An Augmented Reality Framework for Gamified Learning

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Abstract. Formal education with physical objects is resource-intensive and does not scale well. In self-regulated settings, the long-term motivation of learners is an additional issue. Interactive 3D models provide a solution, as they can be replicated as needed. The user experience and immersiveness suffers in conventional Web-based viewers. The concept of mixed reality which encompasses both virtual and augmented reality creates new opportunities. In this article, we present a framework for mixed reality training that allows students to experience 3D models in an augmented reality environment. The resulting app runs on the Microsoft HoloLens and is suited for several settings like bedside teaching and workplace learning. User motivation and learning success are supported by a gamification strategy that rewards the successful completion of quizzes. We evaluated our framework with students of a medical university. Our open source software can be readily employed in various academic and industrial application areas.

Keywords: Mixed Reality, Augmented Reality, Gamification, Learning, Microsoft HoloLens

1 Introduction

Traditional formal learning concepts include book illustrations and physical objects. While images alone cannot convey a vivid understanding of spatial structures, physical objects are restricted in access since they are fragile. Interactive Web-based learning environments allow students to see, transform and annotate 3D models in a computer-generated world. The term mixed reality encompasses the spectrum between the real world that is embedded in augmented reality (AR), and the purely virtual reality [7]. Mixed reality provides an interactive and effective way of learning where the student can freely explore virtual 3D objects from any view angle [15]. These objects are always available and cannot be damaged. They can be shared online to be viewed by many persons at different locations in parallel. Mixed reality is ideally suited for a wide variety of Web-based learning scenarios including problem-based learning and workplace learning. Bedside teaching is considered an ideal clinical teaching modality [10], where medical students examine patient conditions in the patient's room. Especially for human anatomy, a profound understanding of three-dimensional structures is essential. Since AR systems like the Microsoft HoloLens can display information by overlaying the view of the real world, students can combine the study of anatomical models with practical training procedures [5]. Concerning the pedagogical aspect, research indicates that learning anatomy with a 3D model can improve the student's test results [8]. Additionally, students can use the tool in self-regulated learning [14]. During the preparation phase, information like 3D models and quizzes are gathered. Within the learning phase, the new information can be used to enhance knowledge. In the reflection phase, badges show if the learning process was successful.

In this article we present *GaMR*, a gamified mixed reality framework which helps students to understand 3D structures, to keep motivated and to enhance the impression on the long-term memory. It is based on our previous work on a gamification framework that allows learning communities and individual learners to configure game elements and game rules in an intuitive, fine-granular and flexible way, without programming experience [6]. We applied the gamification framework and successfully evaluated its conceptual and technical applicability in a mixed reality context. Students can profit from game-based learning [11] by using quizzes and badges. The resulting collaborative learning application is available as an open source solution[1].

The paper is structured as follows. Section 2 discusses related work and technical backgrounds of the prototype. In Section 3 the conceptual design of the framework is elaborated. Section 4 describes details and challenges of the implementation. The evaluation of the framework is shown in Section 5 and Section 6 concludes the paper with an outlook on future work.

2 Background

In this section we discuss related work and introduce important technical concepts used in our implementation.

2.1 Related Work

Zygote Body [17] is a Web-based 3D viewer for human anatomy. The application offers schematic models of the male and female body where every part of the model is labeled with its English name and an excerpt from the part's Wikipedia article. Additionally, users can add their own annotations and gain access to more detailed models, e.g. of a dissected heart or an eye [17].

[1] https://github.com/rwth-acis/GaMR/

Another interactive application is Anatomy Learning 3D Atlas [1]. It is available for Android smartphones and as a WebGL version for desktop browsers. Pre-made schematic 3D models show segments of the human anatomy.

The Case Western Reserve University presented Holoanatomy[2], a HoloLens application for visualizing anatomy. It features pre-defined annotations.

A Web-based viewer for 3D models is the Anatomy 2.0 application where users can add annotations [9]. Moreover, the application supports collaboration between learners because the annotations and the user's views can be synchronized. The project also allows authors to upload their own 3D models.

The GaMR framework builds on the concepts of these applications and improves them by adding gamification with the aim of increasing the user's long-term motivation and guide the learning process. Additionally, a comparison of the learning tools shows that all but Anatomy 2.0 work with pre-defined content like 3D models and quizzes. This restricts their use cases to the given fields of study. With the GaMR framework, custom 3D models, annotations and quizzes can be added in order to adapt it to the use in arbitrary courses. Moreover, most solutions are still limited to desktop applications. In contrast to this, models on the GaMR framework can be viewed on the HoloLens in mixed reality.

2.2 Gamification

While students can use the presented applications for learning, they do not support the student in long-term engagement. This can be achieved by the concept of gamification. Elements from games like quest systems, points, achievements or badges help to motivate and reward users for performing tasks [4]. This is realized by creating goals. This practice can give feedback about the task progress and when it is finished the rewards trigger a feeling of success.

In order to design gamification, one needs to understand the factors which improve motivation. The Octalysis framework defines eight drives which motivate humans [3]. One of them is *meaning* which states that people like to contribute to an important project with an ambitious aim. Another aspect is *accomplishment*. In the context of learning, students can be motivated by reviewing their progress and remembering their mastered challenges. Additionally, *empowerment* plays a role where the user is given creative freedom. With *ownership*, the students can gain badges which makes their success evident. *Social influence* as in competition but also cooperation can also trigger the interest in a project. Furthermore, *scarcity* motivates the students to continue the task to achieve goals which cannot be reached immediately. *Unpredictability* can also support the user's curiosity to go on exploring the application. The last factor is *avoidance* which means that the user tries to prevent failure and its consequences [3].

[2] https://www.microsoft.com/de-de/store/p/holoanatomy/9nblggh4ntd3

2.3 Technical Background

The developed framework is executed on the Microsoft HoloLens which is a head-mounted display for mixed reality[3]. It continuously performs spatial scans of its environment to create a map of the surroundings. The device can locate its own position and react to user movements. Thus, virtual 3D models can be projected into the real world and stay fixed at their assigned position. This allows the user to walk around virtual objects, inspecting them from different angles similarly to the concept of holograms. Microsoft HoloLens is a standalone device which runs on the Windows 10 operating system. For the development, the 3D engine Unity was used which allows the creation of interactive 3D applications[4]. It provides support for different platforms and devices besides the HoloLens. The engine handles low level functionality like graphics rendering and simulations [16]. C# can be used to implement the application logic [12]. The implemented code is supported by Microsoft's MixedRealityToolkit[5]. This open-source project under MIT license is available on GitHub and contains different basic templates and scripts to speed up the development process in Unity. The gamification framework was developed at RWTH Aachen University [6]. It provides a RESTful API to administer the gamification of applications. Internally, this is realized by a PostgreSQL database. Furthermore, it can generate code for gamification elements and inject it into Web-based systems. The Gamification Framework administers the data as games, quests, actions, achievements and badges [6].

3 Concept

The GaMR framework is designed as a learning tool. Its structure can be seen in Figure 1. Users can display custom 3D models and place them in the environment. Each model is instantiated with an annotation system which allows users to place markers on the object's surface and associate them with text or audio. Authors can create specials annotations sets based on the designated learning content and save them as quizzes. The student's task is to find the corresponding text to the given annotation marker or to match the marker to the text. The framework is gamified by badges and a progress bar to maintain the student's long-term motivation. Authors can define custom images and assign them to the badges. Each quiz contains one of these defined badges and it can be won by the student if all questions are answered correctly. The acquired badges can be exhibited to visualize the student's accomplishments. Additionally, a progress bar shows the amount of correctly answered questions in a quiz.

The gamification data of the quizzes are administered by the Web-based learning service [6]. Its interface is generally organized in games and quests which contain actions. The quests are also associated with the achievements which refer to badges. In order to communicate with the service, a mapping from the

[3] https://www.microsoft.com/de-de/hololens
[4] https://unity3d.com/de
[5] https://github.com/Microsoft/MixedRealityToolkit-Unity

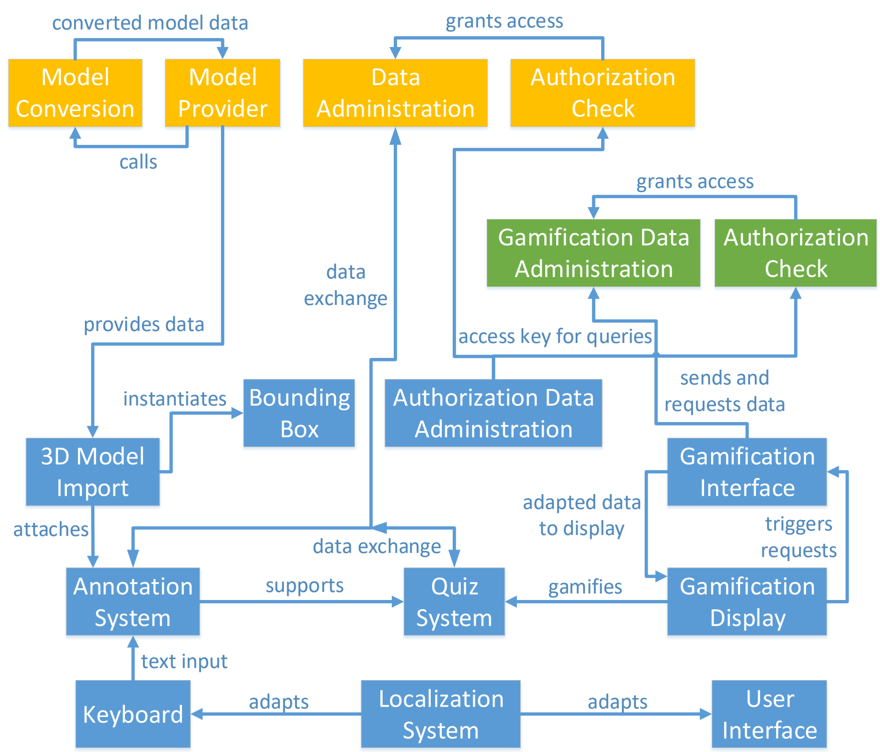


Fig. 1. Components and Data Flow of the Developed System

components of the developed framework to the interface was designed. Similarly to the game which contains quests, the 3D model subjects contain quizzes. Thus, quizzes are regarded as quests. The individual questions of a quiz are mapped to actions of the quest. If a question is answered correctly, the corresponding action is triggered. This way, the quest is fulfilled iff all questions in the quiz are answered correctly. The badge is issued by the Web-based learning service and added to the user's account.

4 Implementation

Integrating a single sign-on authorization, processing the custom geometry, designing the user interface and adding the gamification elements were the challenges of the implementation.

4.1 Authorization

The developed framework uses the single sign-on protocol OpenID Connect which is supported by Google and Microsoft. This login process is required to secure the framework's data from unauthorized access. By handling the core functionality of the authorization and extending it with user identification [13], the protocol is suitable to solve this task. The challenge was to integrate the protocol's communication sequence into the HoloLens app as it usually requires a Web server. It was realized using custom URLs which guide the application flow from the login provider back to the HoloLens app.

4.2 3D Model Import

The framework uses 3D models from the existing repository of Anatomy 2.0 [9]. It mainly contains 3D scanned objects from the medical field such as a brain or skull. The objects are stored in the XML-based X3D file format [2].

Unity does not support the import of X3D files at runtime. However, an author should be able to add new models to the framework without re-compiling it. Thus, a custom solution was implemented. Its import process is displayed in Figure 2. On the backend, the X3D file is parsed and the important information about the geometry like the vertex and face arrays is extracted. After this, they are packed into a JSON string which is offered to the frontend by the backend's RESTful service. This JSON string is also cached in order to optimize the performance for subsequent requests of the same 3D model.

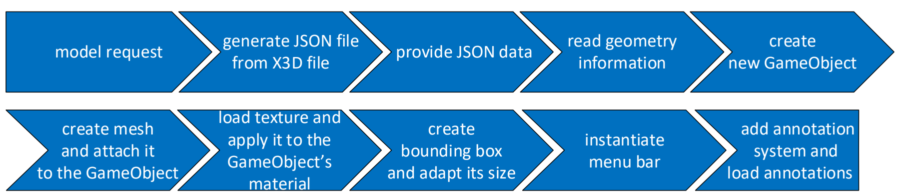


Fig. 2. Linear Process Diagram Showing the Steps to Instantiate a 3D Model

When a user loads a 3D model the frontend requests it at the RESTful service and it receives the JSON file. The contained information is used to construct the object's mesh which represents the object's surface. Unity can directly create meshes based on an array of vertex positions and a corresponding face array.

4.3 3D Transformation Widget

Users need to be able to move, rotate and scale the imported 3D models. Different transformations need to be realized without hiding the model under distracting controls. Graphical layout applications solve a similar two-dimensional problem by drawing a box around created elements; the developed three-dimensional solution is based on the same principle. Imported models are encapsulated in a tight-fitting wire-frame cube as depicted in Figure 3. This bounding box contains

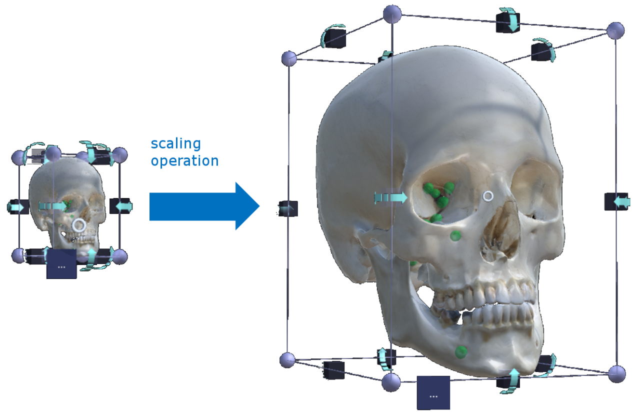
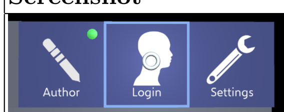
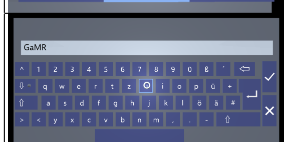
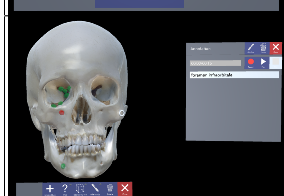
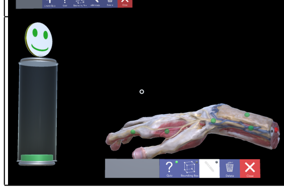


Fig. 3. Bounding Box and its Widgets for Rotation and Scaling

widgets for scaling and rotation at intuitive positions. For instance, the object can be scaled by dragging the corners of the cube. The 3D rotation also beared a challenge as a free 3D rotation is difficult to control with one gesture. Instead of that, the widgets were placed on the midpoints of the cube's edges and only allow rotation operations around one axis at a time.

Table 1. Overview of Developed User Interface Widgets

Screenshot	**Challenges**
	**Button Widgets** • activated by gaze • custom captions • advanced animations for user awareness
	**3D Keyboard** • input field kept in sight • integration into the program flow • adapts to selected language
	**Annotation System** • placement of markers on the model's surface • stores user-defined text, e.g. to label a marked point or region on the model
	**Badges and Progress Bar** • the progress bar rises with the number of correctly answered questions • authors can create custom images for the badge

Widgets are kept at constant size so that they can be selected comfortably.

4.4 UI Widgets

The framework implements various solutions to user interface related problems which are listed with their challenges and features in Table 1.

4.5 Localization

The user interface is localized into the English, German and Dutch languages. The implemented manager loads the translations as a dictionary. It is granted that there will always be a meaningful translation displayed. The localization system also affects the keyboard as it adapts its layout to the chosen language.

5 Evaluation

The framework was evaluated at Maastricht University. Four lecturers and fourteen students from a medical degree program participated in the evaluation. Both groups created annotations on anatomical 3D models like the 3D scan of a skull or brain. The lecturers could use the author functionality to create quizzes and define badges. After that, the students answered the quizzes. Thirteen participants were not familiar with AR reality and did not know the HoloLens. They were enthusiastic about its possibilities and potential use cases for medical learning and training.

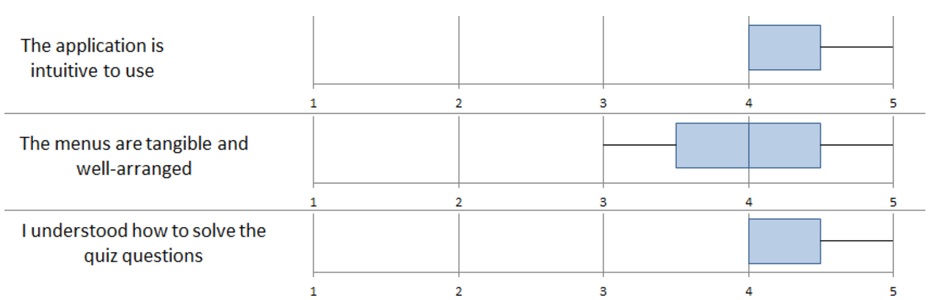


Fig. 4. Excerpt from the Survey Results

Figure 4 shows an excerpt from the questionnaire's result. The participants praised it as visually appealing and commended the intuitiveness of the menu design. The progress bar helped to gain an overview about their quiz results. Badges were perceived as motivating and encouraging to follow up the quizzes.

Furthermore, a technical evaluation was conducted to determine the framework's performance requirements. The framework was running on the HoloLens while the performance data were measured on Unity's profiler and the *Device Portal* of the HoloLens. The results show that the framework runs at 30 frames per second with objects of 30,000 vertices. This standard value allows the human eye to perceive movements smoothly. More complex objects decrease the framerate until objects with one million vertices lead to a memory overflow on the HoloLens. The parsing times of the X3D files to JSON data for sending to the frontend have also been measured. It became evident that objects which run on usable framerates are converted in under one second. A 3D model with 30,000 vertices was converted in around 100 milliseconds on a standard office computer.

6 Conclusions and Future Work

Usually, students learn with physical objects and illustrations in textbooks. Apart from the fact that physical objects are fragile, they are also limited in access. Illustrations in textbooks sometimes do not convey a good impression of the full spatial extents of an object. These learning methods can now be improved by using mixed reality concepts. In this paper, the gamification framework for mixed reality training as a tool for learning 3D structures was introduced. Authors can create quizzes which are based on the annotation system and students have to assign the text of the annotation to the marker or vice versa. In order to maintain a long-term motivation, gamification elements where added to the framework. Students can win badges and a progress bar informs them about their successful learning progress.

Further development will extend the framework by new features. Implemented solutions like the authorization procedure and UI elements will be made available as separate toolkits and libraries. Developers can import them into their projects. The framework will be refined, e.g. by improving its framerate to 60 frames per second as soon as faster hardware is available.

The evaluation showed that the framework can be used in smaller courses. In future, the application will also run on desktop computers and virtual reality devices. As the GaMR framework is not restricted to an educational context, it is possible to be used in various other fields of applications. One example is a design or fabrication pipeline where designers are able to add their 3D models to the repository and can place the virtual prototype in the real environment. The annotations may be employed as bulletin boards to leave notes for others directly on the 3D object. Another use case is the deployment at a practical training scenario during apprenticeship. For instance at a workplace, schematic 3D models of tools or operating panels can be integrated. Instructors have the opportunity to add explanations and process steps to the 3D model as annotations. A trainee can overlay these schematic models over the real tools and be guided through the process based on the tool's operations.

As a conclusion, the GaMR framework provides a learning tool for versatile educational training scenarios.

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