# Virtual Chemistry Exam Preparations Designed as Escape Rooms

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**Abstract:** Chemistry is a very interesting but sometimes for students too theoretical and therefore strenuous topic with a lot of theoretic basic knowledge to be memorized. This can lead to lacking fascination during lectures. In laboratory work chemistry often seems more tangible. In order to enhance the student´s interest for chemistry already for the theoretical basis, new ways for teaching but also exam preparations are being designed. In our work we want to focus on an innovative way for exam preparations combining the theoretical knowledge from the lecture and the practical experience from chemistry laboratory work in a game-based elearning setup. The idea is that in a game-based way students are more motivated to activate their knowledge by solving different tasks. They can combine information and try out various possibilities to find the solution or use additional help (e.g. links to theoretical input). On top, they get direct feedback if their answers are correct. The exam questions are found in a virtual chemistry laboratory. Not only theory questions have to be answered (e.g. by using multiple choice, drag and drop, …), for other tasks virtual chemical experiments (without any danger!) will lead to an answer. Usually a code (numbers, letters, signs, …) has to be obtained which is necessary for continuation. By solving different questions and chemistry tasks, the participants will be able to complete the exam preparation test and to exit the designed Chemistry Escape room with the planned name "ChemScape". Right now, a virtual chemistry laboratory is designed and already some chemistry questions from lecture exams are inserted and implemented in the escape room game. First tests with students will follow until summer. As already another chemistry Escape room station with real materials (solutions, instruments, …) has been tried in different settings – always receiving good marks and enthusiasm for fun, entertaining and good imparting of knowledge, also a virtual Chemistry Escape room game is expected to be well accepted. Gamification is often a very good way for motivation – it can even convert boring seeming topics into real fun and interest and the will to learn more!

**Keywords**: Chemistry, e-Learning, Exam preparation, Virtual laboratory, Digital scientific escape rooms

## 1. Game-Based Learning

The usage of game-based learning (GBL) has evolved in the last decades as it showed very positive effects for education. It works with physical - (e.g. puzzles, cards or other objects to play with) or digital (on a webpage or in an application for mobile devices) or can be a mixture of both. Including educational games and simulations, GBL has been stated especially promising in higher education (Crocco et al, 2016).

One game type in GBL is known as "Escape games". There, players, locked in a room, have to escape by finding hidden items and solving a sequence of puzzles. The subcategory "educational escape games", defined as "an educational approach which uses a game format in which students participate in a series of activities designed to acquire knowledge or skills, linked to learning objectives, by solving a series of puzzles in a given period of time" (Soares et al, 2023) are developed for certain participant groups and have deliberately specified learning goals (Veldkamp et al, 2020). For the learning field medicine Soares et al (2023) describe its usage for surgery training, Hermanns et al (2018) for pharmacology and Molina-Torres et al (2022) for training anatomy.

Hermanns et al (2018) line out, that the designing of escape room tasks is challenging, as tasks have to align with the curriculum, avoid boredom and frustration and have to use a special form of questions as often numerical or alphabetical codes have to be obtained.

Escape games can take place in real environments or can be designed in a virtual manner. In both settings participants must get active, search for puzzles, hints and helpful materials in order to solve the tasks and finally find the way to leave the room.

## 2. Project "ChemScape"

### 2.1 Idea

As mentioned above, different escape room games can already be found in literature in the field of medicine. For chemistry, however, at the moment, there are not many publications – especially not for digital escape games. In text format, an educational homepage offers a chemistry escape room to escape a secret laboratory. (https://unterrichtsheldinnen.de). Peleg et al (2019) describe an adaptable, movable chemistry escape game with experiments to be solved with simple chemical materials and reactions in a real chemistry laboratory. The publication of Monnot et al (2020) reports about adopting escape rooms to large audiences in chemical

engineering and giving the possibility of playing the game in real scenes or on a digital medium. A 2D chemistry escape room with a virtual laboratory on the starting homepage has been created by the German Chemical Society (https://jcf.io) - all tasks, though, are described for performing the experiments in a real laboratory.

In contrast to the above-mentioned chemistry escape room games, in our work, we describe the creation of a digital escape room game for chemistry in 3D. So, in the game it will be possible to grab and move objects and to virtually perform laboratory experiments which will enhance the realistic character. Advantageously the game can be played without the necessity of a real chemistry laboratory environment.

### 2.2 Purpose and Expectations

The particular purpose for the design of a 3D digital chemistry escape game is enhancing interest, understanding, knowledge and, as a consequence, the grades of students in chemistry exams, and therefore additionally providing them with a better knowledge base for natural science or engineering courses connected with chemistry. Also, logic chemical thinking and problem-solving ability for chemical questions should be enhanced. Furthermore, as escape room games are known to be collaborative, task-oriented, time-based and provide immediate feedback, they are motivating and attractive for in-class learning activities (Nicholson, 2018).

In that manner, the "ChemScape" digital escape room game should turn out to be a good way to solidify chemical knowledge, to gain new information, to combine chemical theory in a new manner – also by applying chemical experiments in a digital form, easy and without any danger - and to prepare for chemical exams.

As already a real scene chemistry escape room scenario (with real liquids, instruments and other materials) has been established and tested out in different settings at the University (e.g. as part of a treasure hunt for student visitor groups or as one escape room scenario together with others at a research night event on the campus) – always receiving good marks and enthusiasm for fun, entertaining and good imparting of knowledge - also a virtual chemistry escape room game is expected to be well accepted.

### 2.3 Time Schedule

The presented project started in the first quarter of 2023. At present, a virtual chemistry laboratory has already been designed and some chemistry questions from lecture exams have been inserted and implemented in the digital escape room game. More questions are already selected to be programmed and designed for the game and further tasks will be continuously implemented until summer. Then, also first tests with students will follow and the learning analytics will produce first feedbacks about the chemistry tasks and what could be rearranged and improved. The "ChemScape" will then also be implemented step-by-step in chemistry lectures.

### 2.4 Methodology

After not finding any literature on the implementation of chemical competencies into an universally available virtual escape room, our approach is empirical. The problem of students inadequately preparing for exams due to low motivation is intended to be solved through gamification. However, the problem with gamification is that typically a separate game would need to be programmed for each subject matter, which is a labor-intensive task. Our approach is to design a flexible escape room where questions can be dynamically entered through a CMS (Content Management System). The setup of the room remains unchanged. Therefore, from a didactic perspective, it is necessary to assign each individual competency to one or more suitable door-openers. Depending on the required competencies, a game with the necessary skills is then dynamically generated (see Figure 1). Necessary improvements to the game will be prompted through written feedback from both students and professors.

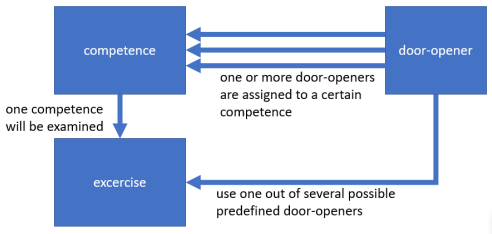


**Figure 1: Dependencies of exercises, competences and door-openers**

### *2.4.1 Requirements*

Since it is an online game, both the creators of the escape rooms (professors) and the players (students) only need an internet connection and a common browser that supports Unity, such as Google Chrome. No additional plugins are required.

### *2.4.2 Game setup*

The "ChemScape" escape game is designed as a virtual 3D laboratory with programmed virtual furniture (mainly laboratory benches, cupboards, fume cupboards, sinks and some safety establishment), equipment as cleaning facilities, analytical instruments (e.g. balances) and a big variety of chemical glass ware and paraphernalia. Figure 2 shows an example of a virtual designed chemistry laboratory room with different instruments, glass ware and laboratory furniture. 1a is a free template from "Unity 3D", 1b shows a working place in the "ChemScape" laboratory with a four-digit door-opener (in red circle) at the current work progress.


**Figure 2a: A virtual chemistry laboratory (free template from "Unity 3D" (https://unity.com/de))**

**Figure 2b: Working place in the laboratory at the current work progress with a four-digit door-opener (in red circle)**

For the designing phase, different types of measuring instruments, as for example balances or pH-meters, have been photographed in real chemistry laboratories on the campus and are currently at the stage of being designed. Figure 3 shows an example for virtually designed glass ware, pipetting aids and an analytical balance. In the shown analytical task correctly pipetting of volumes shall be practiced.

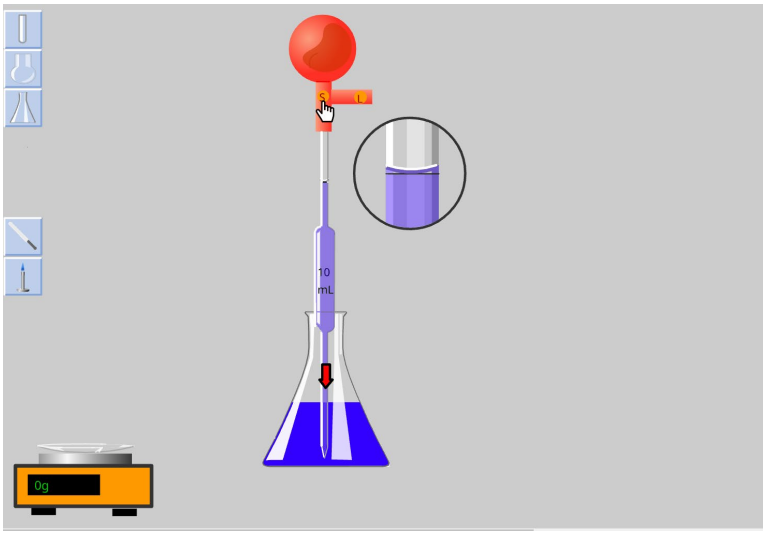


**Figure 3: Example of an analytic task (here correct pipetting of liquids)**

The special feature of the instruments will be their realistic way for usage. In order to use the instrument, it will be necessary to do the same handling procedure as in a real chemistry laboratory. This means for example

inserting the pipette in the liquid, pushing the button "S" at the pipetting aid for "sucking liquid" and stop the sucking process exactly when the meniscus of the liquid is at the line mark.

The different chemistry tasks will cover theoretical knowledge from the lecture as well as associated laboratory experiments. They will either be directly present at the virtual laboratory working place, preferably shown as images, or will appear somewhere after solving the previous question. Figure 3 shows a task example where the participant should understand that liquids should be sorted by increasing pH.


**Figure 4: Task shown as image for a sorting of liquids by increasing pH**

Materials (as e.g. vessels with chemical substances), hints (e.g. a colour code) and useful things (e.g. diagrams, the periodic table, ...) will be close or at the work place – either obvious or hidden (e.g. behind boxes or in the cupboard).

In order to continue (go to the next task or leave the room), we have until now programmed 10 different methods for opening a door of a box, a drawer, a bag or other storage containers where an item necessary for the next task (e.g. a scale or a sheet with the next riddle) or the key to exit the room will be found. Table 1 lists our 10 door-openers.

**Table 1: Types of door-openers**

| No. | Door-opener |
|---|---|
| 1 | Bring images into a certain order with drag and drop |
| 2 | Type a code into a display with the form of the Periodic table of Elements |
| 3 | Select one test tube out of 10 and put it in the right slot, then press a button |
| 4 | Single-choice slot: select the right option in four different slots ("one-armed-bandit") |
| 5 | Weigh a certain amount of substance on a scale and put it in a box |
| 6 | Slider: bring four sliders into the right position |
| 7 | Pipette: get the right amount of a liquid and transfer it into a box |
| 8 | n:n cable-connection for assignment (e.g. name to formula) |
| 9 | Create a certain amount of gas through a chemical reaction (e.g. weigh in $CaCO_3$ and put it in a vessel of HCl) |
| 10 | Drag & drop different objects (e.g. metals and non-metals) and sort them into boxes |

From the didactic point of view, we assigned for every competence that is necessary to pass the exam at least one door-opener.

As an example, figure 5 shows an image task for the competence "electron configuration of chemical elements" that uses door-opener 2.

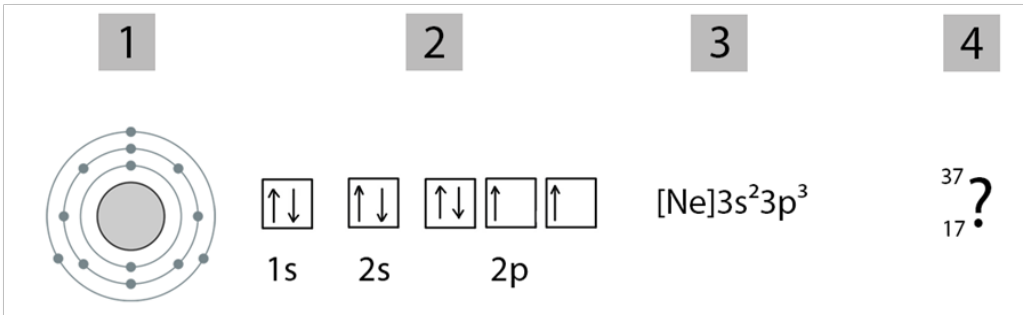


**Figure 5: Example for an image task in "ChemScape"**

The solutions to the elements of the above task (Al, O, P and Cl) will have to be clicked in the door opener designed as a (reduced) Periodic table of elements (Figure 6).

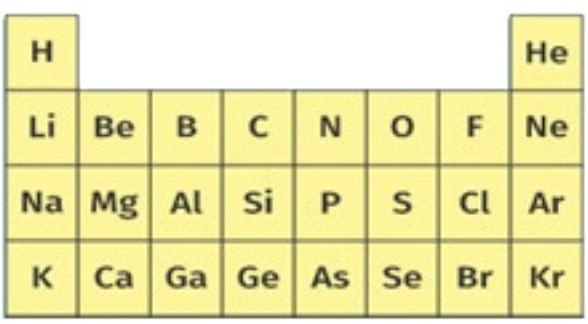


**Figure 6: Periodic table of elements for clicking the correct elements to pass the task**

Another feature will be the possibility (maybe in form of a small figure or a button) to request help (further information for the task or theoretical background).

It will be possible to choose whether experiments or answers can be redone (one or more times) before the results are finally inserted and checked.

### *2.4.3 Technical setup*

All objects are created with a 3D-engine called "Unity 3D" (https://unity.com/de). The whole game runs as web-application. The user-frontend will be a simple website based on php, html5 and javascript. Questions, tips, equipment, and behaviours of the objects are inserted in a mysql database via a content management system and can be extracted dynamically depending on the respective exam. For each problem, it is possible to assign up to three tips.

### *2.4.4 Learning Analytics*

In order to evaluate the difficulties of the questions on the one hand and the way how the different tasks are being solved by the game players, the examiner assigns a code to the candidates, which can be used to identify the students, allowing the examiner to access the results (number of failed attempts, number of hints used, duration of the game). Furthermore, these data collected by all students should be used in the future as a measure of the difficulty level of a question.

Figure 7 shows an example of a learning analytics result how it could look like when implemented in the escape room game. In the example demonstrated six participants processed up to eight different chemistry tasks (shown as question numbers).

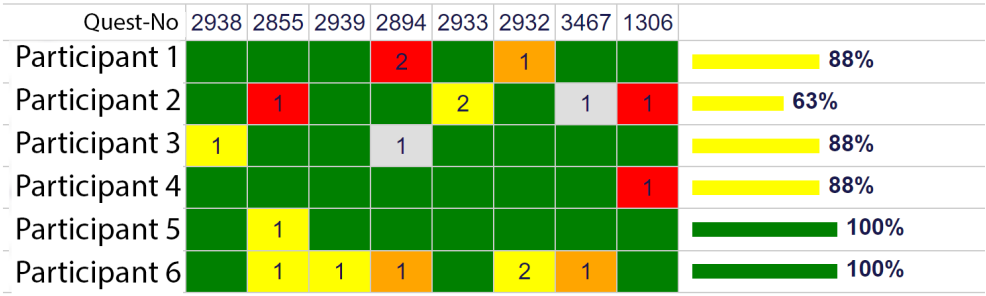


**Figure 7:** Example for a learning analytics evaluation of chemistry tasks

A green color means that the respective task has been solved the first time. Yellow signals that the task was solved after failed attempts (the number shows the attempts). Orange marks mean that the respective task could be accomplished after examining the solution approach. Participants with green, yellow or orange color marks could achieve 100%. Red shows that despite understanding the solution approach, the task has not been accomplished yet. In this case, only less than 100% could be achieved. This was also the case in the example where there were still grey marks – signaling that these tasks have not been processed yet.

### *2.4.5 Evaluation*

An evaluation of the escape room game will be done on different expansion stages of the programming and introduction of the game. Feedbacks from participants and professors will help to further improve the game.

## 3. Conclusion, Discussion and Outlook

The design of a 3D chemistry escape room is challenging – especially as it should also be used as exam preparation tool. But it will be an innovative and useful tool in chemistry courses once a variety of different chemical tasks have been invented and programmed.

After the release of the game, we want to evaluate two aspects: First, an evaluation from the students' side regarding comprehensibility, fun factor, difficulty level, and user-friendliness. Second, an evaluation from the chemistry professors' side regarding improvement in learning outcomes compared to a control group.

As a follow-up of the basic version, more questions, tasks and problem-based learning situations will be designed in following projects.

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