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EXECUTIVE SUMMARY

The goal of the newly developed virtual laboratory is to enable an easy to use system for teaching purposes of radiochemistry experiments. In the beginning of the project several HoTs were selected to be implemented within this virtual lab.

In close cooperation with the respective partners within the project a floor plan for the virtual lab was planned and realized, as well as interior plans for the single rooms. Therefore, many 3D models needed to be created to develop a realistic lab environment. As a foundation to navigate and interact in the virtual lab suitable schemes were selected and implemented. Advanced interactions were introduced like the personal inventory to move objects between workplaces and object storages to create lab equipment dynamically within runtime by the user. A main menu with its elements, to e.g., select a VR HoT, is described briefly.

To further increase the realism and possibilities within the virtual lab advanced systems needed to be developed. These include a fluid simulation, a quest system, a save system and a radiation simulation. These systems help to guide the user through the experiments and enables new possibilities of interaction.

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1 INTRODUCTION

The virtual laboratory developed during the previous CINCH project aimed to train representatives of authorities responsible for the approval of a radioactive controlled area. Therefore, the focus in the first lab was mainly on allowing users to take a close look at all construction and radiation protection details, while the interaction options were very limited.

The newly developed virtual lab was extensively enlarged in the size of the lab, but also in the interaction possibilities. Several VR HoTs are developed and have different requirements in case of used equipment and their usage. First, a navigation scheme was required to move in the lab and paired with suitable interactions with virtual objects using keyboard and mouse.

2 VIRTUAL LAB ENVIRONMENT

In order to realize the necessary VR HoTs, it was a requirement to first create a virtual environment in which the user can move and interact with objects. This environment and its objects must be modelled and arranged in the virtual environment in order to fill the environment with life.

2.1 Virtual Laboratory Rooms

In close cooperation with the partners, a laboratory floor plan was developed that meets the requirements of all VR HoTs. This resulted in 8 rooms and a connecting corridor (see Figure 1).

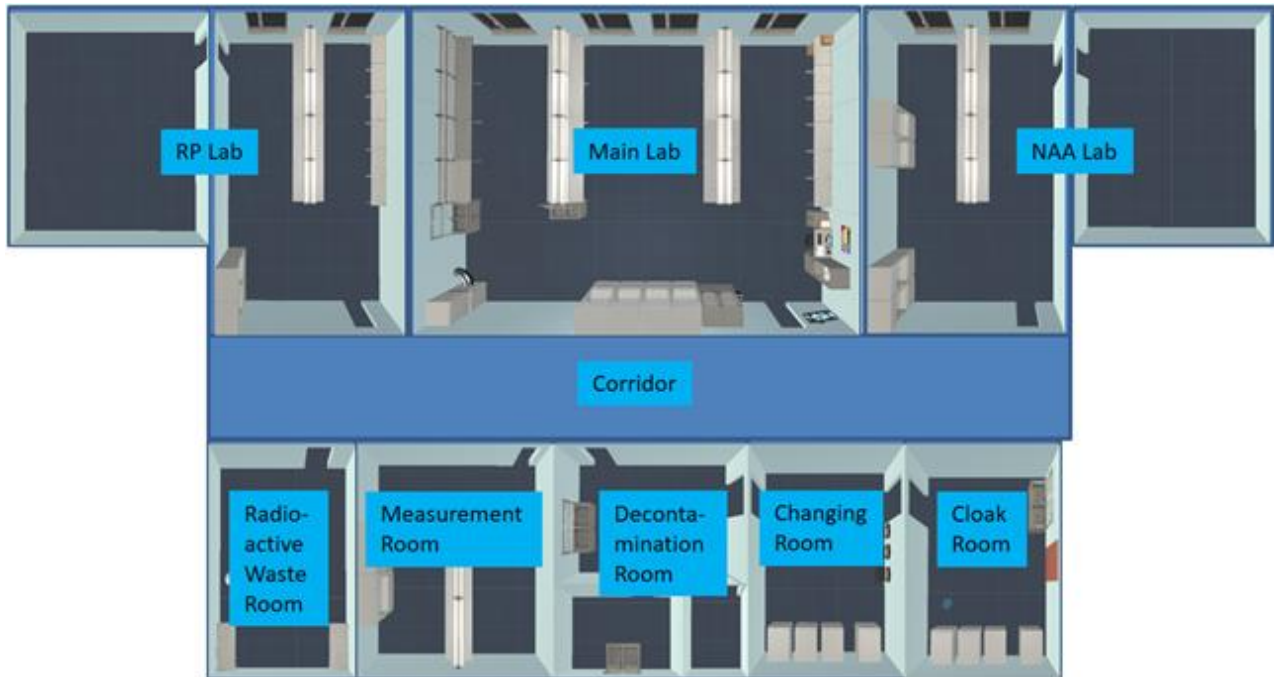


Figure 1: Floor plan of the virtual lab.

Additionally to the overall floor plan, separate interior plans for all the rooms were created which indicates the planned positions of work places, technical devices etc. As an example, see Figure 2 for the interior plan for the main lab. Figure 3 shows some screenshots of different locations in the lab.

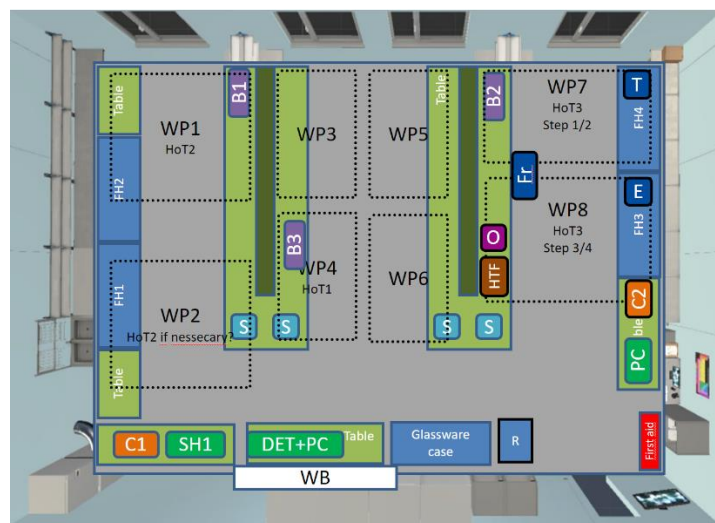


Figure 2: Interior plan for the main lab.



Figure 3: Screenshots of the corridor and the main lab of the current version of the virtual lab.

2.2 Virtual Laboratory Equipment

A large number of 3D models are necessary for the development of the various VR HoTs, as these are required for carrying out the experiments. In addition to the models for the workstations, these include cabinets, but also glass containers and technical devices such as detectors and scales etc. In addition to the good recognisability of the objects, attention must also be paid to the complexity of the geometry, as many complex models quickly lead to a high amount of computing power being required. The creation of 3D models is an ongoing process during the implementation of each VR HoT after each other.



Figure 4: Examples of 3D models that were created so far. In total there were already more than 100 different objects created.

3 GENERAL INTERACTION

The environment with its 3D models is only one requirement of the virtual laboratory. The environment and the individual models still need to be provided with logic and these objects need to be interactable so that the user can perform the planned VR HoTs. In addition, the user must be able to move within the virtual environment and transport objects from one workplace to another.

3.1 Movement in the Virtual Lab

In the early phase of the project, it was first necessary to select a suitable method of movement for the user. The requirement was that the user should be able to explore the virtual laboratory as freely and independently as possible. For this purpose, the method of locomotion used in many video games via keyboard and looking around via mouse was selected and implemented. Thus, the user can use the arrow key or the WASD keys to navigate and move the mouse to change the viewing direction. In the laboratory there are many different workstations with which the user can interact. To do this, the user walks near a workstation and can enter it with a simple mouse click to interact with the objects.

3.2 Interaction with Lab Equipment

After entering a workplace, the camera changes to a fixed position at the workplace and the user can no longer move the camera freely. This allows the user to interact with objects, move and combine objects at the workstation using the mouse cursor. A combination is, for example, when two beakers are moved on top of each other in order to carry out a liquid exchange. Here, only certain object combinations are possible. All combinations that are not implemented are not possible to perform by the user and the object gets a red outline as a feedback. This is called a white list approach.

3.3 Personal Inventory

We implemented an easy-to-use personal inventory with five object slots, where the user can carry objects between workplaces. It is always displayed on the bottom part of the screen. On the left image in Figure 5 a conical flask is placed on the workbench. The right image shows a snapshot of this conical flask in the inventory. In this way, not only an image of this kind of object is shown, also possible fluid inside this flask is visible in the snapshot. This means that the user can always see the current state of the object.

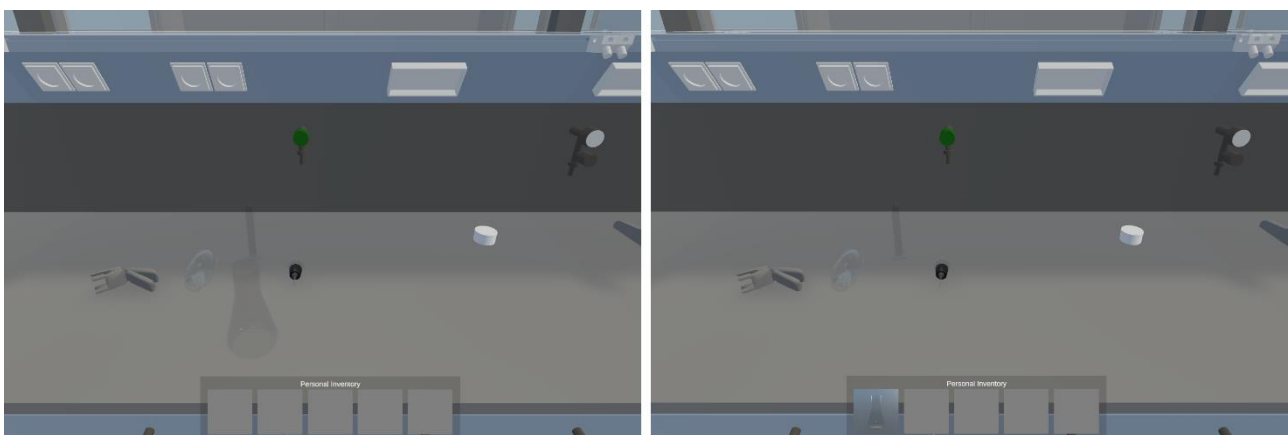


Figure 5: Easy to use drag and drop personal inventory. On the left side, the inventory is empty. On the right side, the conical flask was taken by the user into the inventory and can be carried around to another workplace.

3.4 Object Storages

Certain cabinets in the laboratory are to be used to create laboratory equipment and chemicals. Thus, not all usable objects have to be available directly in the scene, but can be created dynamically. The first version of this object storage can be seen in Figure 6. With the help of drag and drop interaction, objects from this object storage can be dragged into the personal inventory to use them at the corresponding workstations. Here it must still be clarified which objects should be available, since a lot of different objects are required to be used in the VR HoTs. If there is a large number of different objects and chemicals, a suitable filter/category system needs to be considered.



Figure 6: First version of the object storages for lab equipment and chemicals. On the left screenshot two interactable cupboards are displayed (indicated by hovering indicators).

3.5 Usage of Technical Devices

There are also several technical devices in the virtual lab, like a hand foot monitor, a heating block, detectors and more. Generally, these devices are used by left clicking on them and a menu opens which gives the user the possibility to configure, start or stop the device. Figure 7 shows the menu of the hand foot monitor as an example.

Presets

Some objects like the heating block and thermostatic bath have several parameters that can be adjusted. Since several parameters result in a large variety of combinations of these values and many possible outcomes, we reduced the number possible outcomes by using presets. Presets are predefined combinations of the values and the user can choose between them. If the used preset in the current situation is correct, the experiment proceeds further und desired result will be displayed. If the user chooses a preset that will not lead to the correct result, a message is shown that describes what would happen if these values would be used. The experiment only proceeds further when the user chooses the correct preset. Examples for presets are shown in Figure 8.

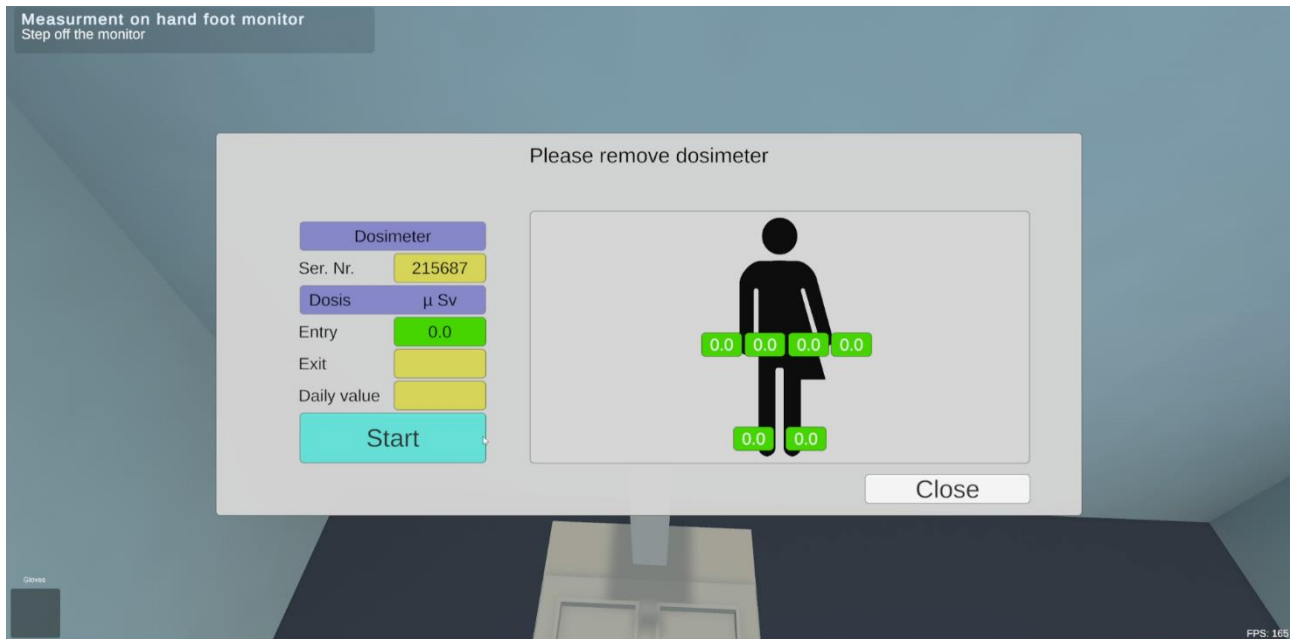


Figure 7: The user interface of the hand foot monitor for the entering and leaving procedure.

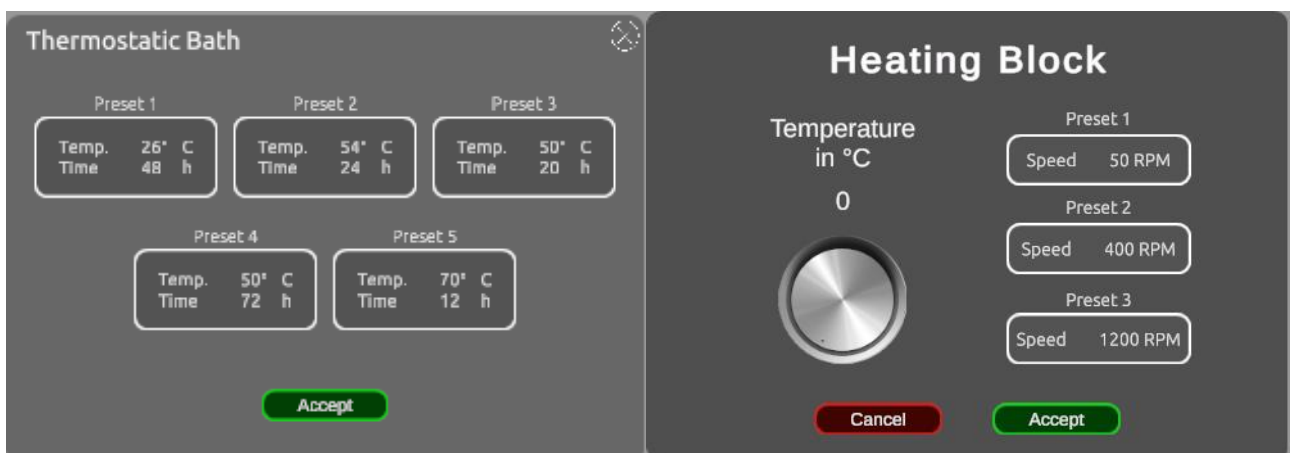


Figure 8: Example presets used for the thermostatic bath and the heating block.

3.6 Main Menu

Since multiple VR HoTs are implemented during the project, we needed a possibility for the user to choose between these VR HoTs. Therefore, we developed a main menu which integrates four different aspects/tabs. First, the VR HoTs choosing menu (see Figure 9), which enables the possibility to start a certain VR HoT from a chosen main quest. When a VR HoT is started, the user gets information on the current active quests in the quest tab (see Figure 10). The third tab shows additional teaching material on the current active VR HoT (see Figure 11). This was needed as a possibility to communicate theoretical background and descriptions that are required to understand and learned by the user. The last tab shows a personal journal (see Figure 12). This is an equivalent to a lab book in the real world and can be used to take personal notes during the experiment. This should enhance the experience and learning possibilities.

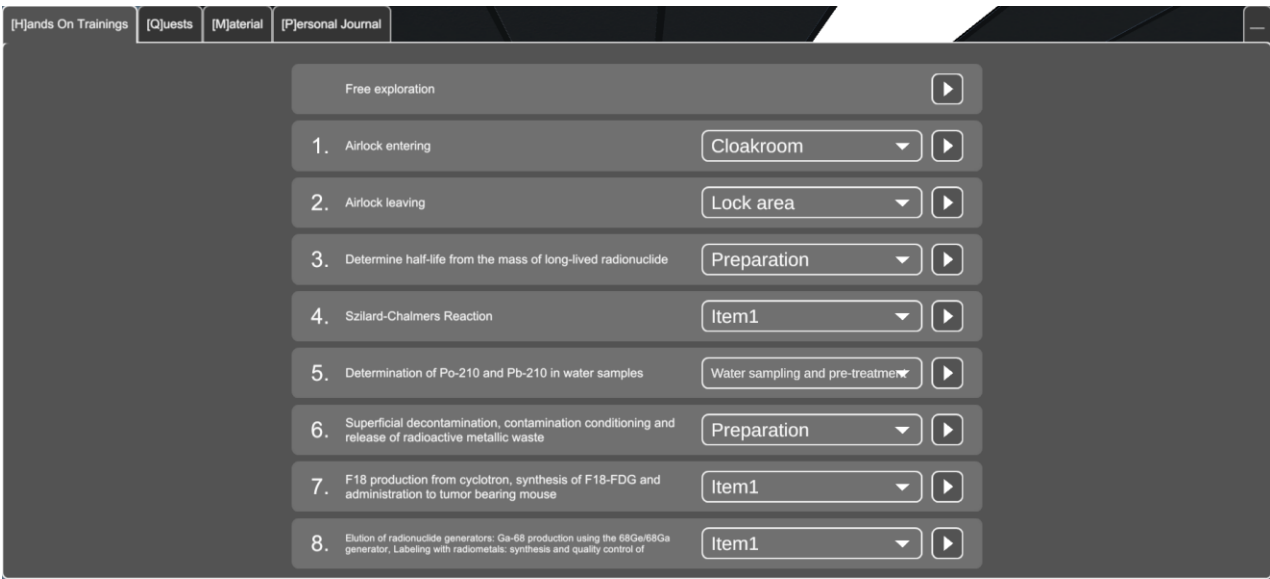


Figure 9: Screenshot of the HoT chosing menu.

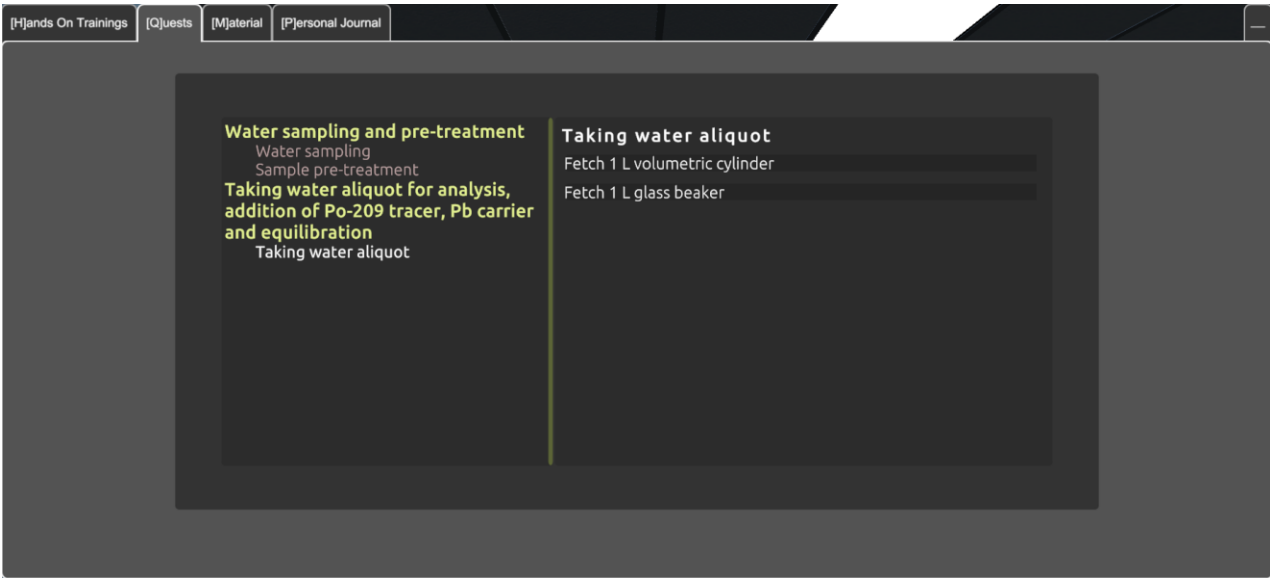


Figure 10: Screenshot of the quest journal menu.

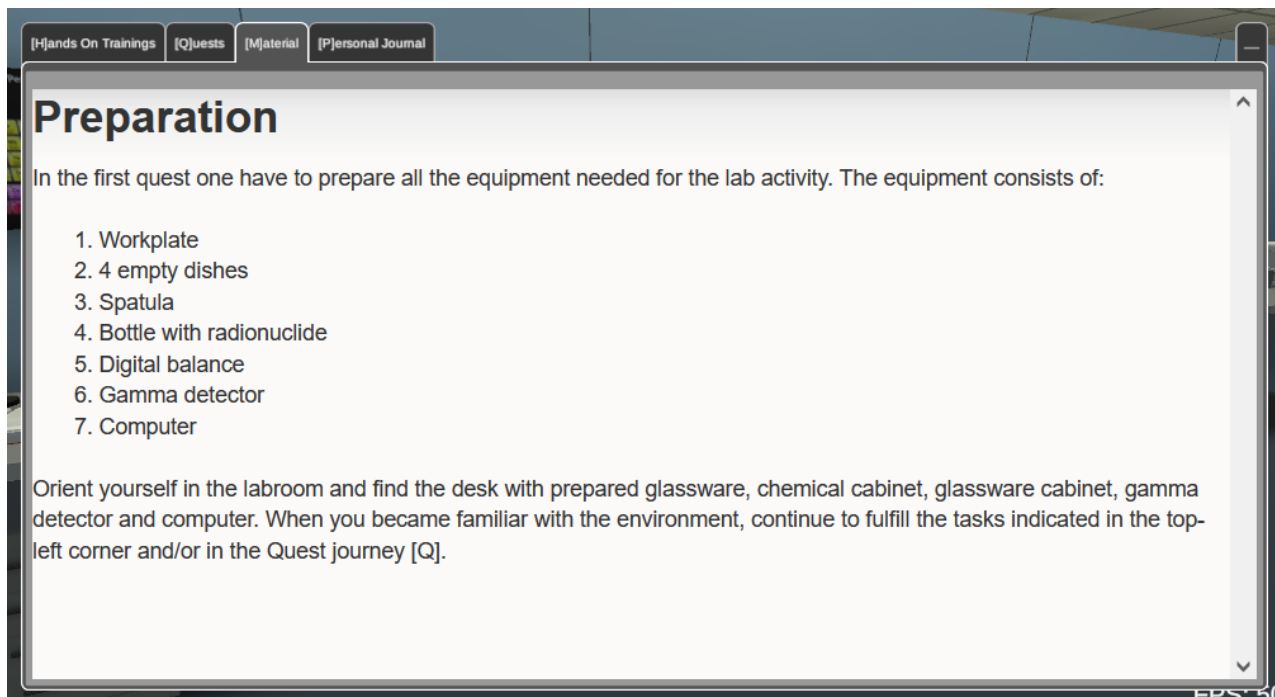


Figure 11: Screenshot of the material tab which shows additional teaching information on the current HoT.



Figure 12: Screenshot of the empty personal journal tab, where the user can write personal notes.

4 ADVANCED SYSTEMS

For some steps in the experimental procedures, special systems are used which are responsible for the visualisation of procedures, present states, store intermediate results or simulate radiation. All these systems are necessary to ensure good usability of the laboratory elements and the VR HoT processes.

4.1 Fluid Simulation System

Many VR HoTs work with liquids. Therefore, it was necessary to first ensure a suitable simulation of liquids. Since realistic fluid simulations are very resource-consuming, a simpler option was necessary. Here, a liquid shader is used that makes it possible to represent liquids in containers. This shader offers a number of parameters with which the liquids can be adequately represented. In addition, the possibility of transferring liquids between different containers was created. Initially, an approach was used to transfer liquids depending on the degree of rotation through direct control over a container. However, this approach turned out to be too imprecise, so that the approach was changed to a direct indication of the quantity to be transferred via the menu (see Figure 13).

A crucial aspect that needs further investigation is the mixing behaviour of different fluids. As a lot of different fluids are required for all VR HoTs, there exist a large number of possible combinations. Here, not all make sense or are useful for the planned VR HoTs. Therefore, we used a similar approach (white list approach) like with the combinations of objects. Only certain predefined fluid combinations are possible and lead to the desired result.

Since the fluids often need to be stirred to create the desired mixture, we worked on a visualization of a vortex that can slowly appear and disappear depending on the input parameters (see Figure 14). This is intended to increase the level of realism and assist in the process of understanding the mixing.

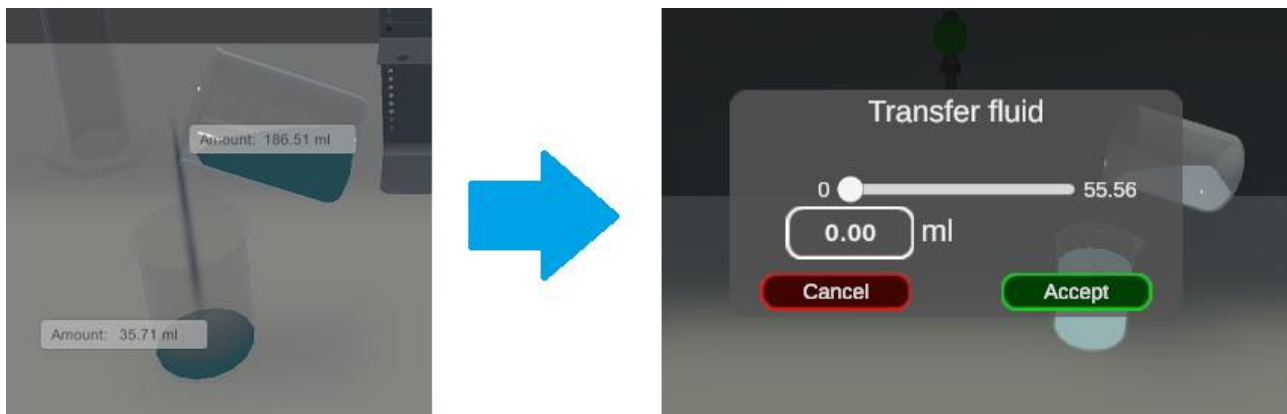


Figure 13: The left image shows the first approach of transferring fluid via direct user input that was withdrawn due to inaccurate handling. On the right the fluid transfer menu is shown that is used to indicate the amount of fluid that should be transferred from one container to another.



Figure 14: Vortex visualization in a beaker.

4.2 Quest System

In order to support the user during the experiments, a quest system was designed. This is a commonly used part in video games to guide the player through a story. These quests will be shown to the user in the virtual lab to guide her/him through the experiment. This is especially valuable for new users that don't know the experiment in detail. We divided our quest system into four hierarchical levels:

1. VR HoT: The VR HoT itself is the highest level of the hierarchy.
2. Major Quests: A VR HoT is structured into different major quests and are more like a rough task description (e.g. "preparation").
3. Minor Quests: Major quests are subdivided into several minor quests. These minor quests clarify the task a bit more (e.g. "preparation of the balance")
4. Tasks: To complete a minor quest, multiple tasks need be finished (e.g. turn on the balance, weight the powder).

We created a quest template that gets parsed by the quest system to automatically create all tasks/quests with their respective connections. Our partners fill this quest template with the tasks/quests they need for their VR HoT.

The active tasks/quest are displayed in two ways in the virtual lab:

- A quest journal can be opened by pressing a keyboard button which shows all the active and already finished tasks (see Figure 15).
- A Preview of active quests is permanently displayed in the upper left screen corner (see Figure 16).

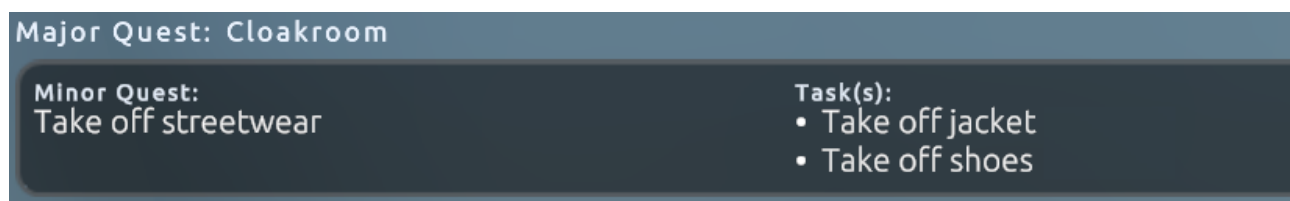


Figure 15: The quest preview of currently active tasks in the upper left screen corner.

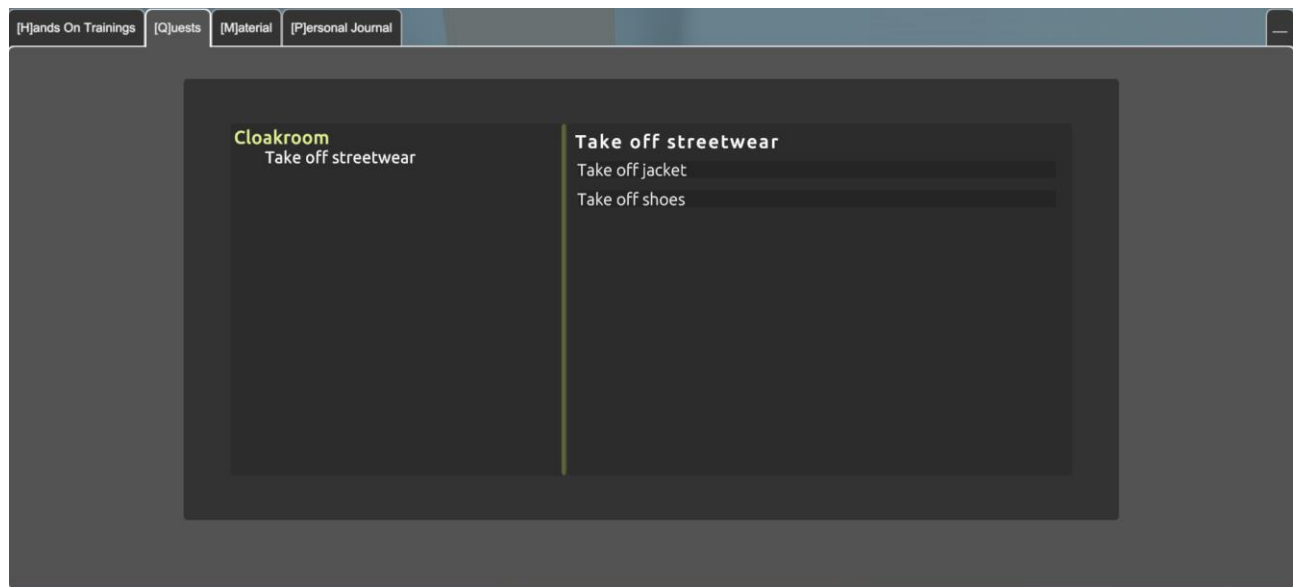


Figure 16: The quest journal with all currently active quests.

4.3 Teaching Information

There is also information that is not possible to communicate via quests/tasks. This information is mainly teaching information like background information and summaries of experiment steps. Therefore, we developed a tab in the main menu where this additional information is displayed when necessary (e.g. at the beginning of a major quest). This information gets dynamically parsed from online html files that can be created and adjusted by our partners, to provide all the information that are necessary to understand the VR HoT.

Halflife determination

The main aim of this scenario is to find out the relationship between half-life of given radionuclide and it's quantity. To reveal such dependence, the absolute determination of activity is required, which is represented by correction of the count rate on thickness (attenuation) of the measured sample.

Learning objectives

1. Nuclear chemistry learning objectives. The user will:
 - Understand the relationship between activity and the amount of the radionuclide.
 - Understand the difference between activity and the measured count rate or counts, and the meaning of the efficiency of the measurement.
 - Understand what is (self) attenuation of the radiation in the sample.
 - Learn what is the shape of the count rate versus mass curve and reasoning of such a shape.
2. VR-Lab learning objectives. The user will learn:
 - How to weight and dose specific amount of powder in the VR-Lab
 - How to operate gamma detector and how to measure samples.

This scenario is composed of four Quests, namely:

1. Preparation
2. Weighting and activity measurement
3. Evaluation of the results and
4. Cleaning the workplace

The difficulty is rather low and user shall be able to finish it in 30 minutes. Feel free to experiment with different amounts of the radiochemical or short and long detection times. How will lower/higher background radiation affect the results?

Figure 17: Text example of the VR HoT description for the half-life determination done by CTU.

4.4 Navigation System

To assist the user navigating through the lab two navigation elements were developed, a minimap and a path visualization.

Minimap

A minimap, as known from video games, was implemented to support the orientation in the laboratory (see Figure 18). The current position in the room is displayed as an arrow from a bird's eye view. Thus, the user always has a relation of her position to other objects in the room. In addition, this minimap can be used in the future, e.g. to set markers for guiding the user to a certain location. In addition, the current room in which the user is currently located is always displayed below the minimap.

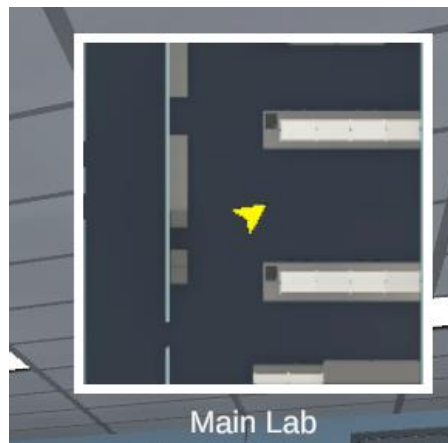


Figure 18: Screenshot of the implemented minimap that is used to improve the orientation of the user inside the lab. The current room is displayed below the minimap.

Navigation path

To help navigating the user through the virtual lab, a path visualization was implemented. Here, the shortest path between the user and the desired location is visualized.

This path is visualized with a path of foot prints...

- on the ground of the lab
- and in the minimap (see Figure 19).



Figure 19: The visualization of the navigation path with foot prints on the ground of the lab (left) and in the minimap (right).

4.5 Save System und User Management

The completion of individual VR HoTs by students can take up to multiple hours, so multiple sessions are necessary. Also, if critical, non-reversible errors occur (e.g. disposing a unique chemical), possibilities to load & save the current state are necessary.

Here, the most flexible and powerful variant would be an online user management, consisting of a backend server and database that can manage user accounts and stores progress of the users. However, this is not feasible with the available resources within the project. Instead, the saving and loading have to be realized locally on the current pc the student uses.

Our initial tests have shown that the creation of individual saving points take up 10^{th} – 100^{th} of MB of disk space and would take minutes for loading. While the required disk space is not problematic, frequently minute-long waiting periods would not lead to an acceptable user experience.

Therefore, we investigated possibilities to restrict the amount of elements and time points where the user can load and save the current state. This leads to an improvement regarding disk space to 1 – 10 MB and 5-15 seconds saving/loading time, which is acceptable. Following this idea, it would be possible to pre-define saving points at each major quest that can be delivered together with the website. This allows a teacher and a group of students to start at different stages within each VR HoT, but still have an equal starting point across each student, which simplifies supervision.

4.6 Radiation Simulation

Several VR HoTs contain the handling of radiating sources. To provide the students with a way to investigate this aspect, a radiation simulation will be developed and integrated into the virtual lab. This simulation is different from the augmented reality application, as it is more precise and thus, realistic. Gamma radiation and a detector showing the resulting spectrum was realized as a web-demo (see Figure 20).

Movable detector and source

Different detector materials



Figure 20: Overview of gamma radiation simulation web application.

The application is able to simulate different effects the photons can cause at a detector. These include the photo-electric effect, the Compton effect and the pair effect. As a result, a realistic gamma-spectrum is obtained (see Figure 21).

Furthermore, the application allows to change between different detector materials. These materials are defined by the chosen background spectrum, the behaviour of the response function, as well as the used geometry. One material is equivalent to a HPGe (High-Purity Germanium detector), resulting in a good resolution. This will be the basis for other, less precise detectors, that can be approximated by “worsening” the HPGe detector.

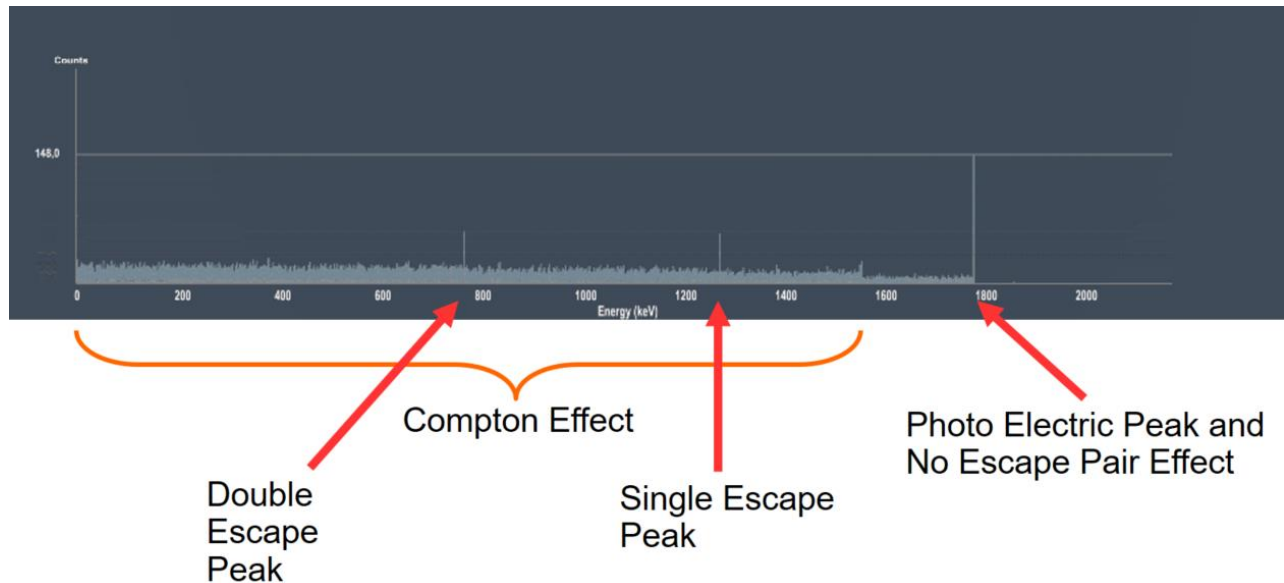


Figure 21: Spectrum of the radiation simulation showing the three effects.

Figure 22 shows an example of the usage of this radiation simulation in the virtual lab. It shows virtual PC screen in the lab for the CTU VR HoT. After the initial setup the user can calculate the background radiation value, as well as the counts per minute for the samples that should be evaluated. Based on the weight values and the measured counts per minute the half-life time is calculated, as well as graphs for visualization of sample values are created.



Figure 22: Virtual PC screen that shows the measured sample values to calculate the half-life time. Also graphs to visualize the sample values are displayed.

5 CONCLUSIONS

All the described implementation and systems were created and developed in close cooperation with the radiochemistry experts within the project. Regularly, current prototypes of the virtual laboratory were made available to the partners for feedback and will also be in the future. This ensures that the final version of the lab will meet the requirements set within the project.