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Visualization of an Electrolysis Process using Augmented Reality

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Abstract
Supplementing reality with non-visible information using the Augmented Reality (AR) technology offers many potentials and opportunities for education. For the electrolysis of zinc iodide, we created an AR experience using the Unity engine, which visualizes the reaction on a submicroscopic level. The goal of the app is to provide a model that promotes understanding about electrolysis and facilitates the formulation of the electrochemical half-cell reaction equations. By exploring the app, the electrolysis can be studied interactively, and the animations can be paused, rewind or fast-forwarded as needed. Moving the camera allows users to view the model in overview or detail. In addition, detailed information about the ions, molecules or electrodes can be retrieved via touch input. The development was supported by interviewing ten teacher training students, which feedback helped us to improve the design and usability of the AR app.

Keywords: *augmented reality, chemistry education, dynamic model, electrolysis*

1 Augmented reality in science education
Augmented Reality (AR) is a technology allowing its users to supplement the real world with virtual objects and can be described as part of the reality-virtuality-continuum (Figure 1) [1]. Azuma and colleagues define three properties to describe AR: (1) AR systems combine real and virtual objects in a real environment (and not in a virtual environment, like the augmented virtuality); (2) AR systems are interactive and run in real time (so they can be manipulated by the user); and (3) AR systems align real and virtual objects with each other (which implies that both are in a specific relationship) [2].

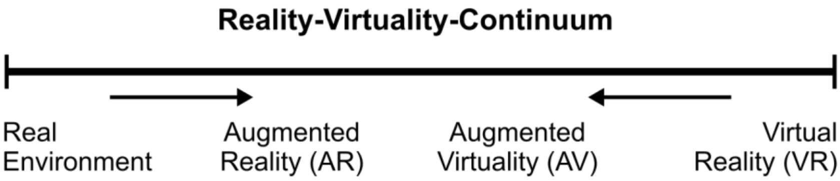

Figure 1. Representation of the reality-virtuality-continuum [1].

AR became more popular with the last recent years, especially in educational settings, and is an important topic in research. The increased number of publications per year is an indicator for this [3, 4]. It can be assumed, that one reason for the raised interest is the technological development in this field, which made it possible to use the technology on simple mobile devices instead of specialized and expensive equipment [4]. The effects of AR on learning processes are still under investigation, but several case studies show promising educational benefits. In their systematic review, Akçayır & Akçayır reviewed 68 study's and identified many advantages and disadvantages of AR. One of the most named effect is an enhanced learning achievement as well as an enhanced learning motivation. Future research has to investigate if these effects are caused by a novelty effect. Also, some studies report an increase and some a decrease of the students' cognitive load [4].
Literature analysis reveals evidence, that AR has the potential to contribute to students' understanding to chemical processes on a molecular level. In order to describe a chemical phenomenon, chemists use three different levels of representation, which are related to each other: the macroscopic, the submicroscopic and the symbolic level [5, 6]. Explanations of macroscopic visible chemical processes

build on the submicroscopic level to illustrate the movements of particles like electrons, atoms, ions, or molecules and on the symbolic level to verbalize these processes. For a complete understanding, students need to be able to transfer between these representations [6, 7]. Teaching, that considers the interdependency of the three levels and focuses on the transfer from one representation to another, improves the learning of chemical concepts and reduces the mental load of the students [8]. By showing the movements of the particles to an experiment via AR, the submicroscopic and the macroscopic levels are shown spatial near and temporal simultaneously, so that the cognitive load is reduced as suggested by the principles of multimedia design by Mayer [9].
In this contribution we present an AR app, which shows the particle movement on a submicroscopic level during an electrolysis of zinc iodide solution. The goal of the app is to provide a model that promotes understanding about electrolysis and facilitates the formulation of the electrochemical half-cell reaction equations. Using the app simultaneously to the corresponding experiments should help students to transfer between the three levels of representations and deepens the understanding of the concept of electrolysis (Figure 2).

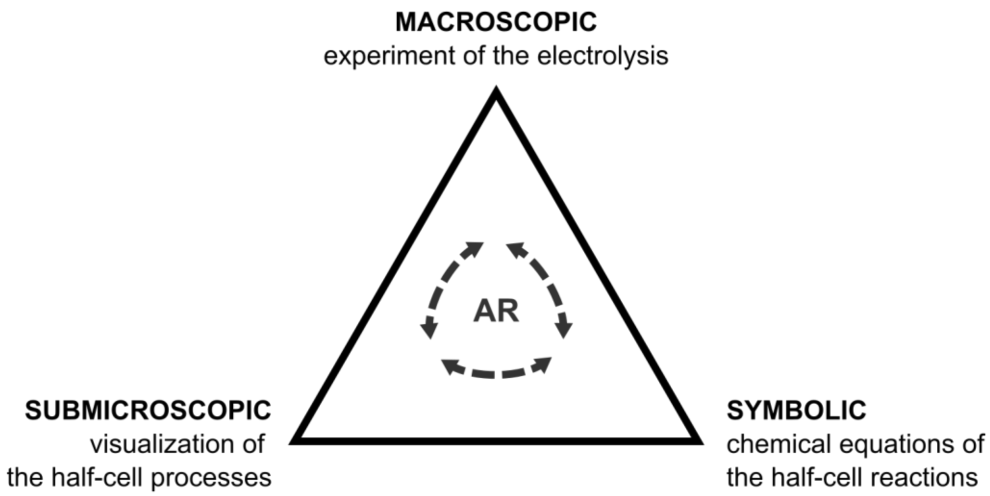

Figure 2. The three levels of representation (Johnstone triangle) [6] applied on the electrolysis.

2 Design of the application: dynamically visualizing an electrolysis

The app was created using the Unity engine, which is free available for individual use, non-profit organizations, and educators (after verification) on macOS, Windows and Linux [10, 11]. With the help of Unity, AR apps for iOS and Android can be developed without major programming knowledge. The resulting application can then be published in the corresponding app stores or, in the case for Android systems, shared as an installation file.
The design is based on some educational considerations, from which we can only present a limited selection here. One important design principle was that we wanted to prevent causing new students' misconceptions. Therefore, we looked at the most common misconceptions in electrochemistry like the idea that the electrolyte is split into its ions during an electrolysis [12].
A big challenge was the visualisation of the involved particles and objects. It was important for us to show the particles in a correct size ratio. Since the electrodes and wires are much bigger and the electrons are much smaller than the particles, we had to find a compromise between displayability and size ratios. While the particles are shown in a space-filling model [13], objects like wires and electrodes are displayed in a macroscopic way and the electrons are only represented via text. This results in a mixture of different levels of representation, which was inevitable if the visualization should stay simple. To keep the animation simple, the formation of polyiodides is not shown. Figure 3 shows the colors and size ratios of the involved particles, which is based on atomic and ionic radii from literature [14, 15]. We decided to color the spheres of an atom and its corresponding ion similar but not exactly the same to suggest a relationship between the two. Using the same color could lead to the misconception, that the substrate stayed the same.

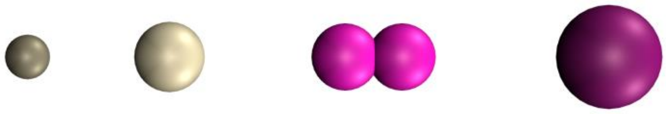

Figure 3. Size ratios and colors of ions, atoms, and molecules. From left to right: zinc cation (Zn^{2+}), zinc atom (Zn), iodine molecule (I_2) and iodine anion (I^-).

One of the most important features of the app is the possibility to discover the reactions on the electrodes while experimenting (Figure 4). AR allows the users to walk around the object with the movement of the mobile device and view the processes as a whole or in detail. We have implemented information panels about the individual objects, which can be accessed by selecting via touch input, and helps to identify them. The animation of the half-cell reactions (Figure 5) can be paused and controlled with a track bar menu, to jump forward or backward. This interactivity allows learners to explore the app and study the shown electrolysis at their own pace. After exploring the app, the half-cell reaction equations can be formulated using the corresponding worksheet (symbolic level of representation).

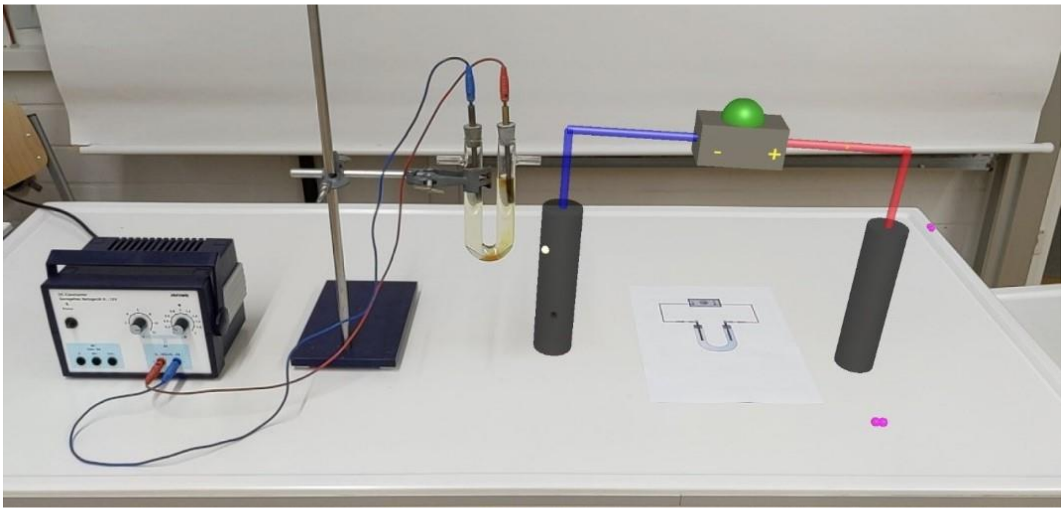

Figure 4. Screenshot of the application. Next to the real experiment on the left side, the augmented reality visualization is shown.

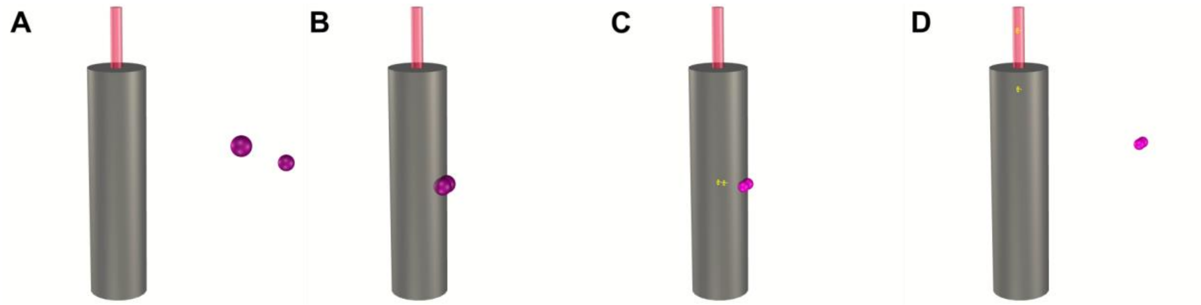

Figure 5. Animation of the reaction of two iodine ions to one iodine molecule at the anode. Two iodine ions diffuse to the anode (A) and interact with it (B). In the next step, the ions oxidize to iodine and transfer two electrons to the anode (C). The new formed molecule moves from the electrode (D). The animation repeats itself constantly and can be paused, rewind or fast forwarded. For the purpose of clarity, only one reaction is shown here. However, two reactions are shown simultaneously in the app.

3 Experiences, limitations, and potential for the future

After implementing the basic functions and animations, we asked ten teacher students for first feedback in an open format. We requested the students to write down anything they notice on a technical and a content related perspective. By analyzing their answers, we improved our model and

fixed some technical issues, *e.g.,* increasing the size of the font. All students recognized the experiment and were able to connect the model with the real experiment.
However, three students noted that the solution and electrolyte was missing. It was necessary to exclude the water molecules, otherwise the essential reaction would not have been visible. As mentioned above, the visualization mixes the levels of representation and shows the electrodes in a more macroscopic way while the particles are on a submicroscopic level. These and other limitations should be critically discussed with learners after using the model to avoid the generation of misconceptions.
Despite these limitations, the use of AR models can be beneficial for learning. The intuitive and simultaneous use of the app could reduce the learners' cognitive load and addressing multiple levels of representation should promote transfer between them. However, whether an improvement in competence in the area of electrolysis can actually be determined should be investigated in further studies. The benefits of the app should also be compared with alternative models, such as instructional videos or interactive animations.

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