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Gamification of a medical learning application VRAna

Bachelor's Thesis (12 ECTS)

Curriculum Science and Technology

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Gamification of a medical learning application VRAna

Abstract:

As the quality of anatomy education is declining worldwide, faculties need to come up with new ways to engage and motivate students. Gamification is a growing trend in various fields including education, and can be an efficient instrument to help students study theoretical information. This work focuses on the gamification of a medical learning application VRAna by introducing several quiz scenarios for memorizing anatomical structures on the bones. The created games can be used as a supplementary tool for learning skeletal anatomy.

Keywords:

VR, gamification, anatomy education, game, anatomy quiz

CERCS: B440 Human anatomy and morphology, S281 Computer-assisted education

Meditsiiniõppe rakenduse VRAna mängustamine

Lühikokkuvõte:

Anatoomiahariduse kvaliteedi langemise tõttu peavad haridusteaduskonnad leidma uusi viise kuidas üliõpilasi kaasata ja motiveerida. Õppevahendite mängustamine on muutunud kasvavaks trendiks mitmetes valdkondades, sealhulgas ka hariduses. Seetõttu võib see olla tõhus vahend, mis aitaks õpilastel paremini tutvuda teoreetiliste materjalidega. See töö keskendub meditsiiniõppe rakenduse VRAna mängustamisele, luues sellele mitmeid anatoomiliste struktuuride õppestsenaariume. Loodud õppemänge on võimalik kasutada luustiku õppel täiendava abivahendina.

Võtmesõnad:

VR, mängustamine, anatoomiaõpe, mäng, anatoomiaviktoriin

CERCS: B440 Inimanatoomia ja -morfoloogia, S281 Arvuti õpiprogrammide kasutamise metoodika ja pedagoogika

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TERMS, ABBREVIATIONS AND NOTATIONS

Cadaver (Estonian *Laip*) a dead body, especially one intended for dissection[1].

Extrinsic motivation (Estonian *väline motivatsioon*) is a motivation to participate in an activity based on meeting an external goal, garnering praise and approval, winning a competition, or receiving an award or payment[2].

Intrinsic motivation (Estonian *sisemine motivatsioon*) is a motivation to participate in activity based on personal satisfaction or enjoyment instead of external factors like a reward or punishment[3].

Scene (Estonian *stseen*) is where one works with content in Unity. They are assets that contain all or part of a game or application. A project can have any number of scenes[4].

Transform (Estonian teisendus) contains position, rotation, and scale of an object. Every object in a Scene has a Transform[5].

User experience (Estonian *kasutajakogemus*) is how a user interacts with and experiences a product, system, or service. It includes a person's perceptions of utility, ease of use, and efficiency[6].

User interface (UI, Estonian *kasutajaliides*) is the point of human-computer interaction and communication in a device. This can include display screens, keyboards, a mouse, and the appearance of a desktop. It is also the way through which a user interacts with an application or a website[7].

Virtual reality (VR, Estonian *virtuaalreaalsus*) is a simulated experience that employs pose tracking and 3D near-eye displays to give the user an immersive feel of a virtual world[8].

VR sickness (Estonian *VR haigus*) occurs when exposure to a virtual environment causes symptoms that are similar to motion sickness symptoms.[1] The most common symptoms are general discomfort, eye strain, headache, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, and apathy[9].

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1 https://www.merriam-webster.com/dictionary/cadaver
2 https://www.sciencedirect.com/topics/psychology/extrinsic-motivation
3 https://www.healthline.com/health/intrinsic-motivation?c=1671319327210
4 https://docs.unity3d.com/Manual/CreatingScenes.html
5 https://docs.unity3d.com/ScriptReference/Transform.html
6 https://en.wikipedia.org/wiki/User_experience
7 https://www.techtarget.com/searchapparchitecture/definition/user-interface-UI
8 https://en.wikipedia.org/wiki/Virtual_reality
9 https://en.wikipedia.org/wiki/Virtual_reality_sickness

INTRODUCTION

Anatomy is one of the base subjects of a medical student curriculum, and learning it is crucial both for patient safety and for understanding other medical disciplines [1][2]. The universities are struggling to provide an adequate level of training, as the time devoted to anatomy learning in the curriculum shrinks, while the cost of maintaining dissection halls remains high [1]. Moreover, universities in many low- and medium-income countries struggle to provide cadavers for medical students due to economic, ethical, or religious hindrances [3].

To address these issues, the VRAna project was started as a collaboration of Tartu University, Lodz University of Technology, and Charles University. The aim of the project was to create an application that can be used as a replacement for cadaveric skeletons for medical students studying human anatomy. The result of work on this project is a VR application where students can explore the human skeleton and interact with the bone models, thus getting a better understanding of the spatial relationship between the parts of the skeleton. The bone models were made by laser scanning bones from the anatomy department of Tartu University, consequently, the models are accurate and can serve as a replacement for real bones. Additionally, the bone structures are annotated, which allows using VRAna as an anatomy atlas [4].

The application was tested by the first- and second-year medical students. The lack of motivation to use the application was continuously mentioned throughout all discussions, and the proposed solution was to give users some tasks and award points for completing them, as well as unlocking features such as different colors of models.

This thesis is focused on increasing the appeal of the VRAna application to students by introducing three game scenarios as well as additional small improvements to make the user experience smoother.

1 LITERATURE REVIEW

1.1 Anatomy learning

Anatomy is one of the first disciplines that medical, dental, and pharmacy students encounter at the university and it provides the knowledge required in many specializations [5][2]. Students have to learn the organization of macro/micro-forms and structures, their shapes, size, and location in the span of a year. Understanding human anatomy is essential for safe clinical practice, and especially so for surgical discipline, while failing to do so results in hazards to patients' safety, surgical malpractice [1], and a lack of understanding in other disciplines [2]. However, there has been a decline in the quality of anatomy teaching in universities, which can be attributed to several factors such as a reduction of the time in the syllabus that is devoted to teaching anatomy, availability of the study materials, low motivation to study theoretical information and availability of faculty time [1][5][2].

Cadavers have been a golden standard for anatomy education for centuries, but maintaining full dissection halls and cadavers themselves is costly [1], and creating new cadavers can be complicated due to the shortage of new bodies. In many countries, cadavers come mostly or exclusively from unclaimed bodies, as donating bodies to science is often prohibited by law or due to religious beliefs and social norms, while some countries only allow imported cadavers. Many universities in low- and middle-income countries are struggling to provide enough cadavers for an adequate level of medical training [3].

As a result, there is an emerging trend to replace or supplement cadaver dissection with other study materials created with the aid of modern technology, such as 3D printing or VR [1][5][6].

1.2 Virtual reality in medical education and training

In the medical field VR simulations can be applied for physical rehabilitation, pain management, surgery training, anatomical education, and treatment of mental health illnesses. In all of these areas, VR has been shown to be both cost-effective and efficient compared to traditional methods [6][7].

Traditional surgical training is based on observing senior surgeons in the operating room and on performing surgeries under their supervision. Due to the increasing complexity of the skills required for a successful surgery as well as the increase in the number of trainees, simply observing surgeons is not sufficient [6]. VR simulations are often used to prepare future doctors for various types of surgeries such as orthopedic [8], laparoscopic [9][10], or neurosurgery [11][12] (Fig. 1).

Surgery simulations provide a risk-free controlled environment for learning without the danger of harming real patients. Students trained with VR simulations perform real surgeries faster and with fewer mistakes compared to the students trained using traditional methods [13][8].

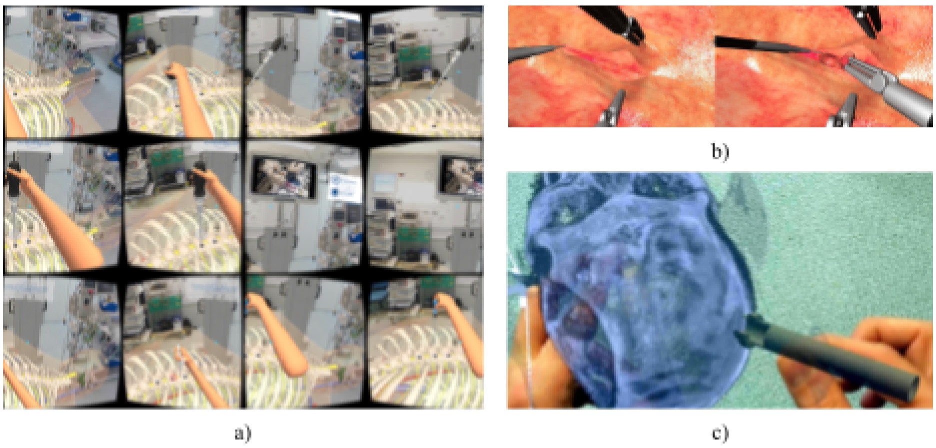


Figure 1: a) Orthopedic surgery simulation [8]. b) Laparoscopic surgery simulation [10]. c) Neurosurgery simulation [12].

Medical VR scenarios are not limited to surgeries, nursing students can be trained with simulations of a cardiac exam (Fig. 2a), a pupil dilation exam (Fig. 2b), and many more [13][14][15]. Other benefits of using VR in medical and nurse training include improved teamwork in medical teams, a better understanding of spatial relationships between the organs, an increase in self-confidence, and general performance improvement [16][13][17][18].

It is important to note that VR alone cannot replace clinical training or learning from experienced medical specialists, instead, it should be used as a supplementary tool in combination with other teaching methods [13]

a) b)

Figure 2: a) Cardiac exam simulation [13]. b) Pupil dilation exam simulation [13]

1.2.1 VR in anatomy education

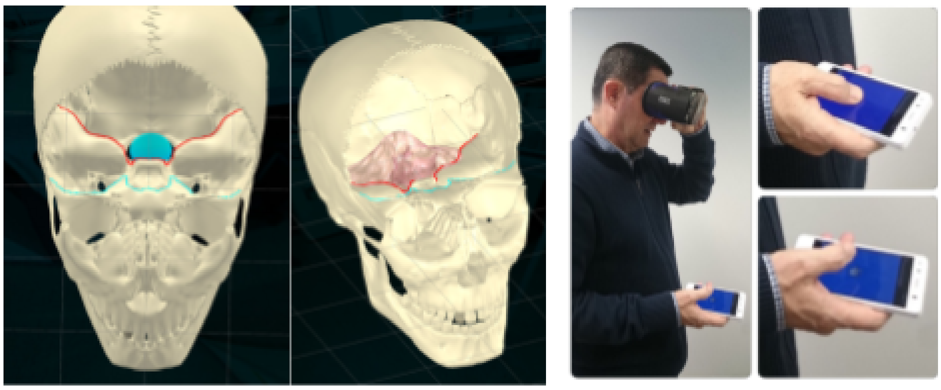
As it was discussed above, VR for medical education is usually focused on complex real-life scenarios as they benefit the most from a controlled environment and the possibility to repeat actions [13]. However, using VR in anatomy education improves test scores and increases student satisfaction while remaining cost-effective compared to traditional teaching methods [19][20].

Several VR applications have been developed for studying anatomy. Izard et al. developed a pilot version of an application for studying cranial structure (Fig. 3a). The application can run on several consumer range headsets, and is controlled with a smartphone (Fig. 3b), and has several modes: guided tour, quiz, vault assembly, and base assembly [21].

Erolin et al. created a collection of anatomical 3D models, where some were created from scratch and some were based on CT-scans (Fig. 4a). Models contained additional annotations, one model was animated and one had a voiceover describing the anatomical structure. Students could view the models and additional information in the Sketchfab VR editor. The feedback from the students was generally positive and mentioned issues included the lack of ability to navigate and steep learning curve [22].

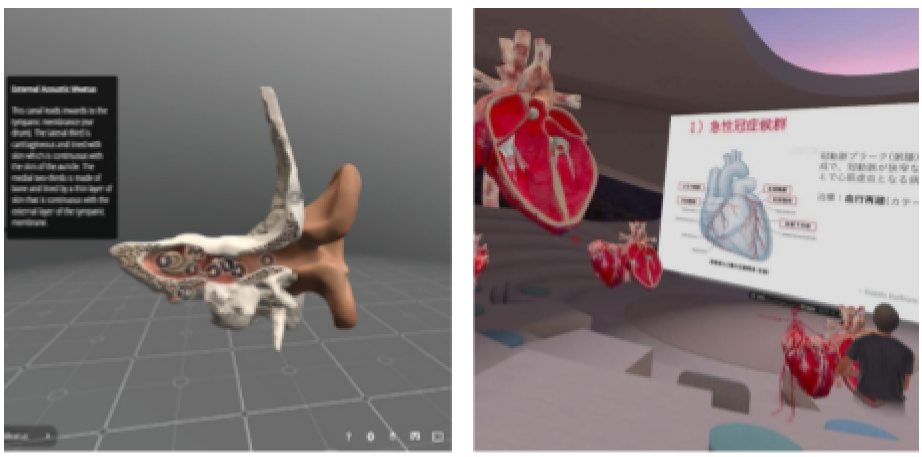
Nakai et al. developed a VR workspace for medical students, where students could attend lectures and interact with the anatomical models (Fig. 4b). The benefits of using this workspace were related to increased visibility and ability to interact with the models, while disadvantages included higher costs compared to 2D learning methods such as Zoom and VR sickness [23].

Kadri et al. designed iVAL, a VR lab for anatomy education. The application is built like an escape room, where a student enters the application, explores the lab, and then has to solve several puzzles to be able to exit the game. For learning skeletal anatomy, students had to explore the lab and the skeleton model (Fig. 5a), then memorize all the skeleton parts (Fig. 5b) and lastly place all bones in their specific locations (Fig. 5c). However, the authors did not provide details about the game design, scoring system, and evaluation of the tasks [24].



a) b)

Figure 3: a) Skull model in the application [21]. b) Controlling the application with a smartphone [21].



a) b)

Figure 4: a) Anatomical model viewed in the Sketchfab VR Editor [22]. b) Anatomy lecture of the heart [23].

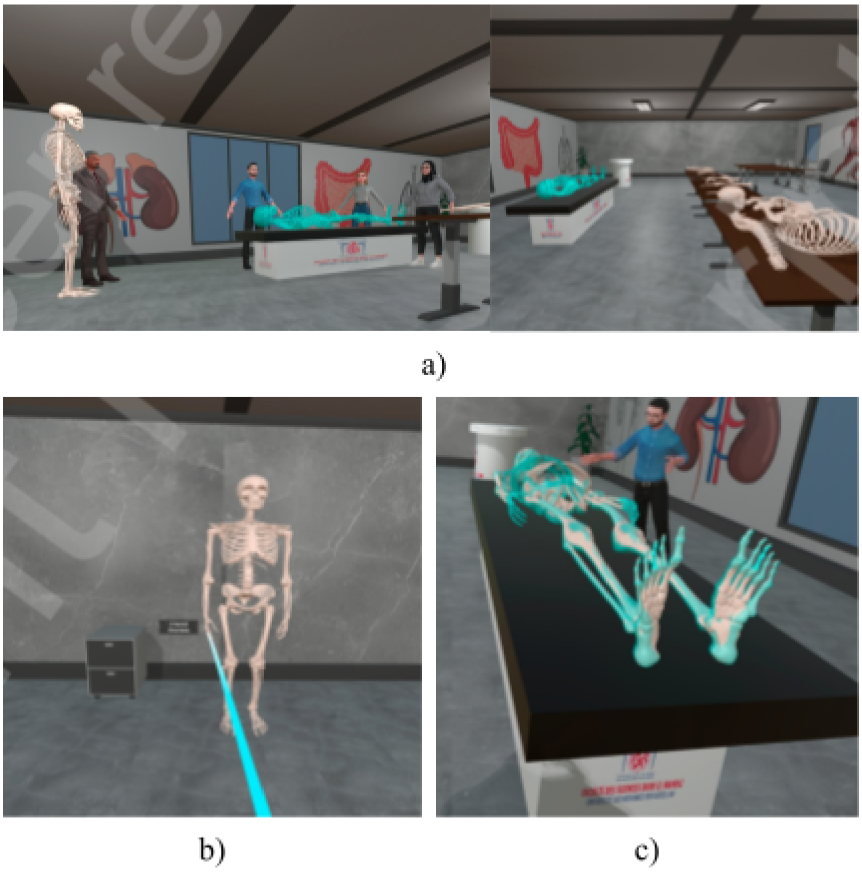


Figure 5: a) iVAL lab [24]. b) Memorizing the name of the skeleton components [24]. c) Placing each skeleton part into its specific location [24]

1.3 Gamification

Gamification is a broad term whose definition varies in different articles [25][26], with gamification as a usage of game design elements to enhance non-game contexts being one of the most commonly used. Gamification is achieved via the incorporation of elements like avatars, scoring systems with badges and points, leaderboards, levels, or any combination of them [25]. Game design elements provide extrinsic motivation that positively affects the engagement and intrinsic motivation of users, and thus are gaining popularity in many domains such as sales, marketing, health, human-computer interaction, and education [27].

1.3.1 Gamification in education

In the educational context, it is important to distinguish between gamification and game-based learning (GBL). Gamification in education includes game design elements like points and badges into existing solutions while having weak or no story. It usually is cheaper and easier to implement and is most appropriate for learning dry technical subjects. GBL often includes character situations and is story-based, which makes it a more suitable option for skill-building and player collaboration [28].

Gamification is rapidly adopted in education, both at school and university levels [29], as well as professional training, as it has a positive impact on cognitive, motivational, and behavioral learning outcomes, and the learning outcomes can be transferred to the non-game contexts. It is, however, important to note, that diverse gamification techniques have to be incorporated to achieve these results, and that gamification alone is not sufficient for providing high-quality education [30][31][32].

1.3.2 Gamification in medical education

Gamification and GBL are extensively used in medical education, where they can be used for learning new concepts or for repetition of the learned material. Gamified applications can provide immediate feedback to the students which is especially important with the reduction of training time combined with the growing number of trainees [2]. Recommendations for gamification in medical education include instant feedback or fast feedback cycles, incorporating only one or two game design elements to keep the focus on the main material and making those elements reusable [33].

Many of the aforementioned applications for learning anatomy incorporate gamification techniques, such as quizzes and skeleton assembly puzzle [21][24], while various surgery simulations and emergency room scenarios use GBL to facilitate skill-building.

2 THE AIMS OF THE THESIS

- Creating several game scenarios for a VRAna application.
- Testing created games on a target demographic.
- Making improvements to the VRAna application to enhance user experience based on the previous feedback.

3 IMPLEMENTATION

3.1 Materials and methods

3.1.1 Hardware

Development was done on a PC running Windows 10 with NVIDIA RTX 3060 graphics card, HTC Vive headset was used for testing. The minimal requirements for a graphics card are NVIDIA GeForce GTX 970, AMD Radeon R9 290 or better. The headset has to be SteamVR compatible, but models that differ from HTC Vive will need a remapping of inputs.

3.1.2 Software

VRAna application was developed on Unity Engine, version 2020.3.27f1. Unity scripts are written in C# language. Unity XR Interaction Toolkit together with SteamVR was used for VR interactions.

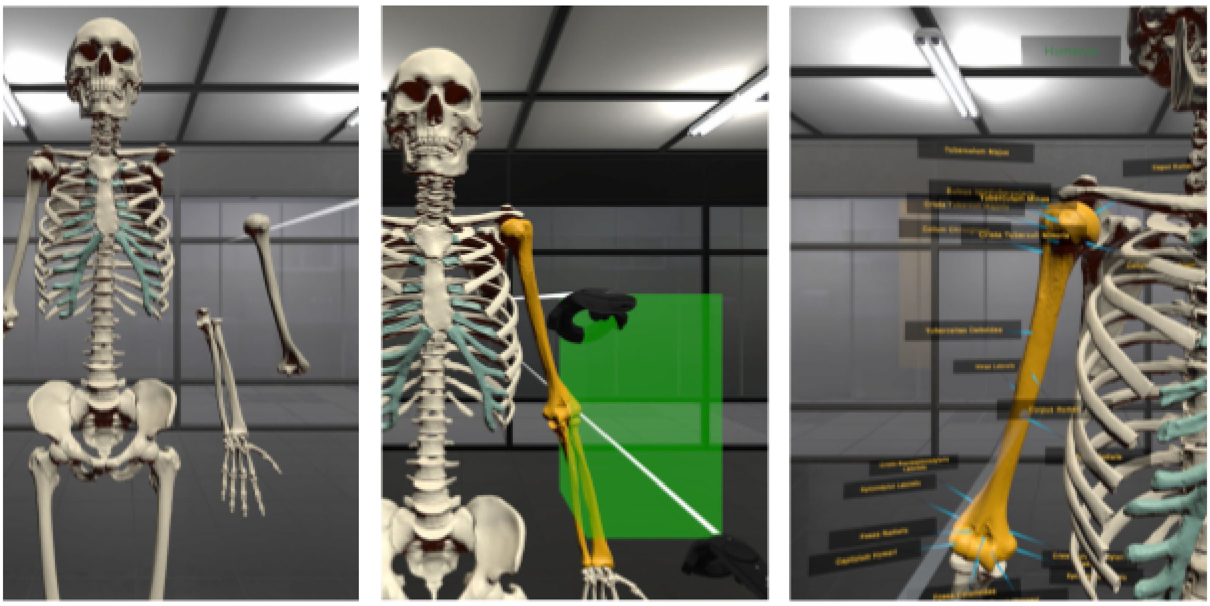
3.1.3 VRAna project

VRAna application consists of one main scene that is designed like an anatomy lab with a full skeleton model and extra copies of several skeletal structures (Fig. 6a), additionally, there are instructions on how to use controllers for navigation and movement (Fig. 6b). Players can interact with all bone models either by selecting them separately (Fig. 7a) or by using a multi-select box (Fig. 7b). Selected bones can be resized, rotated, moved around, or reset to their original position. When the bone is hovered over, players can see additional labels that annotate specific structures on the bone (Fig. 7c). To move around the lab players can either use real-world movement or a teleportation option.

a)

b)

Figure 6: a) VRAna lab. b) Instructions for using controllers.



a) b) c)

Figure 6: a) Selecting a single bone. b) Using a multi-select box. c) Viewing labeled bone structures.

3.2 Improvements based on the previous feedback

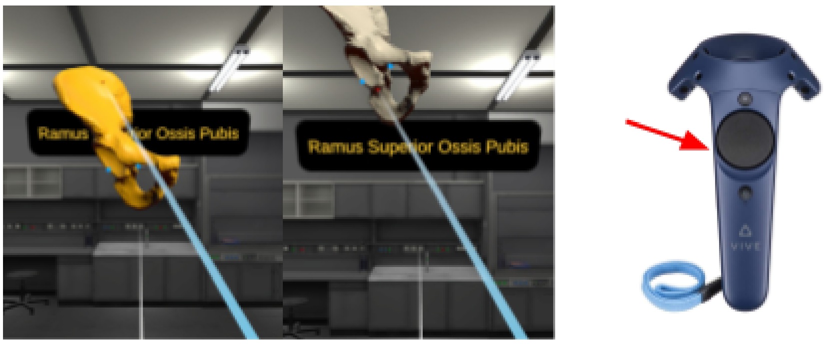
The feedback to the main VRAna application was focused on the lack of engagement and motivation to use it, which was addressed by this thesis. There are, however, other small improvements that are based on the feedback from the medical students.

1. Grabbing of the bones was unstable due to implementation of Unity's XRSingleGrabFreeTransformer class (Fig. 7a). It was fixed by overriding a method that calculated the grab pose in a custom script.

2. The multi-select box size calculation was made based on the world position of the controllers, thus making it dependent on a player's world rotation. This was changed to make the box calculation size depend only on the local position of the controllers. The improvement was intended for a game scenario that remained in a prototype stage and is not used in the other games.

3. Originally players could rotate in the scene just by touching a button on a controller (Fig. 7b), however, the buttons are very sensitive and this resulted in a high amount of unintentional rotation, causing disorientation and VR sickness. The ability to rotate by touching the buttons was removed, leaving the ability to rotate by pressing the same button.

4. The scenes contained occasional duplicate labels or uninitialized fields in the scripts. All of these were removed to make further modifications and debugging easier.



a) b)

Figure 7: a) Bone model position before a bone was grabbed(left) and right after grabbing(right). The attach position is marked with a red dot. b) Touch button on the Vive controller [34].

3.3 Game design

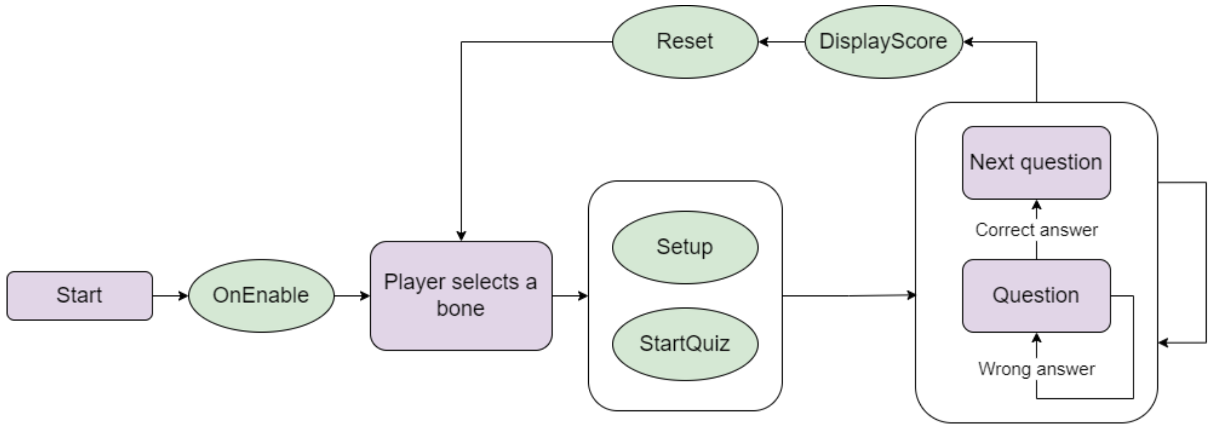


Figure 8: Gameloop that runs in each scene. Green ellipses correspond to the methods in the game manager scripts.

A new scene in the project was created for each game scenario, but the majority of the objects and settings were copied from the main scene. Each scene has a game manager object to which a manager script component is attached, the manager script holds references to other game objects used in the game scenario.

Each manager script has *OnEnable*, *StartQuiz, DisplayScore,* and *Reset* methods (Fig. 8). *OnEnable* method does the initial setup such as finding all UI objects and setting the material for each bone model, this method performs costly computations as it has to manipulate materials and find objects in the scene, but it does not affect the user experience, since the method is called once per scene initialization. The initial setup is slightly different for each quiz.

Game scenarios that require players to select a bone as a quiz topic have an additional *Setup* method that prepares the scene for a quiz. This method moves and rescales the selected bone to make interaction with the bone convenient for players, as well as activating a UI element with the "Start" button.

StartQuiz method initializes the question list and activates the UI element for displaying questions. For initialization of the question lists, label lists need to be shuffled to avoid repeating the same questions on each round. Shuffling is done in place with a Durstenfeld variation [35] of a Fisher–Yates shuffle algorithm [36] (Fig. 9), random integers are generated with the *System.Random* class. Information about bone structure names and locations is retrieved from annotations that were created for the main scene.

DisplayScore method displays a UI element with players' points and the maximum possible amount of points, as well as the "Finish" button. Clicking on this button calls *Reset* method.

Reset method resets the game to its initial state by clearing the question list, zeroing point count, and current quiz topic for quiz scenarios one and two.

```
-- To shuffle an array a of n elements (indices 0..n-1):
for i from n-1 down to 1 do
     j ← random integer such that 0 ≤ j ≤ i
     exchange a[j] and a[i]
```

Figure 9: Shuffling algorithm [36]

3.3.1 Difficulty setting

Quizzes one and two have three difficulty levels: easy, medium, and hard. If the difficulty level is set to easy, players have three attempts, after which the points are not considered toward the final score. With a medium difficulty level points are halved after each of the first three attempts and the following guesses don't count. On a hard level only the first guess counts. Independently of the difficulty level, players have to answer correctly before they can proceed to the next question.

Additionally, there is an option to limit the answer options to the structures from the question list, as opposed to having all structures of the bone as answer options.

These features were added based on feedback from the students and the medical professor who evaluated the game. This input was also used to decide how many questions per round each quiz has by default.

3.4 Quiz scenario 1

The first quiz scenario presents players with a name of a structure and multiple highlighted labels, to score a point players need to select a correct label on the bone. Each quiz round has ten questions, with the possibility to change this number in the Unity Editor.

The scene starts with the instructions and a skeleton in front of the player (Fig. 10a). To select a quiz topic, players have to click on a bone. To make clicking on the labels easier for players the bone is rescaled and moved to a hardcoded location approximately in front of the player's chest (depending on the height of the player). The rest of the skeleton is hidden (Fig. 10b).

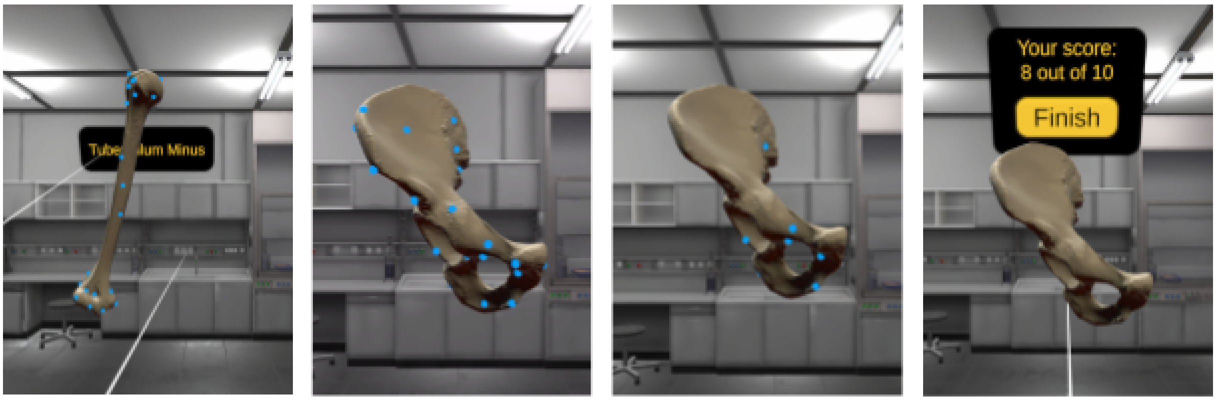
a) b)

Figure 10: a) Initial quiz scene. b) Player has chosen a bone for a quiz.

Once a bone is selected, players can start a quiz by clicking the "Start" button. A question list is initialized from a shuffled list of all bone labels, labels are activated and the first question is displayed (Fig. 11a). As the bones have many labels that are placed close to each other (Fig. 11b), players can choose only to activate labels for the structures from the question list (Fig. 11c).

The player selects a label by clicking on it, the name of the label game object is compared to the current question. If the answer is correct, the question number and the correct answer count are increased and players can proceed to the next question. If the answer is wrong, the behavior differs depending on a chosen difficulty level.

When players answer the last question, they are presented with a score and a button to finish the quiz (Fig. 11d). Clicking on the "Finish" button resets the quiz and players can try again with a new bone.



a) b) c) d)

Figure 11: a) Questions in a quiz. b) All labels as answer options. c) Labels from the question list as answer options. d) Score after solving the quiz.

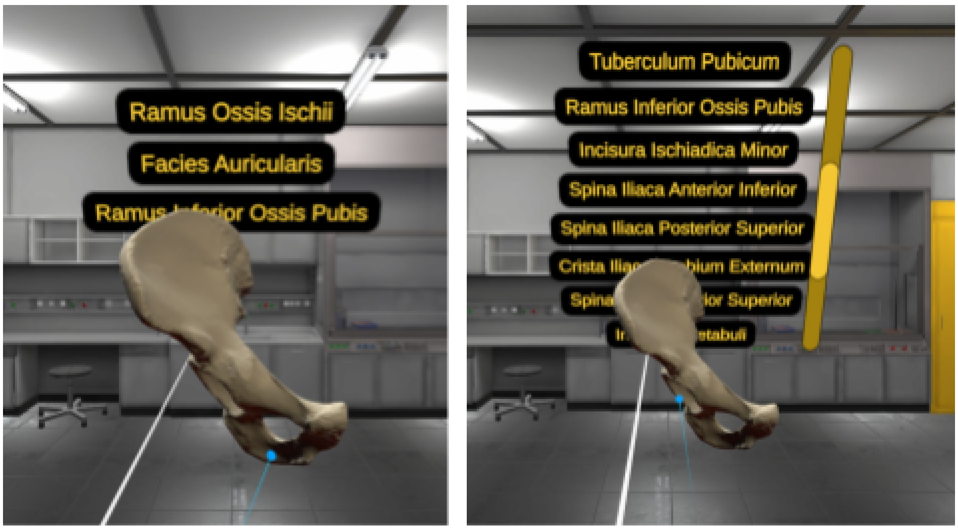
3.5 Quiz scenario 2

The second quiz scenario presents players with a single highlighted label and a list of the structure names, to score a point players need to select a correct structure from the list. Each quiz round has seven questions, with the possibility to change this number in the Unity Editor.

The initial state of the scene and topic selection are identical to the first quiz scenario. Once the “Start” button is clicked, a question list is initialized from a shuffled list of all bone labels. The quiz manager populates a scrollable menu UI element with answer options and shuffles the question list again to prevent questions from being in the same order as the answer choices. Similar to the first quiz, answer options can either include all labeled structures (Fig. 12a) or only those present in the quiz (Fig. 12b). The bone is rescaled and moved in front of the player.

The label corresponding to the first question is activated and players have to answer by clicking on a structure name in the menu. Additionally, a line pointing at the label is rendered to make noticing the labels easier. Similar to the first scenario, there are three difficulty levels for calculating a score.

Same as in the first quiz, after answering the last question, players can see their score and a button to finish the quiz.



a) b)

Figure 12: a) Labels from a question list as answer options. b) All labels as answer options.

3.6 Quiz scenario 3

The third game scenario shows a structure name and two bones to players, to get a point players need to select a bone that this structure is related to. Each quiz has 15 questions and a possibility to change the number of questions in the Unity Editor.

At the start of the game manager script fetches a list of all bones that have labels. Once the player clicks the "Start" button, this list is shuffled and two first distinct bones are selected for a quiz. The bones are moved to hardcoded locations in front of the player and the question list is initialized. The question list consists only of labels that are unique, as several bones can have structures with the same name (Fig. 13a).

Players answer the questions by clicking on one of the bones, the name of the bone is compared to the name of the bone to which a structure belongs to. Each question can be answered only once, as after the first attempt players immediately know the correct answer (Fig. 13b).

After answering all questions players can see their score and start another quiz.

a)

b)

Figure 13: a) Question in a quiz. b) Feedback after the player gave an incorrect answer.

3.7 Puzzle scenario

In the puzzle scenario the goal is to put the bones in their correct anatomical position. The quiz starts with several bones lying on a table and additional bones giving a reference for a target position (Fig. 14), each puzzle covers a part of a skeleton, such as a shoulder joint (Fig. 14a) or an arm plus a forearm (Fig. 14b). In the beginning, this game scenario was the most promising one, as VR allows moving and placing the bones without gravity and thus has an advantage over using cadaveric bones. However, the idea never left the prototype stage due to constraints encountered in the process.

a)

b)

Figure 14: a) Shoulder joint puzzle. b) Arm and forearm puzzle. In both pictures the reference bones are green.

The proposed game mechanic is quite straightforward. The position of a bone is computed relative to the arbitrarily chosen parent bone and considers both positional and rotational offsets. The expected placement is determined by the bone's positional and rotational offset from the parent bone in the original skeleton. To pass the puzzle players have to put a bone close to the target position, where allowed positional and rotational differences from the target are small and arbitrarily chosen.

3.7.1 Limitations

The prototype was constructed and tested, but after evaluation with a medical professional it was decided not to proceed with the development, as the discovered issues would render the game in its current form unsuitable for learning skeletal anatomy.

Problems:

1. Acceptable placement is difficult to calculate programmatically from a target transform and a parent transform. Many skeleton parts have joints where the allowed range of motion and rotation is too complex and allowed positions would need to be customized for each bone group used in a puzzle.

2. Moreover, in some cases, there are different requirements for considering a bone assembly correct. For example, as carpal bones have different shapes in different people, students should be able to place bones in the correct order and the bones should form two rows [37] (Fig. 15). For such cases, a different scoring system would have to be developed separately for each case.

3. The bones come from different people, which means they do not fit together perfectly, and different medical professionals have varied opinions on how they should be assembled. It means that sometimes the students would be unfairly penalized for having a different opinion on the correct anatomical position.

4. Precise control is difficult to achieve in VR, therefore the puzzle would have to accept a wider range of placements. Hence, it would be harder to differentiate between an assembly that is wrong due to a gap in a student's knowledge and an assembly where a student knew the expected position but couldn't place bones exactly as they wanted.

Achieving the desired behavior is possible, especially in collaboration with medical professionals who could provide guidance for requirements and acceptable positions, but the amount of work required to do so was outside of the scope of this thesis.

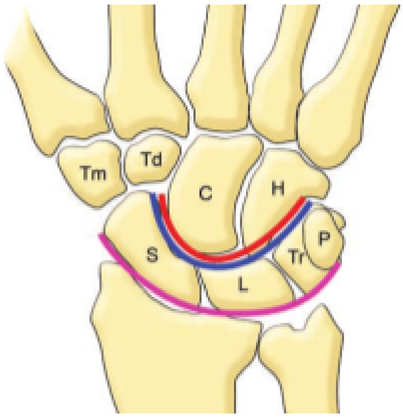


Figure 15: Normal anatomy of the carpal bones [37]

3.8 User interface and user experience

Smooth user experience is an important part of the VR application design. To make the games appealing to the players the interface has to be intuitive, the interactions need to be easy and the environment has to be pleasant to stay in. As a consequence, when developing each game user experience had to be considered on the same level as game mechanics.

Design and testing, however, were time-consuming and limited due to the fact that input from a keyboard and a mouse in the Unity Editor did not always produce the same result as controller input in VR. Moreover, a picture on a computer screen and in a VR helmet has different aspect ratios as well as different saturation and brightness. As a result, many design choices made during development were not applicable and had to be reconsidered and revisited several times.

When testing the application and comparing it to other works, particularly the iVAL lab[24], it became evident that the background colors are too light, while the skeleton is too dark (Fig. 16a, upper). The lack of contrast is even more noticeable if the player is standing behind the light source in the scene. This issue was addressed by changing the color of the background materials, reducing the intensity of a light source in the room, and making the light source follow the main camera so that it acts as a head flashlight (Fig. 16a, lower). The resulting change in contrast between the skeleton and the background can be clearly seen in the grayscale version of a scene (Fig. 16b).

a) b)

Figure 16: a) VRAna lab, original (upper) and modified (lower) colors. b) Grayscale image of original (left) and modified (right) lighting and colors.

To make understanding the games as easy as possible, each game starts with the instructions panel. These instructions explain the rules of the game and the scoring system (Fig. 17a). Questions are displayed on the panel and the panel is automatically resized to fit the text. For the second quiz scenario, answer options are displayed in a list with a scrollbar, the scrollbar is automatically hidden if all elements fit into the view (Fig. 17b). The color scheme of UI elements is chosen to fit the color scheme of the VRAna lab, in particular the yellow plastic material. In quizzes one and two the bones that don't have any annotations are rendered with a dark semi-transparent material, also visible in Fig. 17a.

As an exception to the main color theme, blue color was chosen for the label spheres to increase contrast with the bone color and the background scene. Pointing at the label spheres was difficult for most users, as originally these were made small to be displayed together with structure labels. However, if the spheres were made too large they started covering most of the surface of the bone and colliding with each other. The final diameter of the spheres was empirically chosen to balance between the two. Another label type was tested, where the interactable spheres were some distance away from the bone with a line pointing toward the labeled structure. This, however, made grabbing and rotation of the bones inconvenient, as the spheres could be accidentally clicked on. Consequently, the alternative labels were not used in quizzes.

a) b)

Figure 17: a) Instructions panel, quiz 1. b) An answer list with a scrollbar, elements are resized to fit the text.

In each game, the players need to receive feedback as soon as they give an answer, as instantaneous feedback is one of the important features of VR. The feedback is implemented by changing the color of the selected answer option to red and scaling the model down if the answer is incorrect or setting the color to green and scaling up if it is correct (Fig. 18). To avoid misclicking, players also receive feedback when they hover over an answer option.

a) b) c)

Figure 18: Instantaneous answer feedback in quizzes. a) Quiz 1, before and after giving a correct answer. b) Quiz 2, incorrect answer. c) Quiz 3, incorrect answer.

Despite receiving instant feedback on the answer, players can occasionally double-click on the answer option. To avoid this, after each answer, there is a timeout of one second, during which new clicks are not registered.

4 RESULTS AND DISCUSSION

4.1 Results

As a result of the work done for this thesis, three quiz games were created to enhance the VRAna application. Additionally, minor improvements were done to the main project. The application code can be found at https://bitbucket.org/erichaamer/vrana/src/gamification/

The created games were tested on five first-year medical students. The medical students were asked to play all three games several times and then to fill in the questionnaire, the results are shown in Fig. 19. Additionally, students were asked to give free text feedback on what they liked about the games and what could be improved.

Intuitiveness: How intuitive was the game?

Engagement: How engaging was the game?

Difficulty: How difficult were the tasks?

Clarity: How clear were the instructions?

Usability suppl.: Would you use it as a supplementary tool to study anatomy?

Usability main: Would you use it as a main tool to study anatomy?

Interest: Were you interested in the tasks?

Effort: Did you have to put a lot of effort into the tasks?

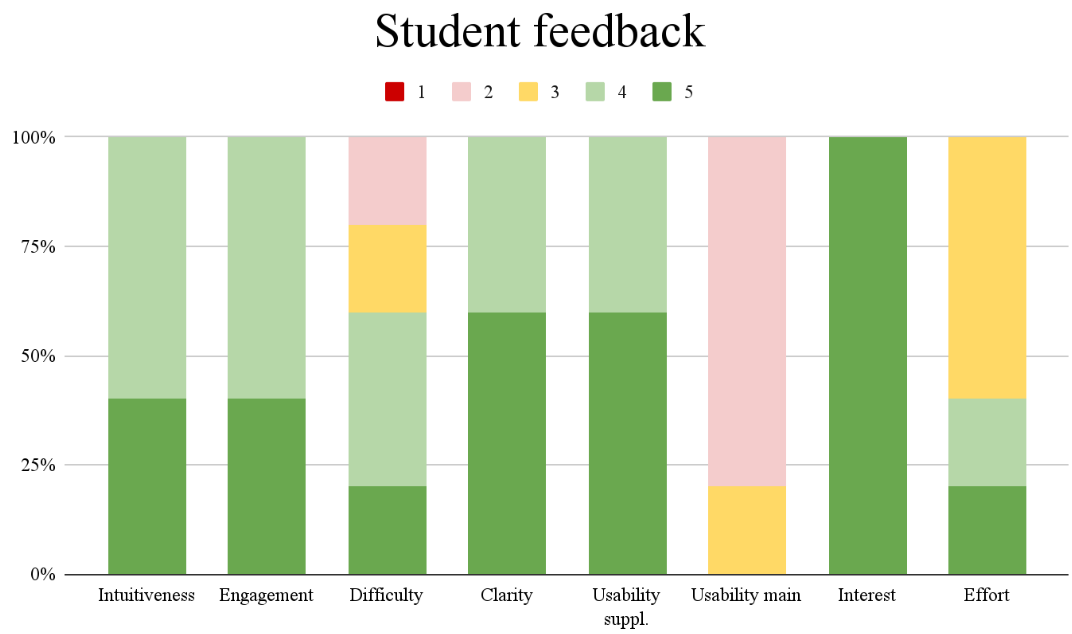


Figure 19: Players' answers to questions about the games, where 1 is "Not at all" and 5 is "Absolutely".

The open text feedback included several suggestions:

1. To have different difficulty levels, as only one difficulty level was implemented when the students were testing the games. This was addressed by adding three difficulty levels with different scoring and an option to hide answer choices that are not present in the quiz.

2. A similar suggestion was to hide the answer choices that were already selected during the previous rounds of guessing. Due to the abundance of labels that are located close to each other, students sometimes forgot which ones they already tried as answer options. This was also partially addressed by the option to reduce the number of answer choices.

3. To change the label spheres to pins. Students found it challenging to aim at the spheres with the controllers in the first quiz and to find the active label in the second quiz.

4. To move the bones closer to the user, which means that the bones were too far away from the player to interact with them conveniently. This was partly addressed by moving the player's starting point in the game closer to the bones.

5. To make UIs less sensitive, as students had issues interacting with UIs in VR. The scrollbar in the second quiz was too sensitive and the buttons could be clicked unintentionally.

4.2 Discussion

The students' feedback was generally positive, as can be seen from the results of the questionnaire. The students found the games to be easy to navigate and engaging, with some students finding the tasks easy and some perceiving them as quite difficult. The results suggest that these quizzes can be used as a supplementary tool to study anatomy, for example for repeating all bone structure names before the exams.

Despite the mostly positive feedback, there are some problems left to be fixed, most of them related to the way the structures were originally labeled. Students had issues with pointing at the label spheres, to address this problem more alternative label visualizations should be tested for the quiz games.

Some bone structures were labeled incorrectly, as the labeling was not done by medical professionals. Likewise, many structures cannot be adequately labeled with a single point, as the name corresponds to an area or a long groove on a bone, which made it difficult to answer some questions in the first and second scenarios. This can be fixed by annotating different types of structures with labels of different color or size.

The problems with UIs arise mostly from the fact that they were not fully tested with a headset and controllers, as the possibilities to do so were limited. UI elements are created with the use of a built-in Unity UI framework, that is most suitable for 2D games and can exhibit undesirable behavior when used in VR.

4.3 Future work

In the future, several aspects of the application can be improved based on the feedback received from the students, as an extension of what was started during the work on this thesis, or as an effort to make the VRAna application more accessible.

The label placements can be revised and the visuals can be improved to make the labels more noticeable in the quizzes. To address the issue with a single label point indicating an area or a groove, labels of several types can be introduced. Additionally, the feedback on how engaging the games were is promising, but the testing should be done on a bigger number of students for a more extended time period, as the environment and the novelty of using VR could affect students' initial opinions.

The prototype of a bone assembly puzzle can be made into a finished scenario with additional feedback from medical professionals. The medical professionals could also provide input on how to incorporate additional game design elements such as levels or progress into the games, as it was not possible to implement these features without guidance from a professional who is qualified to design assignments for medical students.

To make the VRAna application more accessible for students and universities, it could be ported to run on cheaper consumer-level devices such as Oculus Quest or Google Cardboard.

SUMMARY

The aim of the thesis was to increase the appeal of VRAna to the medical students, as tests have shown that the students are not motivated to use the application. To enhance the application three anatomy learning quizzes were successfully developed during the work on this thesis. They were tested on medical students who expressed interest and found the games engaging. These quizzes can be used as a supplementary tool for studying skeletal anatomy and can be further expanded to fit the requirements of anatomy teachers.

In addition, improvements based on the previous feedback were done to the VRAna project and a prototype of a bone assembly puzzle was created.

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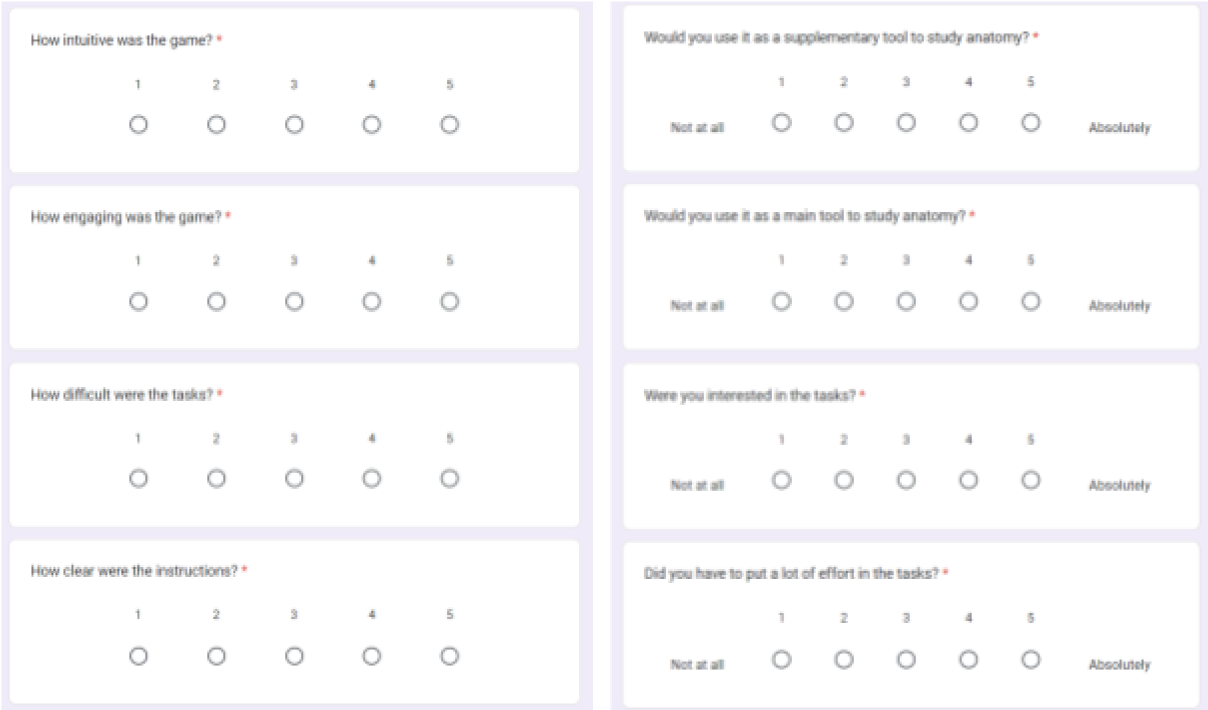
Appendix

I. Questionnaire

Screenshots of the questionnaire that was filled in by the students.



How intuitive was the game? *

1 2 3 4 5

How engaging was the game? *

1 2 3 4 5

How difficult were the tasks? *

1 2 3 4 5

How clear were the instructions? *

1 2 3 4 5

Would you use it as a supplementary tool to study anatomy? *

Not at all 1 2 3 4 5 Absolutely

Would you use it as a main tool to study anatomy? *

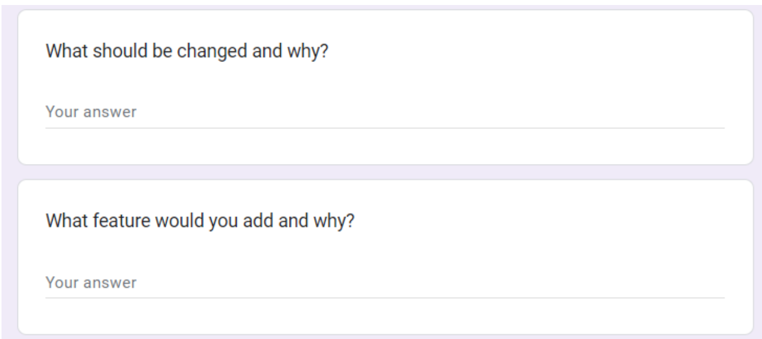
Not at all 1 2 3 4 5 Absolutely

Were you interested in the tasks? *

Not at all 1 2 3 4 5 Absolutely

Did you have to put a lot of effort in the tasks? *

Not at all 1 2 3 4 5 Absolutely



What should be changed and why?

Your answer

What feature would you add and why?

Your answer

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