Journal of Universal Computer Science, vol. 25, no. 12 (2019), 1644-1665
submitted: 17/5/19, accepted: 31/10/19, appeared: 1/12/19

Gamification Support for Learning in Spatial Computing Environments

Benedikt Hensen
(RWTH Aachen University, Germany
hensen@dbis.rwth-aachen.de)

István Koren
(RWTH Aachen Univserity, Germany
koren@dbis.rwth-aachen.de)

Ralf Klamma
(RWTH Aachen University, Germany
klamma@dbis.rwth-aachen.de)

Abstract: With the rise of mixed reality hardware and software, new opportunities in formal higher education arise, e.g. in anatomy, as the usage of 3D structures instead of 2D images or anatomical models supports a better understanding and enhances the learning process. But even with access to virtual 3D models, motivation is a key element for successful learning and for progressing over a longer period of time. Mixed reality spaces offer new opportunities for combining a 3D stereoscopic depth perception of anatomic models together with gamification and interactive learning. Virtual 3D models can be enhanced with additional information which can name and explain separate elements. Therefore, we developed GaMR, a gamified framework for learning in mixed reality, where 3D models can be experienced on the Microsoft HoloLens and the HTC Vive. Quiz creation is supported by placing annotations on the model. Progress is rewarded by badges. The gamification strategy guides the student and gives feedback about the learning progress. This open source gamification framework for mixed reality was evaluated with students and doctors from a medical university. It showed that it can be employed in many academic and industrial use cases.

Key Words: Mixed Reality, Augmented Reality, Virtual Reality, Gamification, Learning, Microsoft HoloLens, HTC Vive
Category: L3.0, L3.6, L5.1, I3.7

1 Introduction

Traditional formal learning concepts include book illustrations and physical objects. While images alone cannot convey a vivid understanding of spatial structures, physical anatomical 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 [Milgram and Kishino, 1994]. Mixed reality provides an interactive and effective way of learning where the student can freely explore virtual 3D objects from any view angle [Trelease and Nieder, 2013]. 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 [Peters and ten Cate, 2014], where medical students examine patient conditions directly 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 [Kamphuis et al., 2014]. Concerning the pedagogical aspect, research indicates that learning anatomy with a 3D model can improve the student's test results [Nicholson et al., 2006]. Students can use the tool in self-regulated learning [Schunk and Zimmerman, 1998]. 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 [Klamma and Arifin, 2017]. 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 [Prensky, 2005] 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.

Parts of this article have been published in the conference proceedings "Advances in Web-Based Learning - ICWL 2018" [Hensen et al., 2018] and in ICWL 2017 [Klamma and Arifin, 2017].

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

2 Background

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

2.1 Related Work

Zygote Body [Zygote Media Group, 2017] 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 [Zygote Media Group, 2017].

Another interactive application is Anatomy Learning 3D Atlas which is available for Android smartphones and as a WebGL version for desktop browsers [AnatomyLearning, 2017]. 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.

In the context of the Mixed Reality Design Lab, Microsoft created an open-source example project for learning the periodic table [Park, 2018]. Individual elements can be selected and additional information is revealed. A 3D model of each element's atom is shown and can be viewed from any angle.

A Web-based viewer for 3D models is the Anatomy 2.0 application where users can add annotations [Nicolaescu et al., 2015]. 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 and HTC Vive in mixed reality.

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

2.2 Mixed Reality Learning Environments

Learning in 3D is well suited for the active learning process. Research for learning in a 3D world shows that there are two main advantages [Schwan and Buder, 2006]. First of all, the stereoscopic presentation of learning content in the form of 3D models creates a feeling of presence. Being in a 3D world every day, a virtual three-dimensional world can immediately feel intuitive and familiar. In addition, mixed reality applications can be multimodal which means that multiple senses are stimulated. This way, the brain can use additional information from other senses to store the new aspects [Schwan and Buder, 2006].

One use-case scenario shows that 3D learning is suitable for presenting real-world objects in a detailed and realistic manner [Schwan and Buder, 2006]. In comparison to 2D images or abstract text, 3D models can convey a better understanding of proportions and size comparisons. Especially in the medical field, students can train for real-life examination and surgery. Due to the added realism, a practical and profound understanding of structures and procedures can be gained. As a bonus, the scale of the 3D model can be adapted to any size. This way, extremely small or large structures can be remapped and viewed in a comfortable scale. Apart from realistic objects, authors can also construct schematic versions of 3D models which focus on the most relevant information. This allows for a combination of realistic and theoretic aspects, e.g. in the form of annotations or overlays.

As AR combines the virtual and real environment, users learn to visualize space and spatial structures in a natural way [da Silva et al., 2019]. Abstract topics which cannot be shown as images can still be represented by 3D data visualizations. The organization of the learning content becomes more effective since it can be positioned in space. The spatial order in relation to the real world can act as further help to recall a great amount of study material. This effect is similar to the learning principle used in the method of Loci. In this mnemonic technique, the learner populates real or imaginary places with mental images associated with the learning content. By walking through this world in the mind, the learner is able to store and reliably recall large amounts of data [McCabe, 2015].

2.3 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 and quests [Deterding et al., 2011]. 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 [Chou, 2015]. 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 make their success evident. *Social influence* can also trigger the interest in a project because of competition and cooperation. 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 [Chou, 2015].

Different studies have inspected the inclusion of game mechanics in working and learning scenarios [Klamma and Arifin, 2017]. One study investigated the social interactions which happen during a learning process in the scenario of an enterprise environment [Stanculescu et al., 2016]. In order to conduct the study, the authors developed a framework which provides leaderboards and badges in a Q&A web application. Gamification is not restricted to use cases in companies but can also be applied in other circumstances, e.g. in university courses. A study which uses gamification in such a setting yielded results about the effect of motivation of the students based on Self-Determination Theory [Shi and Cristea, 2016]. Gamification causes enjoyment, improves the ease of use and creates flow experience where the user is happy about the accomplishments [Herzig et al., 2012]. With the example of DevHub, gamification in communities was studied. The results show that participants benefit from these additional gamification elements by creating a social experience [Takahashi, 2010]. Similarly, studies around the company social-network Beehive showed that gamification can also improve the participation of users [Farzan et al., 2009]. However, gamification needs to be employed carefully as it can lead to off-task behavior, undesired competition or addiction [Andrade, Fernando R. H. et al., 2016]. Gamification designers need to take these factors into account when creating a gamified learning environment. If done well, the constraints can be integrated into the game's mechanics and thus, a fun feeling can be evoked [Nicholson, 2015]. This is due to the fact that the user has to find a strategy to optimize the reward while adhering to the given constraints.

2.4 End-User Participation

New, innovative approaches to an issue need to be deeply rooted in the practices of professional communities to be successful. Therefore, the tools should be actively designed together with their end users. For this reason, existing practices like co-design and participatory design have been established. However, they are often carried out in the context of small focus groups, outside the usual working practices. For this reason, our methodology seeks to establish feedback channels that scale to an arbitrarily large number of users. In order to realize this, agile development practices can be used, in particular DevOps, a recent methodology that aims to establish communication and automation amongst developers and operators. The term itself is a clipped compound of these words. DevOps has been popularized lately as an extension of agile development life cycles. The developers create create applications and the operators put them into practice on servers and thus they work more closely together. Although agile development practices have been introduced to accelerate the identification and realization of user requirements, they do not directly involve end users in the actual development process. Therefore we proposed DevOpsUse, which includes the notion of users who deliver initial ideas, perform beta tests, monitor and who give feedback [Renzel et al., 2017]. Our main instrument to collect comments from users is Requirements Bazaar. In our mixed reality environments, we employ Requirements Bazaar at different stages. Prior to the development phase, it helps collecting initial ideas. Users can also search for existing requirements or sort them according to different criteria. During runtime, users continue writing feedback and add new ideas. This is achieved by a feedback form.

2.5 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 on which the Windows 10 operating system is used. 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 [Westre, 2013]. C# can be used to implement the application logic [Rogers, Michael P, 2012]. The implemented code is supported by Microsoft's MixedRealityToolkit[5]. This open-source project under MIT license is available on GitHub and contains

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

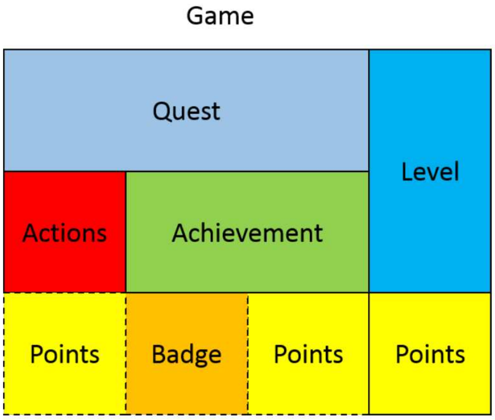
different basic templates and scripts to speed up the development process in Unity.

2.6 Gamification Framework

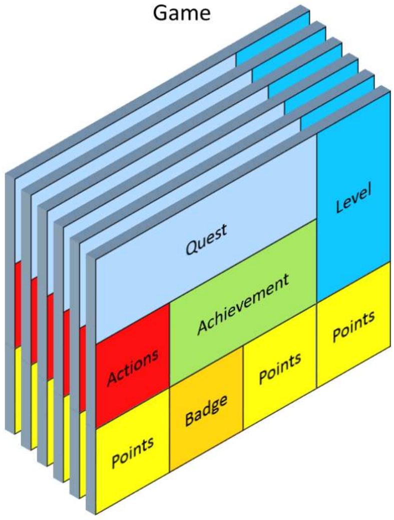
The gamification framework [Klamma and Arifin, 2017] which was developed at the RWTH Aachen University consists of frontends and gamification services. The frontends are implemented as gamification widgets which are based on the ROLE framework [Govaerts et al., 2011]. The ROLE framework is an open-source SDK. Developers can employ it to create personal learning environments (PLE). In the case of the gamification framework, the different widgets are placed in separate ROLE spaces in order to create the Web-PLEs. A gamification manager which has its own ROLE space can be used to create and configure the games. According to the principle of aspect-oriented programming (AOP), members of a Community of Practice (CoP) can inject the gamification widgets into their own Web-based frontends. This process of gamifying existing applications does not require any knowledge of programming skills. This way, members of the CoP can create and configure the gamified learning applications autonomously without support by developers. The injected widgets invoke action functions on the gamification backend services. A gamifier widget helps in finding a suitable place in the learning application where a certain action can be triggered. With the help of AOP, the trigger action function can be executed after an HTML element event has been called.

The gamification data are administered by the backend services of the gamification framework [Klamma and Arifin, 2017]. Its interface is generally organized in games and quests which contain actions. As seen in Figure 1a, a game consists of essential blocks like quests, achievements and actions, etc. In the shown visualization, blocks on the top depend on the blocks which are placed lower. A complex game, shown in Figure 1b contains multiple layers of these game element blocks. Hidden quests can also be realized. They can be shown to the user on the basis of defined constraints. In the procedure to set up the game elements, shown in Figure 1c, a level and a point threshold need to be defined. In addition, a quest can be created by first creating a badge. Then, an achievement is added and it is associated to the corresponding badge or amount of points. After that, the actions for the quest are defined. All these components are assigned to a new quest object. This process can be repeated in order to gain a complex gamification configuration.

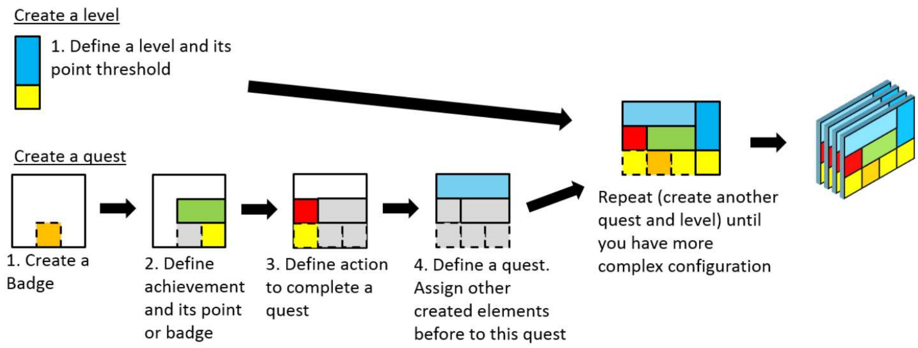
Actions state how the gamification behaves in detail. A member of the CoP performs the instructions of an action. Starting with the input of the learner, the gamifier component maps this specific input to the actions to control the core mechanic. From there on, further internal state changes to game elements



(a) Building Blocks of a Game [Klamma and Arifin, 2017]



(b) Stacked Game Elements Create a Complex Game [Klamma and Arifin, 2017]



(c) Setup Procedure of the Game Elements [Klamma and Arifin, 2017]

Figure 1: Elements and Setup of the Gamification Framework

are performed according to the rules of the game. These changes are constantly visualized to the user.

Game rules define how the separate game elements work together. Based on the rules, a player can proceed and progress in the game. Rules are a set of constraints which state how the member elements of the game are calculated. Member elements include all assets which the user can obtain by performing actions, e.g. badges, points or levels. Members of the CoP can configure the rules to their use cases. Once the gamification has been set up, these rules determine the way how the input which triggers the actions is handled, i.e. under which conditions points are awarded to the user or what requirements need to be met to complete a quest. The quests are also associated with achievements. Achievements can issue badges or points as rewards. The points can be used to progress in a level system. Gaining a higher level can be a condition to continue with further quests since quests can be hidden, revealed and completed. Hidden quests can be revealed by reaching a threshold of points. The quests can also be organized in a hierarchical way where subsequent quests become visible once the blocking previous quests have been mastered. Quests can be completed by triggering one or more actions which have been previously configured to be a part of the quest.

The points which can be gained during the quests by completing actions or gaining achievements can be compared with other learners in leaderboards. The framework distinguishes between two types of leaderboards: There is a leaderboard for comparing members within one CoP and a global leaderboard. When comparing members of different CoPs one has to consider that this only makes sense if the gamification is set up in a similar or identical way. Therefore, during the configuration of the gamification, members of the CoP can choose a distinctive community type. A comparison of members in a global leaderboard is only allowed between CoPs of the same type.

3 Concept

The GaMR framework is designed as a learning tool. Its structure can be seen in Figure 2. 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 framework also contains a feedback form where users can enter comments and suggestions about GaMR's development without leaving the app. The feedback is converted to a requirement and it is posed on the Requirements Bazaar. This way, the continuous development process can be guided and enhanced by the interests and findings of the end users.

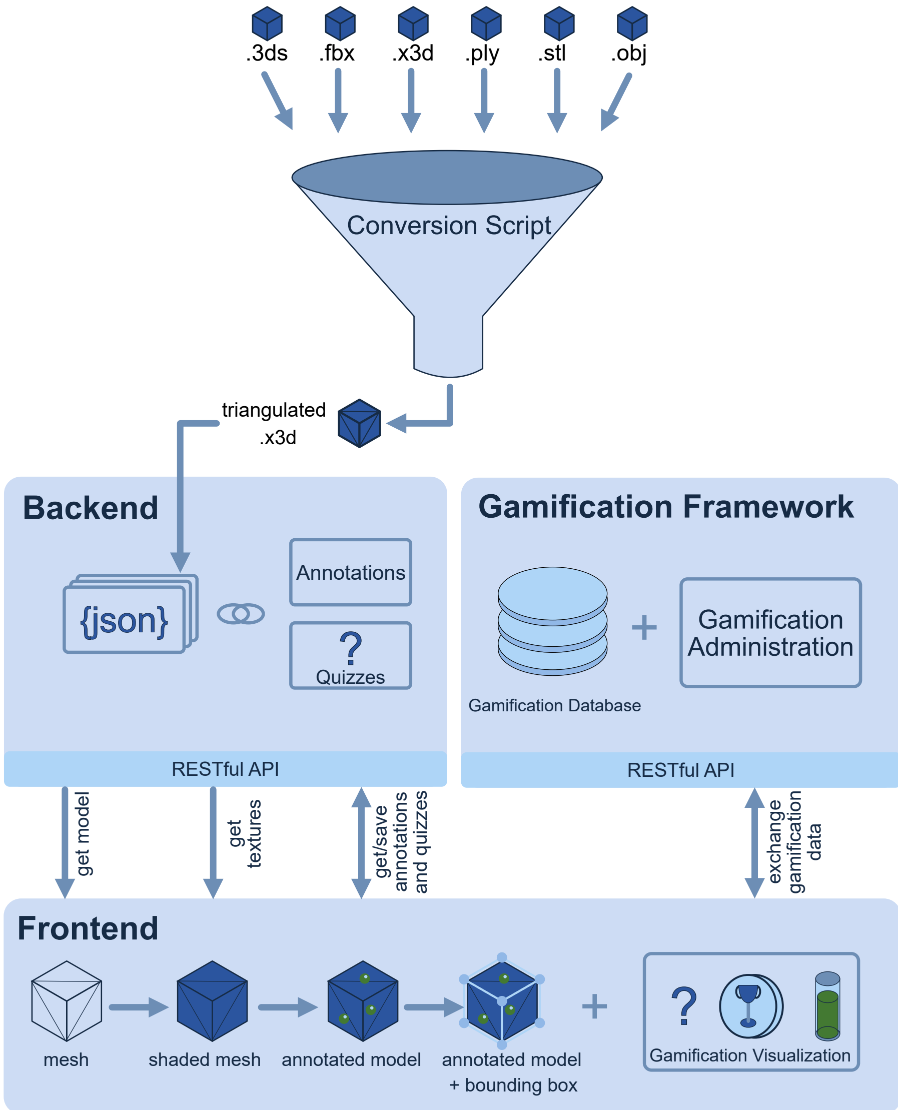


Figure 2: Components and Data Flow of the Developed System

3.1 Gamification Approach

The learning framework applies gamification approaches which are administered by the Gamification Framework. In order to communicate with its services, a mapping from the components of the developed framework to the interface of the Gamification Framework was designed. Similarly to the game which contains quests, the 3D model subjects contain quizzes. Thus, quizzes are regarded as quests. In GaMR, the individual quiz questions are modeled as a special kind of annotation which consists of a location and a text. This means that the workflow for creating quizzes and annotations is interchangeable and does not depend on the content of the 3D model. 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 if all questions in the quiz are answered correctly. A quiz is enhanced by an achievement. The achievement acts as a link between a quiz and a badge which is issued if the user successfully completes the quiz. Since the badges are given out by the Web-based learning service and are added to the user's account, they are permanently available once they have been acquired.

In addition to the integration of the Gamification Framework, 3D elements for gamification have been added to GaMR. A progress bar is displayed during a quiz. It indicates the amount of correctly answered questions in relation to the overall amount of questions. This acts as a motivating element to complete the quiz. Above the progress bar, a 3D representation of the badge is shown. Therefore, users can already see the reward which they can gain. Won badges are gathered in a 3D shelf and indicate the overall successes in multiple quizzes. This view acts as an overview for the learner in order to reflect on successes but also in order to realize knowledge deficits. With the help of GaMR, the student is able to optimize their learning strategy to cover the entire topic.

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. The protocol can solve this task by handling the core functionality of the authorization and extending it with user identification [Sakimura et al., 2014]. 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 the Anatomy 2.0 application [Nicolaescu et al., 2015]. 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 [Brutzman and Daly, 2010].

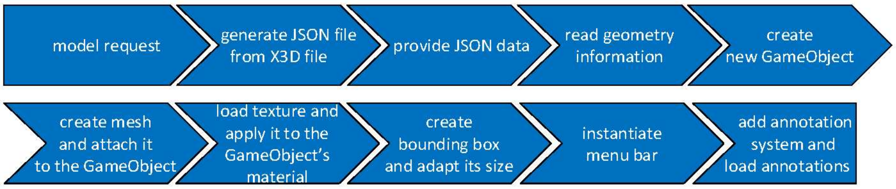


Figure 3: Linear Process Diagram Showing the Steps to Instantiate a 3D Model

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 3. 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.

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.

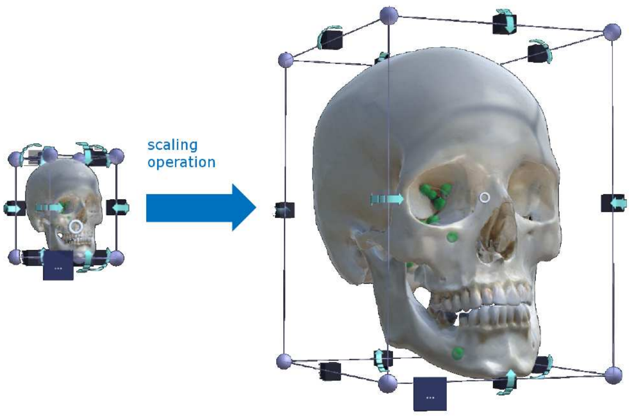


Figure 4: Bounding Box and its Widgets for Rotation and Scaling

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 4. This bounding box contains 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 posed 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. 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.

Since GaMR's initial release, the buttons and bounding box have been extracted from the framework and are now also offered in a separate repository[6]. They are bundled as ".unitypackage" files which developers can import into their own projects where they can be used as a starting point for their own UI.

4.5 Localization

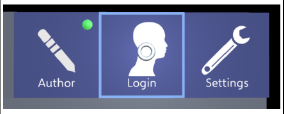
The user interface is localized into the English, German and Dutch languages. The implemented manager loads the translations as a dictionary. It is granted that there will always be a meaningful translation displayed. The localization system also affects the keyboard as it adapts its layout to the chosen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

4.6 Feedback Form with Integration to Requirements Bazaar

In order to realize close user participation, the framework offers a feedback form. By using the same 3D text fields from the annotation forms and the 3D keyboard which was previously developed, users can enter an idea or feedback directly in mixed reality without leaving the app. It was decided to structure the feedback into a title and a description section so that the main point of a comment becomes evident and still, additional information can be provided. The form is connected to the Requirements Bazaar where feedback is converted to a requirement in a dedicated section of the project. Developers can periodically check this section

[6] `https://github.com/rwth-acis/MixedReality-UI-Components`

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

in order to find new user feedback. Then, the feedback can be incorporated into the existing requirements engineering process. For instance, developers discuss it using Requirement Bazaar's comment system, move it to a corresponding category and they can assign themselves for developing the points mentioned in the feedback.

The Requirements Bazaar uses the same Open ID Connect authorization system and the same provider as the framework. Therefore, the access token for GaMR can be reused and it is also accepted by the Requirements Bazaar. This is convenient for the user as no additional login step is required and the feedback post at the Requirements Bazaar is automatically associated with the correct user identity.

4.7 VR Version

In order to increase the flexibility of the framework on the mixed reality spectrum, further implementation efforts were made in order to create a VR version. The development focused on the HTC Vive Pro as the target display device. This head-mounted display is connected to a computer which renders the application's graphics and also handles the computation. One major challenge posed the adaption of the authorization system. On the HoloLens, GaMR was deployed as a Universal Windows Platform app. However, the HTC Vive version is installed as a standalone application. Such applications cannot be activated by custom URL schemata. This means that the user cannot be guided back from the login Web page to the application in the same way as in the HoloLens app. Instead, a solution was realized where the application starts a server. The login procedure redirects the user to the localhost address and port number where the server is locally running. Once an access to this local server is registered, the application can receive the data of the redirection and shuts down the temporary server again.

The VR version requires the authorization code flow of OpenID Connect's authorization procedure. This flow initially returns a code which the application has to trade in for the access token.

The VR version also required changes to the input method. The HoloLens app uses the input handler interfaces of the MixedRealityToolkit. Application developers implement these interfaces in their scripts. The interfaces define special methods which are raised if certain input events occur, e.g. if the user taps on an object or tries to drag it along. The logic which determines when such an event is raised is embedded in the MixedRealityToolkit and uses UnityEvents. The goal for the VR version was to keep the input handler scripts unaltered and to mimic the event raising behavior which was defined in the MixedRealityToolkit. This was done by writing a similar input manager script which can react on button inputs and raises the according events. On the HoloLens, objects are selected by the gaze cursor which is controlled by head movements. As seen in Figure 5, this functionality was replaced with a pointing technique where a ray is emitted from the controller of the VR glasses. The pointing substitutes the gaze control and the trigger on the VR controller is equivalent to an air tap on the HoloLens.

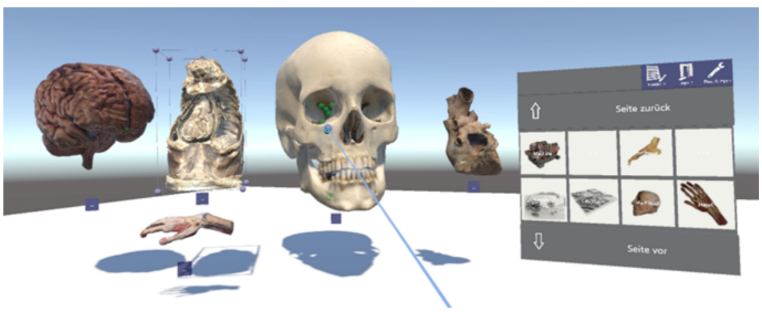


Figure 5: Screenshot Showing the VR Version of the Framework and its Pointing Interaction Technique

Another challenge which is more specific to VR is the problem of traveling larger distances in the virtual environment. In AR, users can move in the real space and expect the virtual environment to follow. Since the tracking sensors are mounted to the HoloLens, this locomotion can be registered and can also be applied to the virtual scene. However, in VR, there is no visual connection between the virtual environment that the user sees and the real room where the user is located. Therefore, it can happen that a virtual place is outside of the bounds of the real room. In combination with a limited and fixed tracking space, this makes it harder to reach this place since the user cannot just walk there. Instead, traveling techniques need to be used. Researchers developed a number of traveling techniques [Boletsis, 2017]. In the framework, a teleportation technique was implemented, as seen in Figure 6. This technique is also commonly used in other HTC Vive applications. If the user presses a button on the controller, an arc is drawn which starts at the tip of the controller. Its end point in the environment marks the target position to which the user can jump once the button on the controller is released again. The advantage of choosing the position by an arc instead of a straight line is that the user can teleport behind objects and to places which are not in view. A grid on the virtual environment also helps the user in estimating the distance which is covered by the teleportation operation.

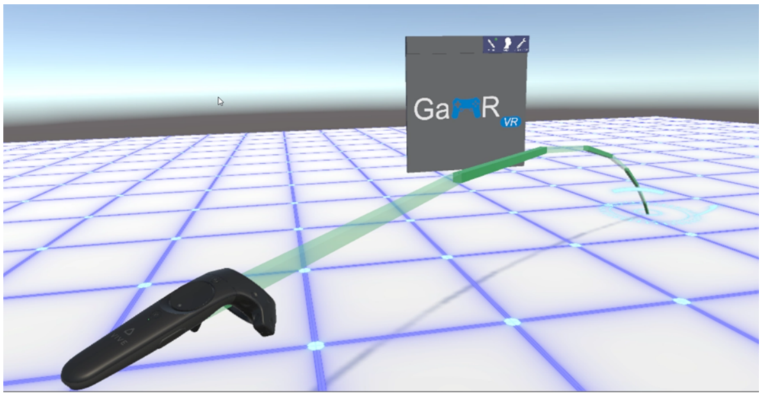


Figure 6: Screenshot of the VR Version Showing the Teleportation Visualization

5 Evaluation

The framework was evaluated at the medical school of the Maastricht University. Eighteen participants consisting of fourteen medical students and four doctors attended the evaluation. In the context of an anatomy lecture, the framework was applied in order to support the effectiveness of the teaching process. Starting with a prepared list of anatomical 3D models like the 3D scan of a skull or brain, the doctors created quiz questions and annotations in a first session. The doctors could choose from a selection of previously designed badges and add them to their quizzes. Then they answered a questionnaire about the application. After that, the students were introduced to the Microsoft HoloLens and learned about its interaction gestures. They could use the application and answer the recently set up quiz questions, respectively. Both groups created annotations on anatomical 3D models. Finally, the students were also asked to fill out a questionnaire. The questionnaires contained a range of quantitative and qualitative questions.

Thirteen participants were not familiar with AR and did not know the HoloLens as seen in Figure 7. They were enthusiastic about its possibilities and potential use cases for medical learning and training.

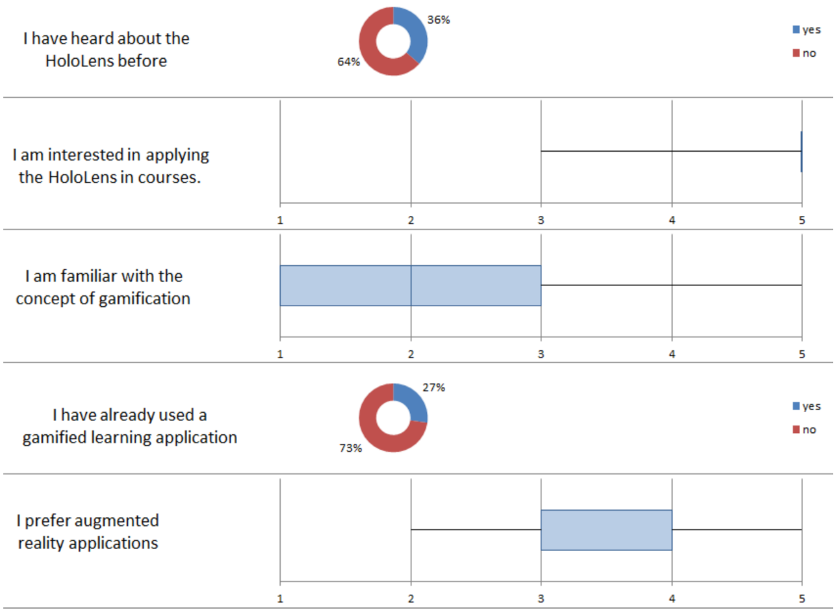


Figure 7: Excerpt of the Questions Which Were Asked Before the Evaluation

Figure 8 shows an excerpt from the questionnaire's result concerning the usability. The lecturers commented that they would like to use the application in a small course. They were immediately able to create quizzes and praised the intuitiveness of the process. The lecturers were also impressed by the fact that they only had to set the quiz up once and that it could be reused in subsequent courses and lessons. They noticed that numerous quizzes on the same 3D model

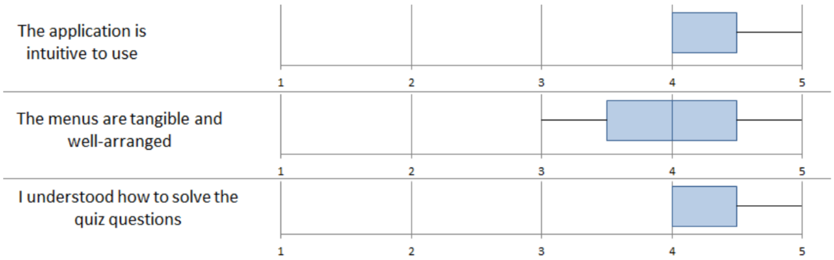


Figure 8: Excerpt from the Survey Results Concerning the Usability

could be created. In addition, it became evident that they could create a library of 3D models and enhance them with numerous quizzes for all aspects of the anatomy courses. Furthermore, they were very interested in speech recordings which can be attached to the annotations since they can provide additional information. Therefore, a multimodal learning experience can be achieved where the learning content is perceived by multiple senses at once. The doctors were delighted that the virtual anatomical models cannot be harmed and that they can be viewed by a larger amount of students simultaneously. The doctors also realized that they do not need to supervise the usage of the virtual 3D models.

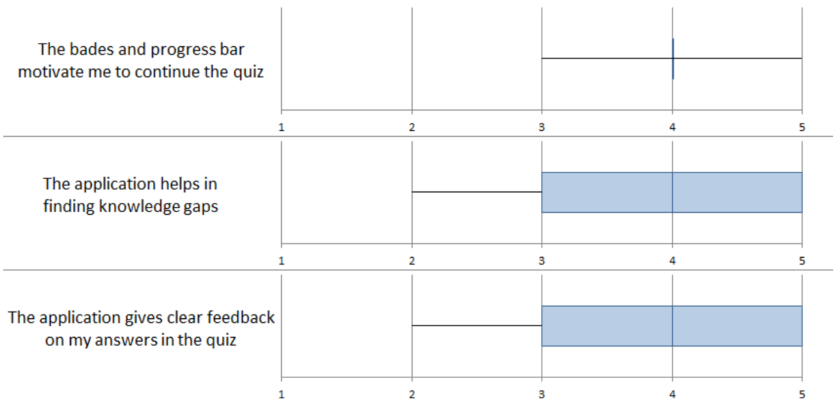


Figure 9: Excerpt from the Survey Results Concerning the Conceptual Approach

The medical students were excited about using the HoloLens as a new technology and they enjoyed studying with the gamified framework. They said that the gamification aspects of the framework increase the fun factor and thus the motivation in general. This can be seen in the results shown in Figure 9. The students see advantages over their usual studying methods like reading books or articles online. The combination of 3D models, annotations and gamification allowed them to freely explore the anatomic model. This way, they showed a higher activity level and inspected the model in more detail.

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. Remarks were made about the HoloLens' high price and weight of the head-mounted display. This was expected since it is a development-kit which is not meant for the consumer market yet. This shows that currently, the HoloLens is not suitable for private use but can still be a valuable addition to university courses and workplace learning where the device can be shared by various people and each participant wears the device for a fixed amount of time. Students and lecturers were unfamiliar with the concept of gamification but were interested in it. The HoloLens can be connected to a PC in the same network. Thus, the computer can show the view of the HoloLens as a camera feed which includes the inserted AR elements. This way, the application is not only perceived as a toolkit for one person but a group experience is forming. If someone makes a mistake or answers a question correctly, the other participants can see this and learn from others.

Furthermore, a technical evaluation was conducted to determine the framework's performance requirements on the HoloLens. 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 less than 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, online articles 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. The repository which contains the extracted UI elements will be extended by further elements which have been developed in this framework. They will also be ported to the upcoming version of the MixedRealityToolkit which features an overhauled input system. At the moment, the developed authorization procedure requires a manual step in the project generation where the code for the protocol handling routine is inserted into the final Universal Windows Platform (UWP) app source code. In Unity, scripts can be implemented which automate the compilation process. Such a tool can also be used to generate the necessary additional code for the authorization procedure in the final app.

The evaluation showed that the framework can be used in smaller courses. It became obvious that the learning application benefits from the gamification approach. Additionally, the immersive display of the 3D models in mixed reality enhanced the students understanding of the 3D structures because of the interactivity. The new technology required an exploration phase but this also increased the interest of the students in the learning application. 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 in mixed reality.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 687669 (WEKIT) and from the European Union's Erasmus Plus program, grant agreement 2017-1- NO01-KA203-034192 (AR-FOR-EU).

References

[AnatomyLearning, 2017] AnatomyLearning (2017). Anatomy Learning. `http://anatomylearning.com/en/`, Accessed in August 2019.

[Andrade, Fernando R. H. et al., 2016] Andrade, Fernando R. H., Mizoguchi, R., and Isotani, S. (2016). The Bright and Dark Sides of Gamification. In Micarelli, A., Stamper, J., and Panourgia, K., editors, *Intelligent Tutoring Systems*, volume 9684 of *Lecture Notes in Computer Science*, pages 176–186. Springer International Publishing, Cham.

[Boletsis, 2017] Boletsis, C. (2017). The new era of virtual reality locomotion: A systematic literature review of techniques and a proposed typology. *Multimodal Technologies and Interaction*, 1(4):24.

[Brutzman and Daly, 2010] Brutzman, D. and Daly, L. (2010). *X3D: Extensible 3D Graphics for Web Authors*. Morgan Kaufmann.

[Chou, 2015] Chou, Y.-k. (2015). Actionable Gamification. *Beyond Points, Badges, and Leaderboards*.

[da Silva et al., 2019] da Silva, M. M. O., Teixeira, J. M. X. N., Cavalcante, P. S., and Teichrieb, V. (2019). Perspectives on how to evaluate augmented reality technology tools for education: a systematic review. *Journal of the Brazilian Computer Society*, 25(1):3.

[Deterding et al., 2011] Deterding, S., Dixon, D., Khaled, R., and Nacke, L. (2011). From Game Design Elements to Gamefulness: Defining “Gamification”. In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*, pages 9–15. ACM.

[Farzan et al., 2009] Farzan, R., DiMicco, J. M., and Brownholtz, B. (2009). Spreading the honey: A system for maintaining an online community. In *Proceedings of the ACM 2009 International Conference on Supporting Group Work*, GROUP ’09, pages 31–40, New York, NY, USA. ACM.

[Govaerts et al., 2011] Govaerts, S., Verbert, K., Dahrendorf, D., Ullrich, C., Schmidt, M., Werkle, M., Chatterjee, A., Nussbaumer, A., Renzel, D., Scheffel, M., Friedrich, M., Santos, J. L., Duval, E., and Law, E. L.-C. (2011). Towards responsive open learning environments: The role interoperability framework. In Kloos, C. D., Gillet, D., Crespo García, R. M., Wild, F., and Wolpers, M., editors, *Towards Ubiquitous Learning*, pages 125–138, Berlin, Heidelberg. Springer Berlin Heidelberg.

[Hensen et al., 2018] Hensen, B., Koren, I., Klamma, R., and Herrler, A. (2018). An Augmented Reality Framework for Gamified Learning. In Hancke, G., Spaniol, M., Osathanunkul, K., Unankard, S., and Klamma, R., editors, *Advances in Web-Based Learning – ICWL 2018*, pages 67–76, Cham. Springer International Publishing.

[Herzig et al., 2012] Herzig, P., Strahringer, S., and Ameling, M. (2012). Gamification of erp systems - exploring gamification effects on user acceptance constructs. *Multikonferenz Wirtschaftsinformatik 2012 - Tagungsband der MKWI 2012*, pages 793–804.

[Kamphuis et al., 2014] Kamphuis, C., Barsom, E., Schijven, M., and Christoph, N. (2014). Augmented reality in medical education? *Perspectives on medical education*, 3(4):300–311.

[Klamma and Arifin, 2017] Klamma, R. and Arifin, M. A. (2017). Gamification of Web-Based Learning Services. In Xie, H., Popescu, E., Hancke, G., and Fernández Manjón, B., editors, *Advances in Web-Based Learning – ICWL 2017*, pages 43–48, Cham, Switzerland. Springer International Publishing.

[McCabe, 2015] McCabe, J. A. (2015). Location, Location, Location! Demonstrating the Mnemonic Benefit of the Method of Loci. *Teaching of Psychology*, 42(2):169–173.

[Milgram and Kishino, 1994] Milgram, P. and Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12):1321–1329.

[Nicholson et al., 2006] Nicholson, D. T., Chalk, C., Funnell, W. R. J., and Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Medical education*, 40(11):1081–1087.

[Nicholson, 2015] Nicholson, S. (2015). A RECIPE for Meaningful Gamification. In Reiners, T. and Wood, L. C., editors, *Gamification in Education and Business*, pages 1–20. Springer International Publishing, Cham.

[Nicolaescu et al., 2015] Nicolaescu, P., Toubekis, G., and Klamma, R. (2015). A Microservice Approach for Near Real-Time Collaborative 3D Objects Annotation on the Web. In Li, F. W., Klamma, R., Laanpere, M., Zhang, J., Manjón, B. F., and Lau, R. W., editors, *Advances in Web-Based Learning – ICWL 2015: 14th International Conference, Guangzhou, China, November 5-8, 2015, Proceedings*, pages 187–196, Cham. Springer International Publishing.

[Park, 2018] Park, D. Y. (2018). Periodic Table of the Elements. `https://docs.microsoft.com/de-de/windows/mixed-reality/periodic-table-of-the-elements`; Accessed in August 2019.

[Peters and ten Cate, 2014] Peters, M. and ten Cate, O. (2014). Bedside teaching in medical education: a literature review. *Perspectives on medical education*, 3(2):76–88.

[Prensky, 2005] Prensky, M. (2005). Computer games and learning: Digital game-based learning. *Handbook of Computer Game Studies*, pages 97–122.

[Renzel et al., 2017] Renzel, D., Koren, I., Klamma, R., and Jarke, M. (2017). Preparing Research Projects for Sustainable Software Engineering in Society. In *2017 IEEE/ACM 39th International Conference on Software Engineering: Software Engineering in Society Track (ICSE-SEIS)*, pages 23–32. IEEE.

[Rogers, Michael P, 2012] Rogers, Michael P (2012). Bringing Unity to the Classroom. *Journal of Computing Sciences in Colleges*, 27(5):171–177.

[Sakimura et al., 2014] Sakimura, N., Bradley, J., Jones, M., de Medeiros, B., and Mortimore, C. (2014). OpenID Connect Core 1.0.

[Schunk and Zimmerman, 1998] Schunk, D. H. and Zimmerman, B. J. (1998). *Self-Regulated Learning: From Teaching to Self-Reflective Practice*. Guilford Press.

[Schwan and Buder, 2006] Schwan, S. and Buder, J. (2006). Virtuelle Realität und E-Learning. *E-Teaching.org, Tübingen*.

[Shi and Cristea, 2016] Shi, L. and Cristea, A. I. (2016). Motivational Gamification Strategies Rooted in Self-Determination Theory for Social Adaptive E-Learning. In Micarelli, A., Stamper, J., and Panourgia, K., editors, *Intelligent Tutoring Systems*, volume 9684 of *Lecture Notes in Computer Science*, pages 294–300. Springer International Publishing, Cham.

[Stanculescu et al., 2016] Stanculescu, L. C., Bozzon, A., Sips, R.-J., and Houben, G.-J. (2016). Work and Play: An Experiment in Enterprise Gamification. In Gergle, D., Morris, M. R., Bjørn, P., and Konstan, J., editors, *CSCW '16*, pages 345–357.

[Takahashi, 2010] Takahashi, D. (2010). Website builder DevHub gets users hooked by "gamifying" its˜service.

[Trelease and Nieder, 2013] Trelease, R. B. and Nieder, G. L. (2013). Transforming clinical imaging and 3D data for virtual reality learning objects: HTML5 and mobile devices implementation. *Anatomical sciences education*, 6(4):263–270.

[Westre, 2013] Westre, A. (2013). *Design Games for Architecture: Creating Digital Design Tools with Unity*. Routledge.

[Zygote Media Group, 2017] Zygote Media Group, I. (2017). ZygoteBody. `https://www.zygotebody.com/`, Accessed in August 2019.