commons* is retrieved and stored in the VR environment (Translation: “Search *DenkXweb*”).

The core functionality of the application is that the user (in our workflow the teacher) can select this text and image information individually in an overview and compile it in so-called information points (Figure 5). These information points can be placed in different locations, making it possible to create a virtual tour. In addition, teachers can add individual texts and images to the 3D model. To do this, the additional media must be stored in a specific Windows folder. They can then be called up together with the other scraped media within the VR application. The created information points are stored in a JSON file. This file has the function of a save file, allowing a prepared teaching scenario to be saved.

Figure 5. Left: Selecting one of the retrieved images to create an information point. Right: An information point including two images and additional text arranged by the teacher.

3.1.2 Gameplay

A user interacts with two controllers in the VR application. The teleport function allows the user to move freely around the interior and exterior of the *Einhardsbasilika*. All contents of the information points behave like floating 3D elements, which the user can grab and move (Figure 6). Even these simple interaction options allow numerous use cases for history lessons. For example, students can work on assignments using information from the information points, they can go on a virtual tour and analyze historical text and image sources in the context of the building, carrying out a source analysis.

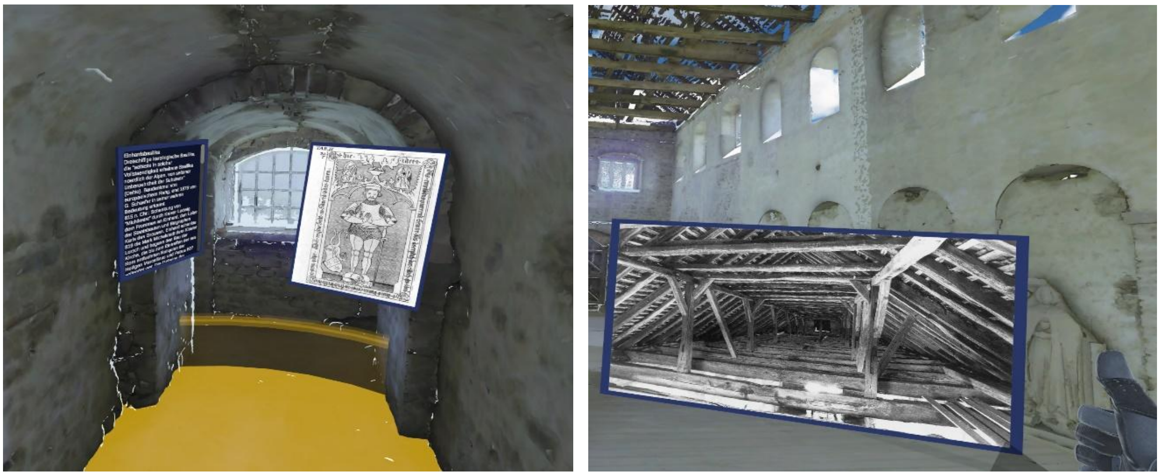

Figure 6. Left: An information point of one custom image and additional text arranged inside the crypt of the virtual *Einhardsbasilika*. Right: A user can grab and move elements, for example, to compare images with the surroundings.

A simple reward system has also been implemented. If a user explores all available information points, a text message and simplified fireworks appear (Figure 7). To provide an overview of progress, the number of total and already explored information points is continuously displayed on the right-hand controller.

Figure 7. Left: Indication of the progress in exploring information points. Right: Once all information points have been explored, fireworks and the message “Tasks completed!” appear.

3.2 AR Application

In 2016, the AR game ‘Pokémon Go’ was released. Its users aim to catch small monsters (Pokémons) as soon as they appear as augmented objects in the real environment. There are also ‘Pokéstops’ where players can collect special items. Pokéstops are often located at places of interest or other special locations. At these locations, players receive information about them. The social component also plays an important role, as the game places its users in direct competition and enables them to compare themselves. The technical concept of this popular game served as inspiration for our AR application. Table 2 provides an overview of the concept and game mechanics. It shows that the application primarily addresses explorative and self-directed learning.

Table 2. Concept and game mechanics of the AR application

Aspect	Category	Learning form according to Freericks et al.	Explanation
AR tracking	Game Mechanics	Explorative learning	The player can move freely with the smartphone in and around the *Einhardsbasilika* and in the crypt, as tracking is provided in these areas using the *Immersal SDK.*
Menu for selecting destinations	UI	Self-directed learning	The player can select rooms or prominent items from a list using touch interaction on the display and is then navigated to these locations.
Arrows on the ground	UI, Game Mechanics	–	Blue arrows on the ground visualize the shortest path between the player's position and the chosen destination.
Success feedback	Game Mechanics	Self-directed learning	When a destination has been reached, a short text message appears.
Displaying (learning) content	UI, Game Mechanics	Explorative learning	If the player approaches a prominent location—whether selected as a destination or not—to less than three meters, text and image information about this location is displayed.
Group work	Didactic integration	Cooperative learning	If the application is used within a small group, the smartphone can be passed around or content can be read out loud and discussed together

3.2.1 Tracking

A large number of AR applications in the field of cultural heritage use AR reference targets that a user has to scan. Examples are QR codes as in the applications of [17] and [23]. When comparing several educational AR applications, [19] found that many of them rely on *Vuforia*, which means that individual images can also be used as AR reference targets. On the other hand, geolocalized AR applications such as CaldanAugmenty [9, p. 339] are suitable for larger outdoor areas. The authors of that application point out that existing GPS AR applications are mainly aimed at tourists and less at young people. Indoor tracking without reference targets can be realized using Bluetooth beacons attached to the ceiling. However, there are only a few examples of this complex procedure, such as [25, p. 82].

The *Einhardsbasilika* is a medium-sized building, primarily composed of a large hall and adjoining rooms. It can be completely walked around. The wall is mainly made of coarse stones to which markers cannot be attached. The navigation and positioning of the AR application were finally implemented using the *Immersal SDK* [39]. For this purpose, the *Immersal Mapper* app was used to record the interior and exterior of the *Einhardsbasilika*, thereby generating a coarser-resolution point cloud model that allows position matching invisibly to the user. When the user starts the smartphone application, the camera image is continuously compared with the stored point cloud model. If the user is within the site of the *Einhardsbasilika* and the initial tracking has been established, brief user feedback is provided.

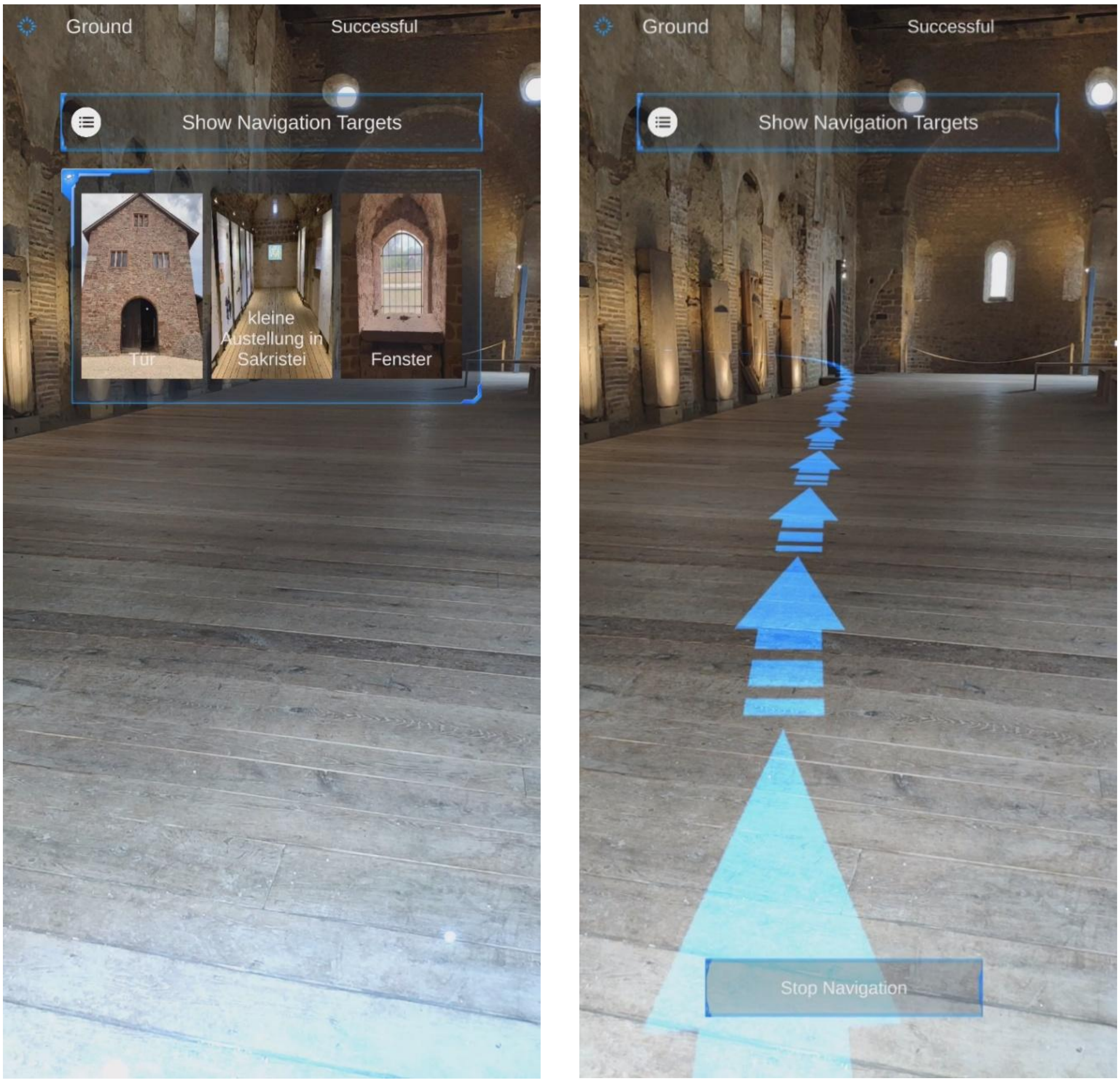

Figure 8. Left: Selecting a waypoint. Right: Blue arrows mark the route to a selected waypoint.

If the positioning is lost for a short time later on, the user is also informed. During use, the application appears to the user like a GPS AR application with a higher accuracy of up to approximately 0.5 m. The tracking is therefore not suitable for overlaying the environment with AR content with centimeter accuracy but is more than sufficient as navigation support.

3.2.2 Gameplay

In coordination with a teacher, five distinctive points in and around the *Einhardsbasilika* of historical significance were identified and implemented in the application as waypoints (Figure 8, left). These include, for example, gravestones in the main hall or the Gothic passageway into the sacristy. The user can specify these waypoints as a destination and the application will then navigate to them. For this purpose, the remaining route is displayed as a series of animated arrows on the floor (Figure 8, right). A curator tool like the one for the VR application was not developed, as it would have been much more technically complex. Accordingly, the application's content is not flexible and cannot be adapted by a teacher. As there are no labels or signs inside the basilica, the application is intended to help users find individual rooms and distinctive locations independently during the on-site exploration.

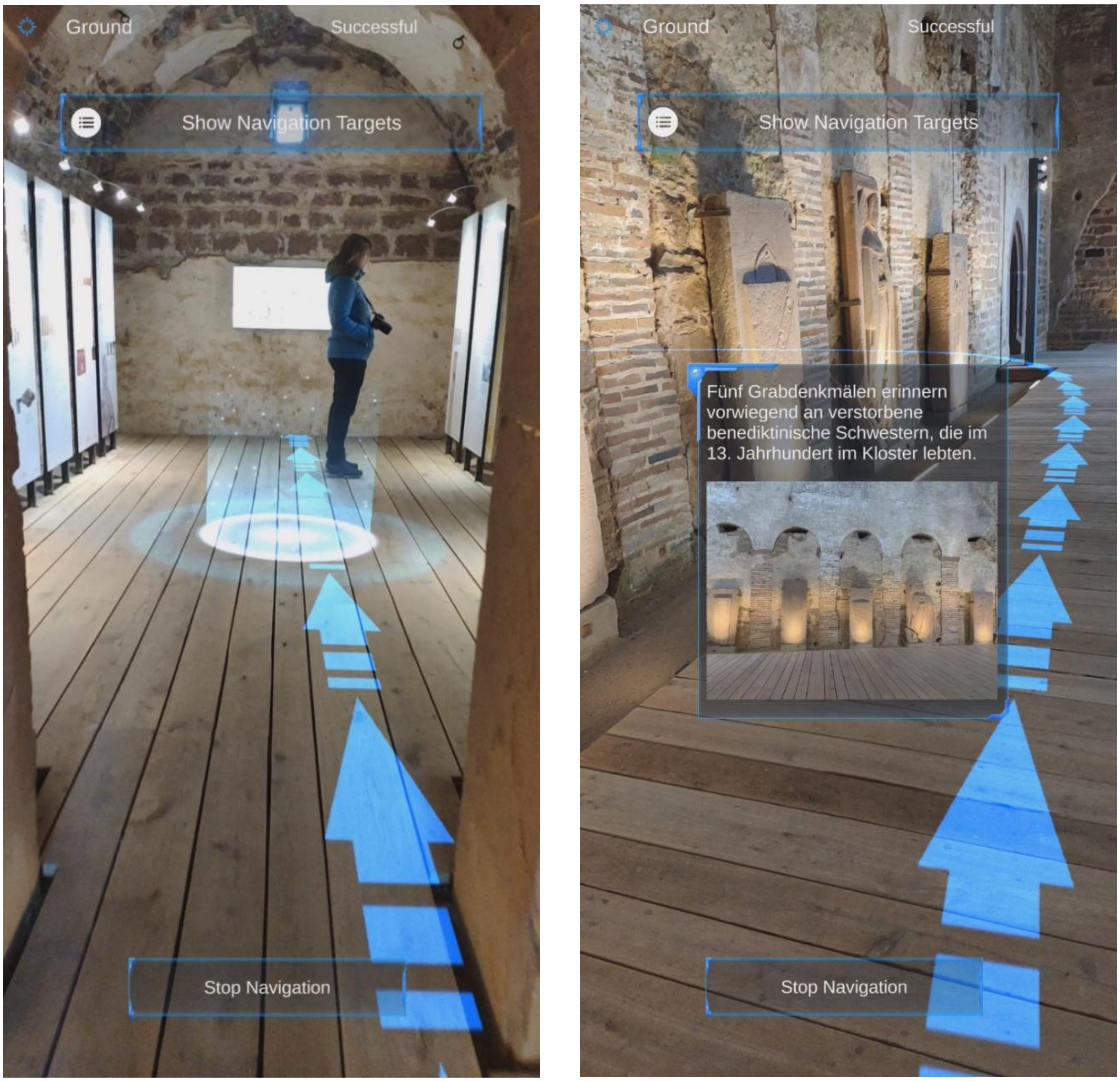

Figure 9. Left: Approaching a waypoint marked with a blue circle on the ground. Right: When a non-selected waypoint is reached accidentally or deliberately, its information is displayed, too.

The waypoint is shown as an animated blue circle (Figure 9, left). When the waypoint is reached, the user is informed and the blue dots on the ground disappear. In their place, a photo and an accompanying text of the distinctive location are displayed. This information is also displayed if a non-selected waypoint is reached accidentally or deliberately (Figure 9, right). The navigation was implemented in *Unity* using the integrated pathfinding system. Since the 3D tracking reference model is invisible in this application and the user is walking, drift effects are hardly noticeable. Days without precipitation and with medium cloud cover represent excellent conditions for visual tracking. In contrast, the lighting conditions in the basilica and especially in the underground crypt are unfavorable, but this did not negatively affect the tracking quality for navigation purposes.

4. User Study

A user study was conducted as part of a history lesson in an 11th-grade class in Michelstadt. The 20 students were between 17 and 18 years old. This chapter describes the preparation of the lesson, its practical implementation, and the follow-up.

4.1 Preparation

First, a lesson plan was drawn up to structure the 90-minute lesson. The lesson topic was ‘Authority in the Middle Ages’. This topic is specified by the curriculum for history lessons in an 11th-grade class but can be freely customized. The lesson was planned in such a way that the school class would receive an introduction to the content from the teacher, complete a digital questionnaire (pre-test), and then be split up: One half was initially to work on worksheets in groups for 20min and then try out the VR application at the two VR stations in adjacent rooms. For this purpose, the students should be redivided so that approximately five students are assigned to each VR station. A work assignment was designed by the teacher to make working with the VR application more effective. The other half of the class should go through the same phases, but first, try out the VR application and then work on the worksheets in groups. At the end of the lesson, a short conclusion with all students and the completion of a final questionnaire (post-test) was scheduled. Table 3 summarizes the lesson plan.

Table 3. The summarized lesson plan. Note: The ‘elaboration’ and ‘consolidation’ phases were in reverse order for half of the class.

Duration	Phase	Content	Methodology	Media
10 min	–	Welcoming, pre-test	–	Projector
10 min	Getting started	Reactivation of knowledge from previous lessons, picture of Charlemagne's coronation as emperor (secular and ecclesiastic power), map of the Frankish kingdom, governance	Teacher talk, Check-in	PowerPoint, Projector
20 min	Elaboration	Working out the importance of the church for Frankish kingship at the micro level	Think-Pair-Share	Worksheets
20 min	Consolidation	VR application with work assignment: The *Einhardsbasilika* as a specific, local example of the intertwining of secular and ecclesiastic power	Group work	2x HTC Vive
5 min	Securing results	Summary	Teacher talk	–
15 min	Transfer	Post-Test	–	Projector

As mentioned in Section 2.7, the curriculum does not allow for more time to go on an actual excursion and to enable the students to try out the AR application. Instead, the AR application was tested by the authors of this paper beforehand and videos, screenshots, and descriptions were made. This enabled the students to evaluate the AR application, at least theoretically, based on these materials. Furthermore, they were to compare the AR application with the VR application and the think-pair-share phase of the lesson.

The teaching materials included worksheets on the topic of ‘Authority in the Middle Ages’ and a work assignment for the VR stations. This work assignment was structured in three parts:

1. Describing the visible external structure of the basilica
2. Looking at the history of the basilica, paying particular attention to the changes in ownership and use
3. Source analysis of a memorial slab that was originally located in the *Einhardsbasilika* from the perspective of secular and ecclesiastic power.

The history teacher needed about an hour to select this content from the public databases described in Section 3.1.1 and to arrange it as information points in the VR application in suitable places (information about the building on the outside, memorial slab in the crypt, and so on). In addition to texts and images from the databases, the teacher also entered content manually. Thanks to the implemented JSON save file system, the teacher was able to copy the prepared scenario from one VR station to the other.

At the end of the preparations, a pre-test with 7 questions and a post-test with 15 questions were developed. The pre-test asked for general data such as age, and previous experience with VR and the *Einhardsbasilika*. To be able to answer RQ2 later, we derived indicators from Freericks' four forms of learning that are easy for the students to understand and fit both the *Einhardsbasilika* and the lesson plan. Planning and carrying out an on-site excursion would also be based on the four forms of learning. Figure 10 illustrates this derivation of indicators. We did not provide an indicator for the third form of learning (hands-on learning/holistic learning), as this form of learning is not/rarely addressed in the applications, as shown in Table 1 and Table 2. The indicators/characteristics are asked in the pre-test and again in the post-test. In addition, the post-test contains in-depth questions on the VR application and AR application and on weighing up their use alongside or instead of an excursion to the *Einhardsbasilika*. The questions of the pre-test and post-test can be found in the appendix.

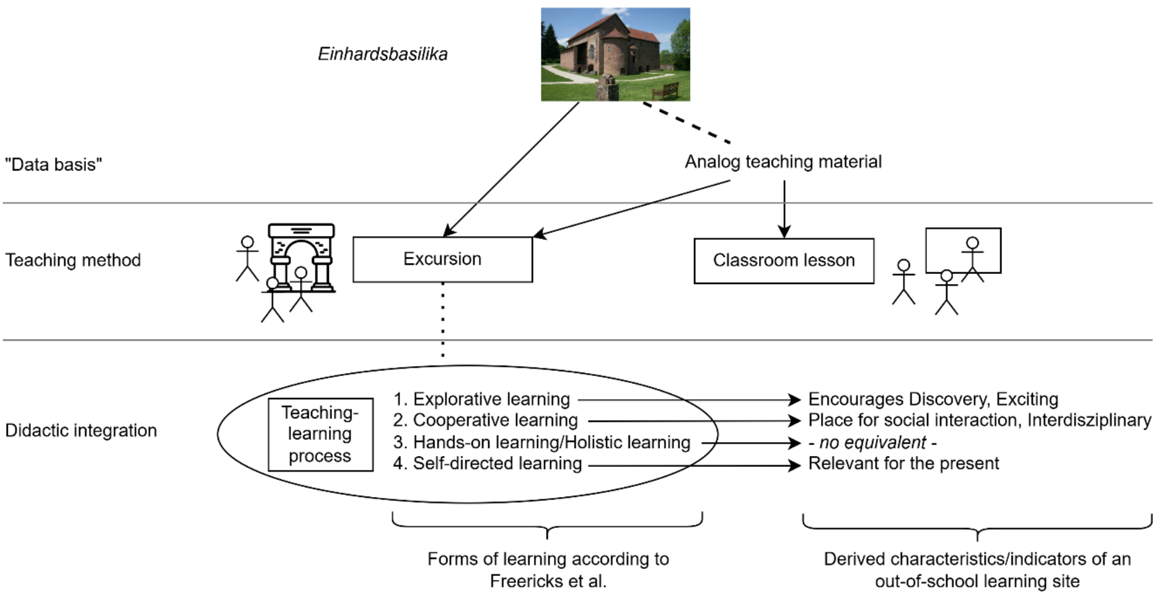

Figure 10. Indicators/characteristics derived from Freericks' forms of learning based on the assumption that the didactic framework of an excursion would be based on these four forms of learning.

4.2 Implementation

The lesson was held on July 03, 2024, in the afternoon. It was the last week before the summer vacation.

Immediately after the welcome, the students took the pre-test. QR codes were used to enable students to take part in the pre-test and later in the post-test using their phones. There were a few comprehension questions on the derived indicators to characterize an out-of-school learning site (including ‘authentically historic’ and ‘relevant for the present’). While the teacher gave a 10-minute introduction, two authors of this paper prepared the two VR stations. After the introduction, the first two groups of five students each went to the VR stations and received a short introduction on how to interact with the two controllers. Afterward, one student went first and put on the VR headset, while the others navigated him through the virtual *Einhardsbasilika* based on the work assignment and wrote notes (Figure 11, left). Within the 20 minutes scheduled for testing the VR application, all students in a small group were able to try out the application one after the other. Meanwhile, the other half of the class worked on worksheets on the topic of ‘Authority in the Middle Ages’ in a wider context (Figure 11, right). After 20 minutes, the groups switched.

Figure 11. Left: Five students work on the assignment at one of the two VR stations. Right: Meanwhile, the other half of the class is working on worksheets in groups.

As scheduled, the whole class came back together 20 minutes before the end of the lesson. After the teacher's summary, the students completed the post-test. As the post-test contains extensive questions, including many with free text answers, 15 minutes were estimated for it when planning the lesson. It turned out that this time estimate was realistic. After answering the questions, the students were allowed to leave the classroom.

4.3 Follow-Up

With the students' consent, photos and screenshots of the application were taken during the lesson and had to be sorted. The students' answers to the pre-test and post-test were transferred to the PSPP software for evaluation. The VR equipment could remain at the same location, as the rooms used are designated for VR applications.

5. Results

11 of the 20 students were male, 7 were female and 1 was diverse (no response: 1). Almost 75% were 17 years old, and the others were already 18. However, the age and gender of the students had no significant influence on any of the responses, which was verified through t-tests. Only one person stated that he or she had already used VR in a school context. 58% had never tried VR in their private life and 37% had done so at least once in the past. One person stated that he or she uses VR more than once a week.

42% stated that they did not know the *Einhardsbasilika*. A further 21% only knew it by name. The remaining students had visited the *Einhardsbasilika* in the past, several of them within the last 12 months (Figure 12). The students were also asked whether the *Einhardsbasilika* had already been covered in school lessons. This was not the case for 74% of students, while 11% had at least studied the basilica in theory. 16% had already visited it as part of a school excursion.

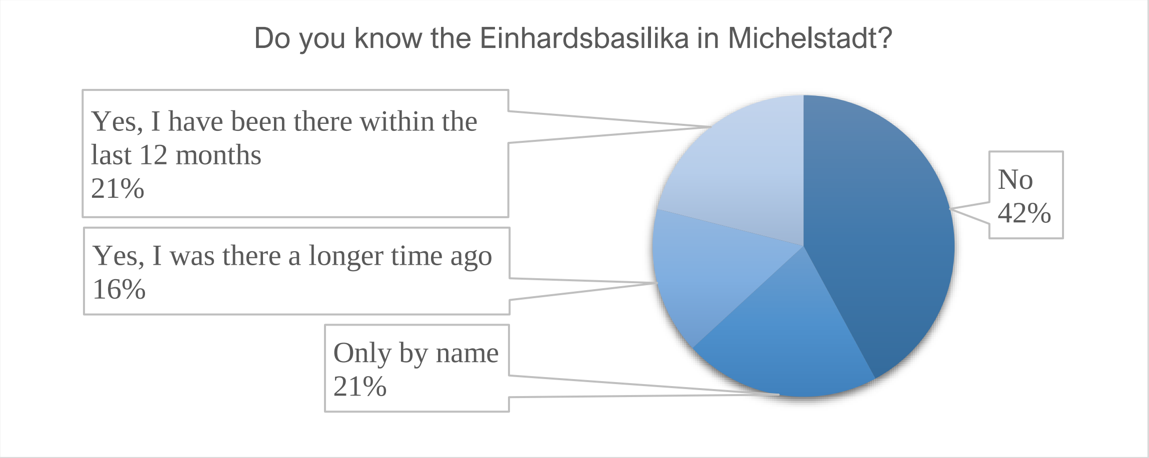

Figure 12. Students' answers to the question of whether they know the *Einhardsbasilika*. 19 answers.

5.1 Can our VR Application Replace an On-site Excursion?

As part of the pre-test, the participants were asked on a Likert scale from 1 (not at all) to 5 (completely) to what extent the following indicators derived in Figure 10 apply to the *Einhardsbasilika*:

- Interdisciplinary
- Exciting
- A place for social interaction
- Encourages discovery
- Relevant for the present

In addition, the indicator ‘authentically historic’ was included in the survey. This is not derived from Freericks' learning methods but from the lesson's learning objective. The students should recognize that the *Einhardsbasilika* is basically historical, but that numerous structural changes have been made over the centuries.

The results are shown in Figure 13. The eight students who did not know the basilica at least by name skipped these questions.

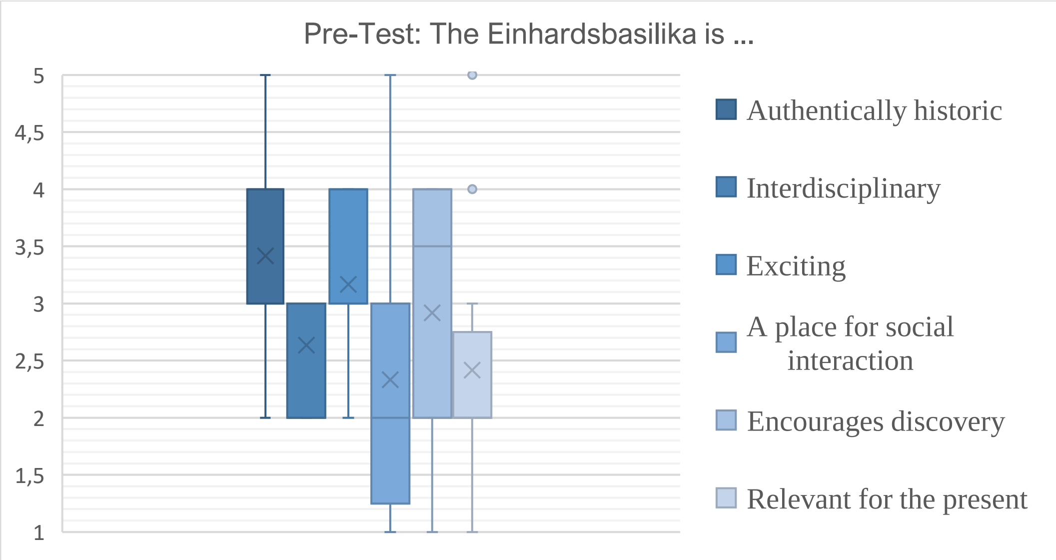

Figure 13. Applicability of characteristic features of out-of-school learning sites to the *Einhardsbasilika* (pre-test, 12 answers). Scale: 1 (not at all) to 5 (completely).

The same questions were asked again in the post-test. The answers are shown in Figure 14.

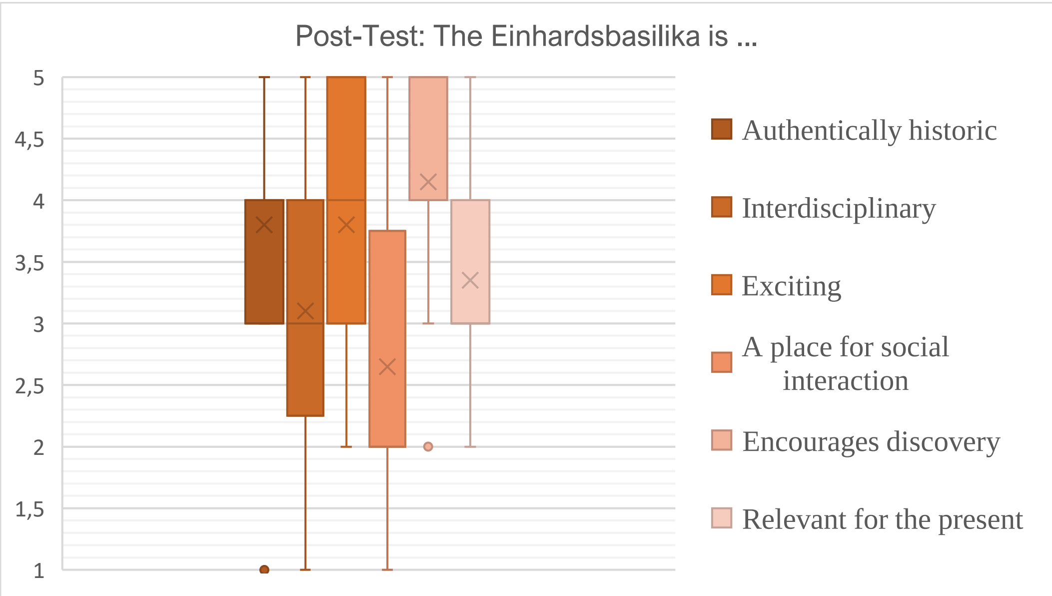

Figure 14. Applicability of characteristic features of out-of-school learning sites to the *Einhardsbasilika* (post-test, 20 answers). Scale: 1 (not at all) to 5 (completely).

Overall, it can be stated that the characteristics for describing the *Einhardsbasilika* were improved in all considered dimensions through the use of the VR application. There was a particularly strong increase in the attributes ‘exciting’ and ‘encourages discovery’. One exception is the attribute ‘authentically historic’, which was only rated slightly higher. With this attribute in particular, it would have been expected that the students would recognize that the *Einhardsbasilika* in its current state is the result of many renovations and conversions and can therefore only be described as authentically historic to a limited extent. It is also noticeable that the indicator ‘relevant for the present’, which was assigned to self-directed learning, hardly increased at all. This suggests that either this indicator was not clearly understood by the students or that the game mechanics derived from it were not sufficiently perceived. The results suggest that the VR application supports explorative and cooperative learning in particular.

T-tests conducted on the post-test evaluations revealed no significant differences in the assessment of characteristics between students who first used the VR application and then worked through the lesson unit with worksheets, and the other half of the class, who did the activities in the reverse order. The results ranged from ‘exciting’ with t(18) = 1.91, p = 0.073 to ‘encourages discovery’ with t(18) = -0.35, p = 0.73.

On a Likert scale from 1 (not at all) to 5 (completely), the students responded with a score of 2.85 (standard deviation: 1.39) that a virtual visit to the *Einhardsbasilika* could replace an excursion there. However, the students who had already visited the *Einhardsbasilika* saw a virtual visit alone as less promising than those who did not know the *Einhardsbasilika* or only by name (Figure 15). A t-test revealed no significant difference in the students' responses regarding whether they completed the worksheets first and then the VR application, or the other way around (t(18) = 1.91, p = 0.405).

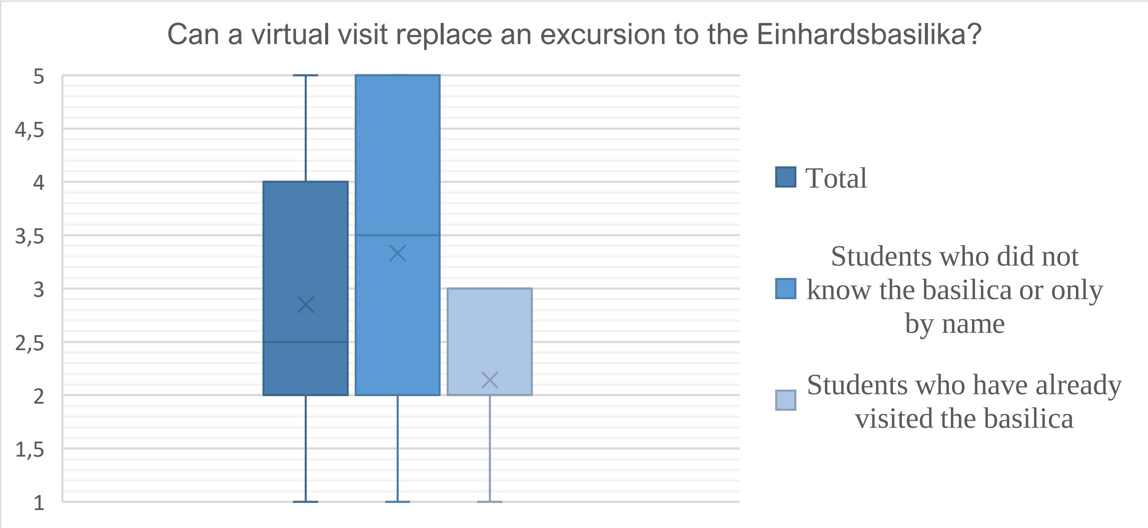

Figure 15. Students' responses to the question of whether the VR application can substitute an excursion. Scale: 1 (not at all) to 5 (completely). 20 answers.

The students were asked to give reasons for their assessments. The following assessments were representative:

- “On-site, it is possible to take a closer look at things and perceive the atmosphere better.”
- “The experience on-site is completely different. However, there are destinations that are difficult to visit on an excursion and a VR excursion would be a very, very good solution.”
- “When the technology is more mature, then yes. But not yet at this stage. Besides, an excursion is always better than normal lessons.”

The statements show that students attribute a high value to an excursion and that the mere format of an excursion is experienced as ‘more pleasant’ than regular school lessons. However, the idea was expressed that a VR application is particularly suitable for cultural sites that cannot be visited as part of a school excursion.

Students were also asked what a possible combination of an excursion and the use of the VR application might look like. 60% of the students stated that an excursion should be carried out after trying out the VR application, while 35% saw it the other way around (no matter: 5%).

When asked what they liked about the VR application, the students gave the following answers (selection):

- "It looks realistic and you can move around freely."
- "Great fun factor. Good insight."
- "It's really cool what you can achieve with technology. That you can simply look at buildings with the help of VR without having to visit them."

Points of criticism included:

- "The graphics."
- "Sometimes it was laggy and the scan wasn't that good."

On a scale of 1 (not at all) to 5 (completely), the students gave an average of 3.15 (standard deviation: 1.09), indicating that the VR application had made them curious to visit the *Einhardsbasilika* in real life. The question of whether the VR application added value to the lesson topic was answered with an average of 3.95 (standard deviation: 0.89). In summary, the students' assessment of the potential of the VR application to supplement the content of the lessons was largely positive. Although a complete substitution of an excursion was viewed critically, the motivational added value and the interest in a subsequent real visit were clearly confirmed. The results underline the function of the VR application as a stimulus and not as a substitute for real learning experiences.

5.2 Does the AR Application Offer Added Value for an On-site Visit?

As the students only answered questions about the AR application based on functional descriptions and images of the application, their subsequent assessments must be treated with a certain degree of caution. However, the students indicated that the information provided about the application was more than sufficient for them to assess it and compare it with the VR application.

On a scale from 1 (not at all) to 5 (completely), the students gave a score of 4.25 (standard deviation: 0.79), indicating that the AR application made an on-site visit more attractive. They gave the following reasons (excerpts):

- "It makes it cooler, more modern, and more appealing."
- "It simplifies the search. You can directly understand the historical events."
- "I think it's good that this 'scavenger hunt' gives you information about the places where you are."
- "It definitely makes the visit more exciting and interesting, but it's not an absolute must."
- "Can be helpful for some people. But it's not an option for me, as I tend to get distracted and the 'discovery' factor is taken away."

When asked what the advantages of the AR application are compared to the VR application, the students gave the following answers, among others:

- "You only need your phone for this."
- "You can still perceive everything with all your senses."
- "Merging with reality."
- "Easier to operate."

The students gave the following disadvantages of the AR application compared to the VR application (selection):

- "You have to spend time going there."
- "It's not in 3D on the phone screen."
- "Not as attractive, could bore some people."

5.3 Weighing up Different Teaching Settings

At the end of the post-test, the students were given a choice of the following teaching settings:

1. Excursion with the AR application & VR application for preparation or follow-up
2. Excursion without the AR application & VR application for preparation or follow-up
3. Excursion with the AR application
4. Excursion without the AR application
5. VR application & worksheets in school lessons (as today's unit)
6. Only VR application in school lessons
7. Only worksheets/theoretical approach in school lessons

On average, 35% of the students preferred the first variant and 20% each preferred the second and 6th variant. Depending on whether the students tried out the VR application before or after completing the worksheets, there were considerable differences in the answers to this question. It must be considered that both groups in this analysis consist of only ten students. The students who tried out the VR application before working on the worksheets estimated the potential of the AR application to be significantly lower than their classmates. These in turn preferred the first scenario (50%), i.e. the combined use of AR and VR (Figure 16).

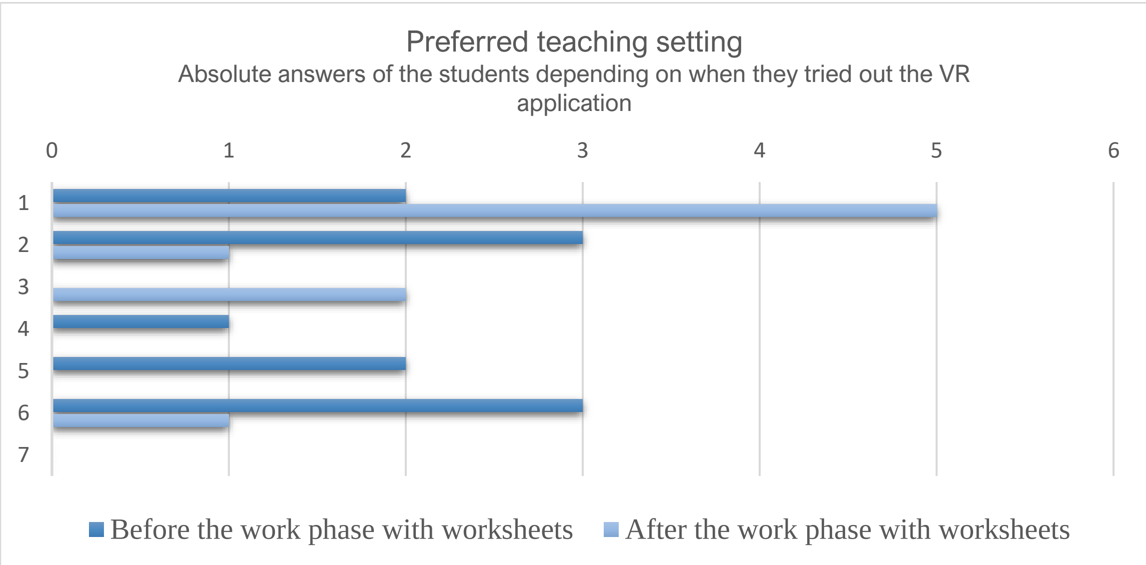

Figure 16. Students' preferred teaching settings based on when they used the VR application during the lesson. The settings are numbered on the left, the bars indicate the number of responses.

There are also differences in the answers to the same question depending on whether the students have already visited the *Einhardsbasilika* in the past (Figure 17). Students with on-site knowledge tend to prefer a variant that includes an excursion and tend to prefer the AR application more than the other students.

Overall, the results show that the majority of students prefer hybrid teaching scenarios in which real excursions are supplemented by digital applications such as VR and AR. The combined approach—VR for preparation, and AR for on-site assistance—is perceived as particularly conducive to learning. At the same time, there are differences depending on previous experience of using VR, which indicates the importance of the didactic embedding and sequence of the methods. Digital tools are therefore not preferred across the board, but are valued as flexible components in a diverse teaching concept.

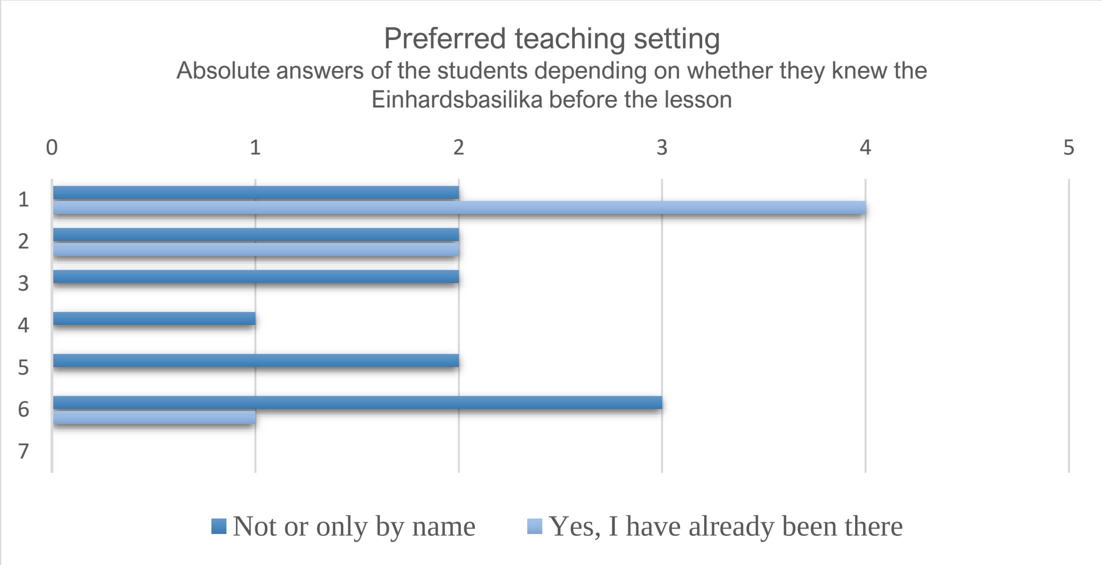

Figure 17. Students' preferred teaching settings based on their prior knowledge of the *Einhardsbasilika* before the lesson. The settings are numbered on the left, the bars indicate the absolute number of responses.

6. Discussion

Regarding RQ1, we found that due to the clear definition of the forms of learning according to Freericks et al., it was largely possible to assign them to design elements and game mechanics of the applications. We assigned most elements to the forms of explorative learning and self-directed learning. Cooperative learning resulted from the small group approach of the applications. Holistic learning, on the other hand, is underrepresented. In Freericks' definition, holistic learning means addressing as many sensory channels as possible. As our applications only address the visual sense, they cannot be described as holistic. It was possible to derive indicators, even though there is a great deal of leeway here and it cannot be ruled out that the students interpreted the terms differently. The students rated the indicators ‘encourages discovery’, ‘exciting’, and—albeit to a lesser extent— ‘a place for social interaction’ and ‘interdisciplinary’ more highly after using the VR application. This corresponds to explorative learning and cooperative learning. Although game mechanics, which can be assigned to self-directed learning, dominated the applications' design, there was no comparable increase in the associated indicator ‘relevant for the present’. There could be two reasons for this: Either the indicator was chosen inappropriately or the game mechanics associated with self-directed need to be developed more dominantly in order to become more prominently recognized by the students. It might be a good idea to design the work assignments for the students in such a way that they specifically address game mechanics that would otherwise be “overlooked”.

To summarize, we answer RQ1 as follows: Assigning the four forms of learning according to Freericks et al. to the key elements of a VR/AR application is quite possible, but the derivation of indicators to measure the ‘success’ of the forms of learning among the students should be done very carefully.

RQ2 explores how students and teachers evaluate the supplementation or potential replacement of a school excursion with the (combined) use of a VR/AR application from both didactic and organizational perspectives. Our user study indicates that completely replacing a school excursion with the VR application is not in the students' interest, who attach great importance to an excursion. In particular, students who had already visited the *Einhardsbasilika* were against replacing an excursion with VR. However, the students had a positive opinion of the integration of the VR application into the lesson. A very intuitive social exchange could be established through group work using the VR application. This exchange was significantly greater than in the group work phase with worksheets. Students see the potential of the VR application more in preparation than follow-up. In addition, the AR application was considered very suitable in its design to complement an on-site excursion.

In summary, the VR application was considered a useful supplement to a possible school excursion to the *Einhardsbasilika*, but it cannot replace it. If an excursion is carried out, most students recognize additional benefits from using the AR application. Our VR application was designed from the beginning to be flexibly integrated into a specific lesson context by a teacher. This goal was achieved by developing a curator tool that allowed the teacher to insert all the media into the digital model of the *Einhardsbasilika* without any problems. All the teacher needed was general Windows knowledge and no programming skills. This shows that the VR application can be understood as a customizable teaching method. According to *Dörner et al.* [40, p. 9], our applications fall into the category of educational games, which are a subgroup of serious games focusing specifically on the formal educational sector. This classification supports the alignment of our approach with structured school curricula and formal didactic models. As our AR application cannot be adapted by a teacher in terms of content, it should only be used as support during an excursion to make it easier for students to orient themselves. This allows the teacher to concentrate more on conveying history-related content.

6.1 Practical Recommendations

We provide teachers with the following practical recommendations for the use of XR applications in school lessons or during excursions:

- In the school where the user study was conducted, there are permanently installed VR stations, which is probably an exception but significantly reduces the amount of follow-up work for the teacher.
- If VR is used in small groups, the handling should be introduced in a large group beforehand and not in the small groups. This can save valuable time. Ideally, the VR stations should be supervised by another teacher or a suitable person.
- In our case, the verbal exchange between the active person and the other four students in a small VR group worked well. The prerequisite for this was a large monitor that enabled the other students to easily follow the perspective of the active participant.
- Students' concentration quickly wanes with longer texts in VR. Long texts should preferably be made available to students in printed form.
- While a VR application can be set up by a teacher, using the AR application requires more involvement from the students in advance. This includes the availability of an AR-capable smartphone and installing the app before the excursion with the risk of unknown compatibility problems. However, an on-site navigation application can greatly reduce the teacher's workload.

6.2 Limitations

Our formative study included 20 participants, which is low compared to other studies. Today, the *Einhardsbasilika* is a predominantly empty building that offers few opportunities for interaction with objects. Therefore, the site does not adequately address the form of ‘holistic learning’. The AR application could only be evaluated to a limited extent, as it could not be practically tested by the students. In addition, no separate excursion to the *Einhardsbasilika* was carried out, which means that the students' previous experiences with the site—whether positive or biased—limit the objectivity of the findings. The evaluation primarily relied on self-reports; no explicit learning assessment was conducted. Finally, the study was carried out during the last week before the summer vacation, when all grades had already been finalized.

This timing may have reduced the participants' motivation to fully engage with the lesson. As with other studies, deriving generalized guidelines based on a single use case is naturally only possible to a limited extent (cf. [25, p. 140]).

6.3 Comparison with Previous Research

In [6], a VR application as a substitute for a museum visit led to more motivation, but less learning outcome than a museum visit. Our study showed that the students were motivated to make a real visit to the basilica precisely because of the VR application. It can be debated whether the excursion to a museum per se is perceived as more boring by students than a visit to a cultural heritage site and therefore the ‘benchmarks’ are not quite the same. In [31], 360° videos—i.e. not XR applications—were rated slightly better than a physical field trip with primary school students. [32] came to a similar conclusion as we did, seeing a VR application more as a supplement to real travel/excursion. Their focus was on tourism, but we confirm their findings for formal education based on our user study. The students saw our AR application as a useful addition to a field trip. [24] emphasized the advantages of using smartphones over VR headsets in their application. Based on our setting, we assume that the VR application for use in the classroom and the AR application during a field trip are not in competition with each other, as they represent different phases of the teaching-learning process (preparation and follow-up vs. actual excursion). [25] recognized the risk that a ‘monolithic’ XR application with complicated technology and interwoven game mechanics would not be used beyond a single pilot project. They were addressing operators of cultural sites with their statements and we can also confirm them for a school environment. The customizability of the VR application by the teacher—made possible by the curator tool—ensures that our VR application is easy to prepare and can be used for different teaching settings.

In summary, the results of our study are in accordance with the still rather sparse findings to date when weighing up a school excursion against XR applications. In addition, they have a large overlap with findings on the use of XR in the context of tourist visits to cultural sites, which illustrates the proximity of these areas.

6.4 Future Research

A larger-scale study with more participants, including an excursion, would be desirable to answer the research questions in a more differentiated way. However, it is questionable whether such a larger study can still be carried out in a school context, as the classes undertake excursions independently. Small cultural heritages such as the *Einhardsbasilika* are rarely frequented by young people in a non-school context, which means that a study conducted outside the classroom would need to run for an extended period to involve a large number of participants.

Consideration could be given to the potential benefits of enhancing the game experience by using an elaborate game design as the foundation for the game mechanics. The same applies to storytelling. However, it should be noted that the limited time available for such an application in class (20 minutes per group in our study) and the group dynamics within a small group can be an obstacle to following an elaborated storyline. In our case, we derived the game design directly from the hypothetical planning of an actual excursion in which groups of students explore a cultural heritage largely independently based on a work assignment. Such a ‘scavenger hunt’ is a classic experiential/playful element in formal education. Therefore, in a further study, the connections between the four forms of learning according to Freericks et al. and game design could be specifically investigated.

To adequately depict the form of holistic learning, which is underrepresented in our study, we recommend selecting a more multifaceted excursion location that appeals to more sensory channels. An augmented virtuality application could possibly depict this better than a VR application. In future studies, which, like ours, cover a whole lesson, the working methods could be assessed more regarding the learning objectives and the content to be taught. Ideally, in addition to a post-test, a learning assessment should be carried out at the end of the lesson.

7. Conclusions

In this article, we have examined whether XR applications can supplement or even replace school excursions. Our approach focuses on the four forms of learning by Freericks et al. [2] that are related to out-of-school learning sites. Based on the playful design of a real excursion, we developed a VR and AR application to explore the *Einhardsbasilika*, a local historical site in Michelstadt, Germany. Laser scans, digital/analog learning materials, and an AR scan served as the data foundation.

We related the design aspects and game mechanics of the applications to the four learning forms according to Freericks et al. Next, we devised comprehensible indicators/characteristics to allow students to evaluate the degree to which the learning forms were incorporated into the applications. The teacher's perspective was addressed by discussing the organizational and didactic constraints of integrating the applications into the classroom. In addition, we emphasized how important the adaptability/flexibility of a corresponding application is and developed a curator tool that provides a teacher with simple ways to insert media from public databases as well as individual images and texts into the virtual *Einhardsbasilika*.

A formative user study was conducted with 20 students from a local school class. For this purpose, a history lesson was comprehensively planned and the VR application was adapted by the teacher to the teaching topic ‘Authority in the Middle Ages’. Using a pre-test and post-test, the students' assessments of the *Einhardsbasilika*, the VR application, and the concept of the AR application were collected. Our study concludes that students place a very high value on school excursions and that XR applications should not replace them, but rather supplement them. Based on our results, we recommend that further research investigate the links between Freericks' forms of learning and the game design of serious gaming applications in more detail.

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Conflicts of interest

We, the authors, declare that we have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Pre-test questions

1. Gender
   - *Male*
   - *Female*
   - *Diverse*
   - *Not specified*
2. Age [Free text answer]
3. How often do you use virtual reality (VR) applications?
   - *Never*
   - *Rarely (<=1x/year)*
   - *Occasionally*
   - *Very often (>=1x/week)*
4. Have you already used VR in a school context?
   - *No*
   - *Yes*
5. Do you know the Einhardsbasilika in Michelstadt?
   - *No*
   - *Only by name*
   - *Yes, I was there a longer time ago*
   - *Yes, I have been there within the last 12 months*
6. Was the Einhardsbasilika a subject in your school lessons in the past?
   - *No*
   - *Yes, theoretically (books, worksheets, etc...)*
   - *Yes, as an excursion*
7. To what extent do you think the following characteristics apply to the Einhardsbasilika?
   - Each on a Likert scale from 1 (not at all) to 5 (completely)
     - Authentically historic
     - Interdisciplinary
     - Exciting
     - A place for social interaction
     - Encourages discovery
     - Relevant for the present

Post-test questions

1. When did you use the virtual reality (VR) application?
   - *Before working on the worksheets*
   - *After completing the worksheets*
2. How did you engage with the VR application?
   - *Practical try-out with VR glasses*
   - *As a viewer*
3. To what extent do you think the following characteristics apply to the Einhardsbasilika?
   - Each on a Likert scale from 1 (not at all) to 5 (completely)
     - Relevant for the present
     - Encourages discovery
     - A place for social interaction
     - Exciting
     - Interdisciplinary
     - Authentically historic
4. In your opinion, can a virtual visit to the Einhardsbasilika using a VR application in class replace a school excursion there?
   - Likert scale from 1 (not at all) to 5 (completely)
5. Give reasons for your decision. [Free text answer]
6. If trying out the VR application were to be combined with an on-site excursion: What would be an appropriate order?
   - *VR first, then excursion*
   - *First excursion, then VR*
   - *No matter*
7. What did you like about the VR application? [Free text answer]
8. What did you not like about the VR application? [Free text answer]
9. Has the VR application made you curious to visit the Einhardsbasilika?
   - Likert scale from 1 (not at all) to 5 (completely)
10. Does the VR application offer added value for the lesson topic 'Authority in the Middle Ages'?
    - Likert scale from 1 (not at all) to 5 (completely)
11. In your opinion, does the use of the AR application make a visit to the Einhardsbasilika more attractive?
    - Likert scale from 1 (not at all) to 5 (completely)
12. Give reasons for your decision. [Free text answer]
13. What are the possible advantages of this AR application compared to the VR application? [Free text answer]
14. What are the possible disadvantages of this AR application compared to the VR application? [Free text answer]
15. Which of these teaching settings would you personally prefer about the Einhardsbasilika?
    - *Excursion with the AR application & VR application for preparation or follow-up*
    - *Excursion without the AR application & VR application for preparation or follow-up*
    - *Excursion with the AR application*
    - *Excursion without the AR application*
    - *VR application & worksheets in school lessons (as today)*
    - *Only VR application in school lessons*
    - *Only worksheets/theoretical approach in school lessons*