

# Linking Learning Tools, Learning Companion and Experimental Tools in a Multitouch Learning Book

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**Abstract** Multitouch Learning Books (short: MLB) are digital interactive E-Books that can be used in class enriched with individual tools. Due to their multifunctionality, they offer an excellent framework for integrating further didactic functions exceeding the role of a learning companion. In this study a Multitouch Learning Book was developed which contains all three didactic functions of ICT (Information and Communication Technology). The MLB provides the digital framework for the series of lessons and accompanies the entire learning process. Learning tools include isolated applications, Augmented Reality and measured data logging, which fulfills the didactic function of an experimental tool. The topic "galvanic cell" was implemented and tested in two different classes. The intervention resulted in unanimously positive feedback from teachers and pupils alike

**Keywords:** ICT, science education, digital media, chemistry education, middle school, high school, Multimedia Learning, Multitouch Learning Book

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## 1. Introduction

Media diversity is a frequently discussed topic in classroom development. In the age of digitalization and increasing media equipment in schools, there is an increasing demand for suitable and didactically reflected digital materials. The materials, presented below, refer to current didactic research and combine it with digital competences [1] and the functions of digital media in chemistry teaching [2]. As discussed by Seibert, Kay and Huwer [3], ICT can be used in different functions in science education (learning tools, learning companions, experimental tools). Because of heterogeneous and diverse classrooms, ICT often fulfills more than one function. This article focusses on Multitouch Learning Books, which structures the learning process in lessons and includes learning tools and experimental tools.

## 2. Galvanic Cells: A Unit in a Multitouch Learning Book

The topic of galvanic cells is covered in the presented teaching curriculum: The pupils should be able to describe

and explain the structure and function of a galvanic cell. They should have the ability to identify the necessity of a reference half-cell by means of a test series and thus be able to draw conclusions about the electrochemical series. Using a Multitouch Learning Book, pupils practice working independently with digital media. In addition, the initial focus is on developing a problem question about how a battery works by naming the components of a battery using the Augmented Reality app. The aim of this preliminary exercise is to name and assign the components of a galvanic cell. Based on this, the pupils should be able to explain the functionality of a galvanic cell at the particle level and explain the necessity of a diaphragm. To secure this knowledge, pupils formulate partial equations and the redox equation of the Daniell element. In order to deepen the acquired knowledge, pupils conduct experiments to combine given half cells and determine the resulting voltages. The measured results are documented in the Multitouch Learning Book. The measured results are documented in the MLB and explained by means of the electrochemical series and the solution tension. In this way, the different voltage measured values can be compared and correlations can be established between them. By collecting data in the MLB, the measured values can be quickly and elegantly compared with the literature

values and deviations can be justified. Further expected voltage values can now be calculated from this knowledge.

## 2.1. Learning Companion Content

The Multitouch Learning Book as a learning companion combines all materials of the series in one book. The MLB accompanies the learning process throughout the entire three-week course. Depending on the hardware of the school, the pupils can take the Multitouch Learning Books home with them.

This E-Book follows a linear learning process [4]. The teacher instructs the individual teaching sequences and accompanies the pupils' learning. There are no non-linear learning paths, as a structured learning path was assumed at the beginning of the book design. This also means that the E-Book cannot be completely used in class without instruction. In contrast to conventional materials the presented material only includes a short instruction by the teacher to open the learning path and activate learning processes. The developed digital materials contain many pupil-centered tasks and activities. As mentioned above, only the learning initiation is teacher-centered. However, the E-Book also includes pupil activities, meaning that a continuous cognitive and motivational learning process is promoted among the pupils.

### 2.1.1. Multitouch Learning Book to Frame the Unit

The Multitouch Learning Book forms the framework for the series of lessons on the subject of the galvanic cell. The interactive E-Book contains five chapters:

**Chapter 1:** Repetition of redox reactions to activate prior knowledge

**Chapter 2:** Discussion of the battery as an example of the galvanic cell and transfer to the Daniell element

**Chapter 3:** Pupil experiment on the potential difference of different half-cells

**Chapter 4:** Serious Games for the individual promotion of pupils as a buffer in the respective lesson

**Chapter 5:** Feedback page for pupils for the evaluation of the materials

Within these five chapters all three didactic functions of ICT can be found. The MLB is the learning companion that combines the individual lessons and unites them in a meaningful way. In the following chapter, the digital materials and the corresponding teaching series are described in detail.

#### 2.1.1.1. Chapter 1: Repetition and Prior Knowledge Activation

In the first lesson of this class the pupils have to recollect their knowledge from past lessons about redox equations. In two short exercises they pupils find the correct order of rules to setup a redox equation. The second exercise contains an experiment known to pupils from past lessons where the pupils should repeat and redo the respective partial equations and the total redox equation. In addition, well-known technical terms are offered in a reference field in order to promote the use of scientific language in class.

Equipped with this knowledge, pupils progress to the actual series of lessons.

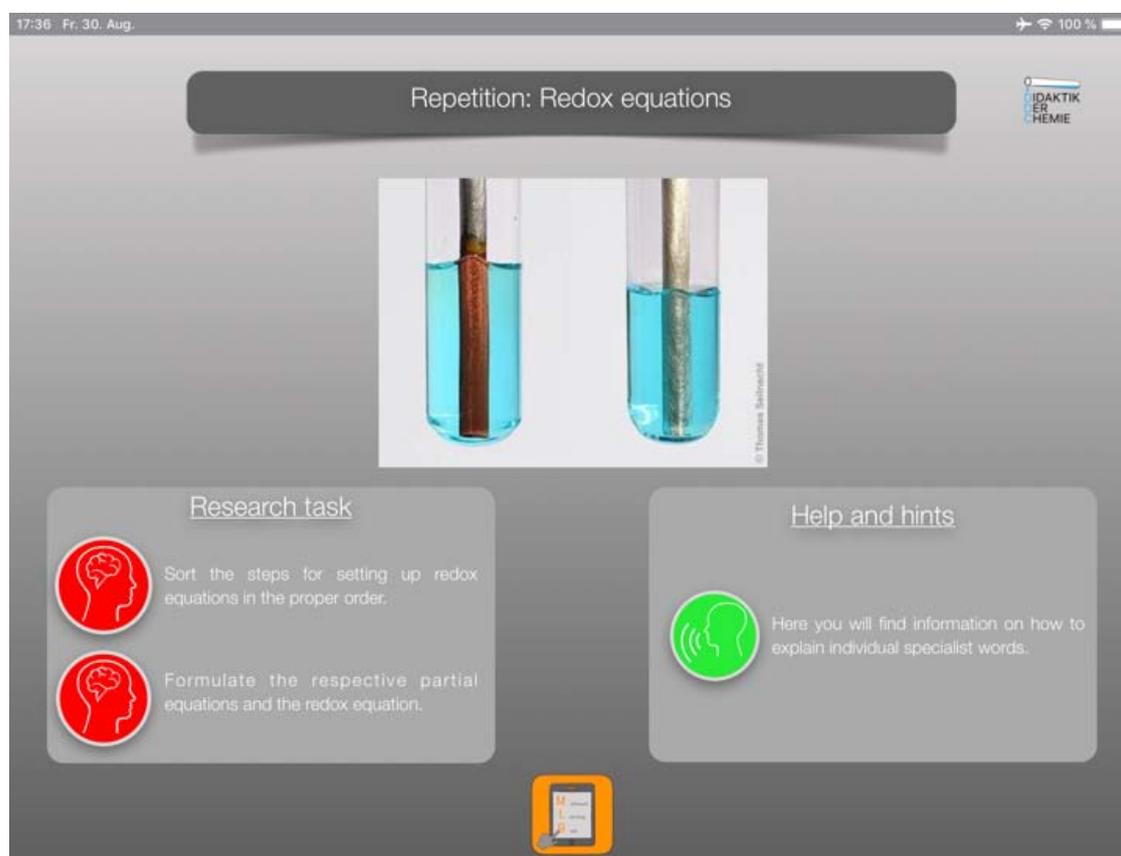


Figure 1. Chapter 1: Repetition and prior knowledge activation



Figure 2. Chapter 2: Introduction book page

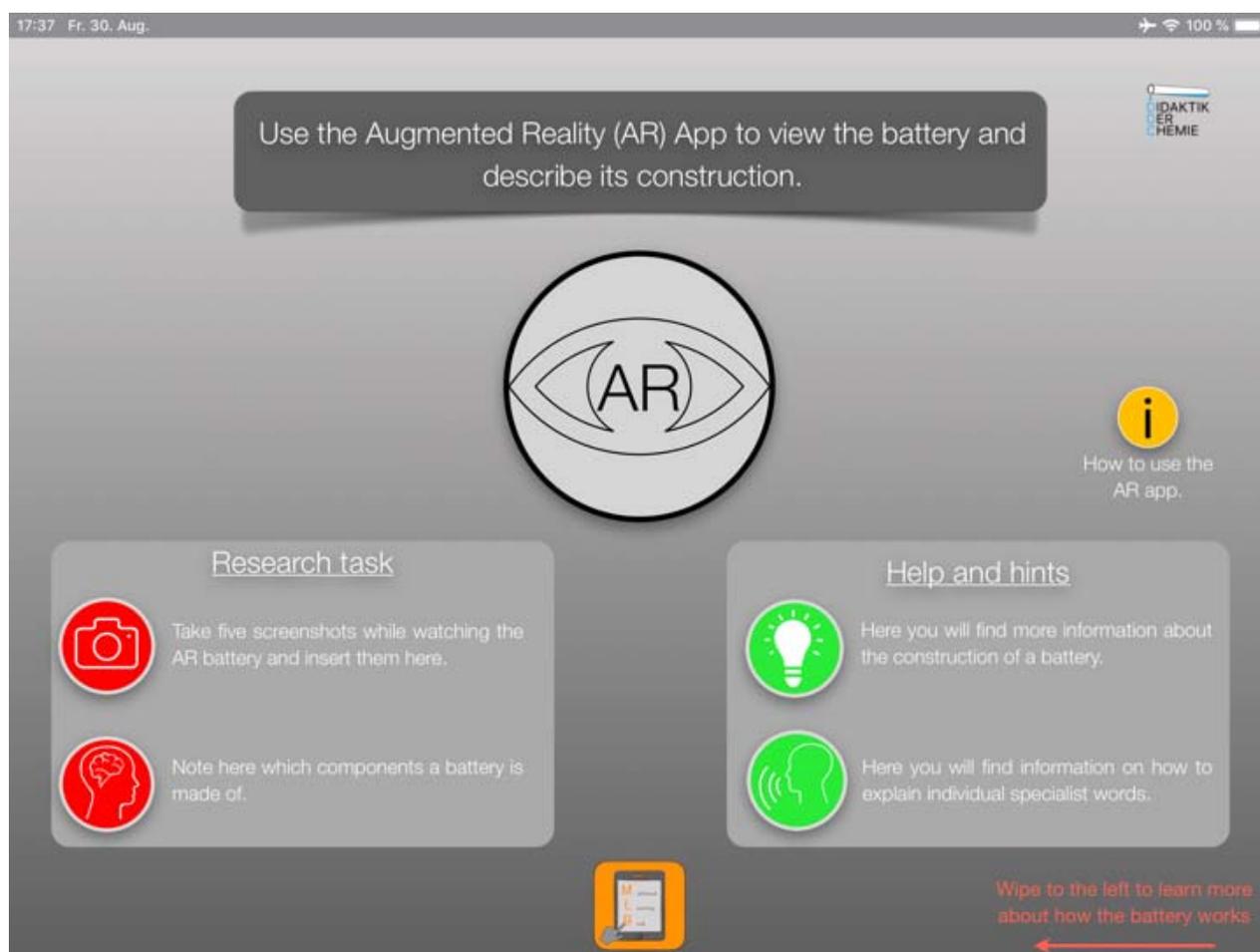


Figure 3. Chapter 2: The battery and the AR-tool

### 2.1.1.2. Chapter 2: The Battery as a Galvanic Cell

This chapter focuses on the development of the galvanic cell in general. As an introductory topic, the battery and its relevance to the pupils' everyday life is covered. A gallery with pictures of various everyday objects highlights the importance of the battery as a part of those objects (see Figure 2). On the basis of this

knowledge it will be explained how a battery works and by which principle it functions. After highlighting the relevance of the battery, its operating principle is explained.

In this section, the tablet is used as a learning tool in the form of Augmented Reality (see Section 3.2) in order to better understand the structure and function at macroscopic and microscopic level.

Linking these digital materials aims at assisting pupils to comprehend the functionality of a battery (see Figure 3). As observing the inside of a battery is impossible due to safety reasons, a digital model of a mono-cell is augmented by the tablet.

On this page of the E-book, pupils are offered help to facilitate the use of the app/to ease the use of the app and language support to formulate the explanation of the experiment.

The first task for the pupils is to document the virtual battery by taking five pictures. The second task is to insert the terms explored for the individual components in an interactive sketch (see Figure 4). The purpose of this unit is to introduce the various components of a battery and their technical terms in order to apply them to general examples in the following sections. In this case, this simplified example of a galvanic cell represents the Daniell element, which will be used further below.

On the next page of the book, the Daniell element is introduced as a simplified description of the functionality of a galvanic cell (see Figure 5). The experiment is demonstrated by the teacher and explained by the pupils. At this point AR materials are integrated again. This integration leads to a conscious pupil activation during a teacher demonstration experiment. Using the AR app, the

components of a Daniell element can be viewed by the pupils on the tablet or be displayed by the teacher using a projector (detailed description see section 3.2). Here the pupils should be able to link the previously developed terms to the components of the battery and identify the Daniell element as a simplification of a mono-cell in their half-cells. To secure their knowledge, pupils complete a task to add technical terms to a sketch of a Daniell element (see Figure 6).

Up to this point, the components of a galvanic cell, in particular the battery and the Daniell element, are only explained on a macroscopic level. The focus of the next page of the book is on the microscopic level of the processes. On the next page of the book, the focus will be on this observation (see Figure 7). The next page includes two tasks as its primary content, the first being a cloze describing the functionality of a Daniell element. The focus is on the most important chemical terms. The cloze also includes technical terms the pupils are already familiar with in order to initialize a curricular linking of knowledge. The second task requires the pupils to establish the partial equations of the two half cells and the total equation of the redox reaction. The page also contains aids to assist comprehension and language support to promote the correct use of chemical terms

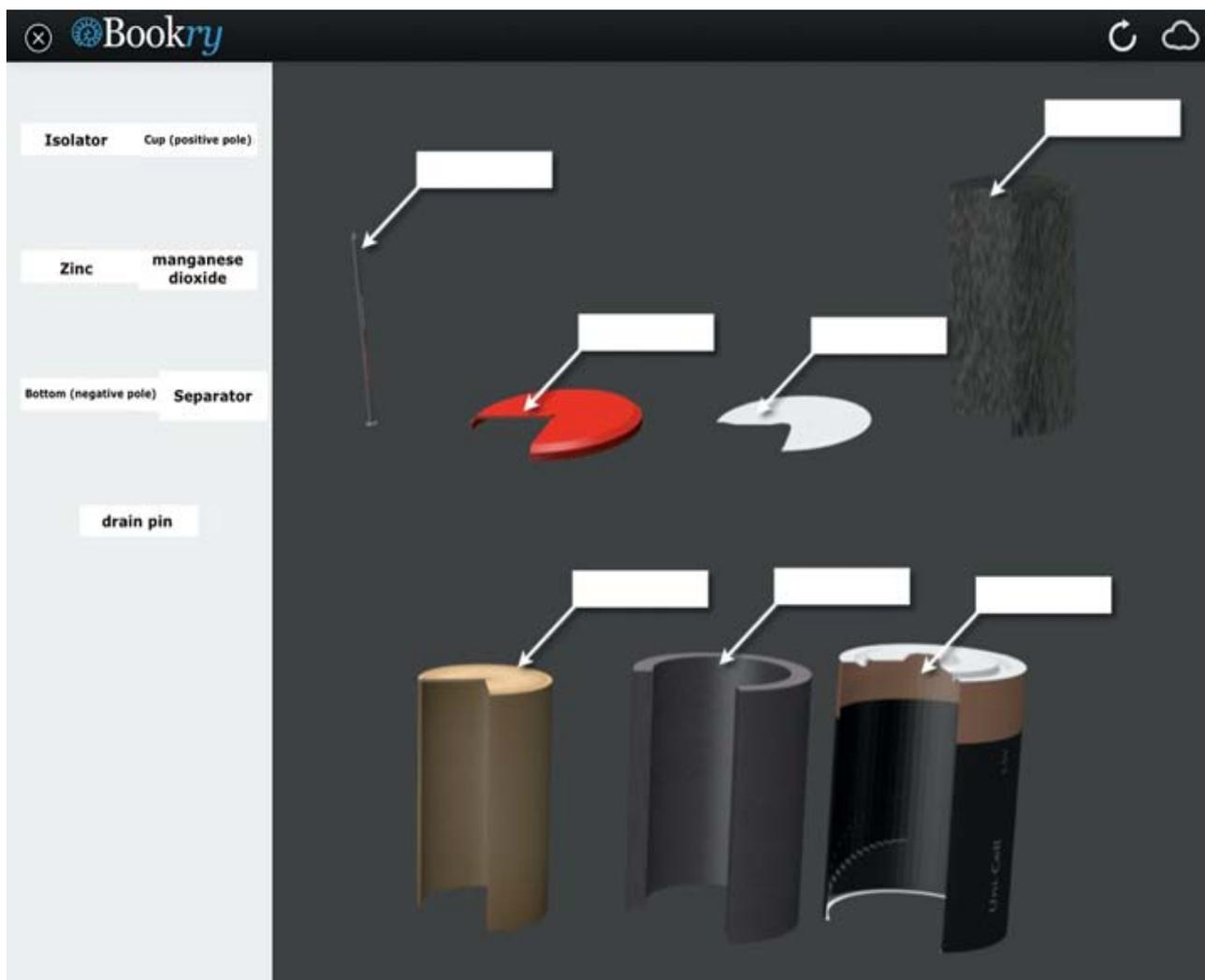


Figure 4. Chapter 2: Task to sort the components of a battery

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To simplify the battery, we will first consider the following experimental setup:



**Research task**

 Label the image using the technical terms discovered in Research Task 1.

 If you have already finished, add this gap text to the Daniell element.

**Help and hints**

 Here you will find information on the explanation and structure of a galvanic element.

 Here you will find information on how to explain individual specialist words.

**How does a galvanic element work?**  
[Click here to learn more...](#)

Figure 5. Chapter 2: Introduction of a Daniell element

Bookry

Construction of a

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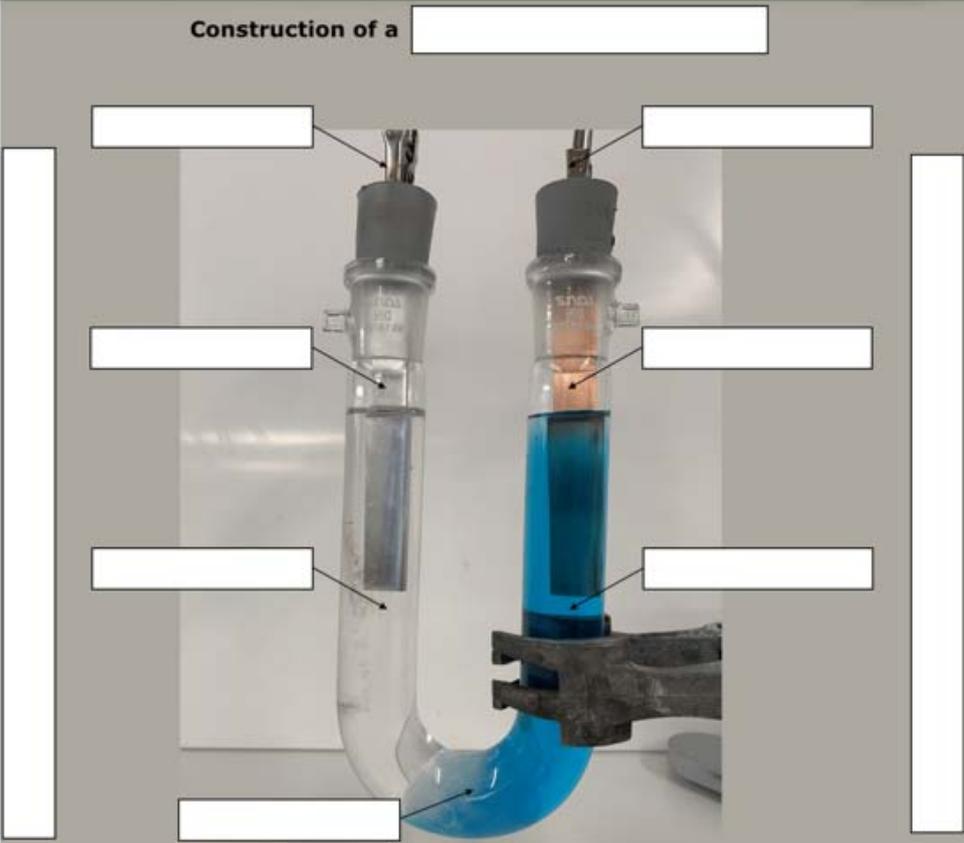


Figure 6. Chapter 2: Task to sort the components of a Daniell element

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What happens in a galvanic element at the particle level?

EDAKTIK ERHEMIE

Research task

- Explain the experiment with the help of the gap text.
- Formulate the respective partial equations and the redox equation in the experiment shown.

Help and hints

- Here you will find an animation showing the processes at the cathode, at the anode and in the area of the diaphragm.
- Here you will find information on how to explain individual specialist words.

Continue with chapter 2...

Figure 7. Chapter 2: Microscopical level in a Daniell element

In this case, the pupils' comprehension is assisted by an animation that visualizes the two processes in the half cells on a microscopic level. In addition, an AR application is available for the pupils, which augments the processes into the real object (see chapter 3.2).

### 2.1.1.3. Chapter 3: Pupil Experiment about the Potential Difference

With the help of the knowledge from the first two chapters, the experiment is carried out in chapter 3 (see Figure 8). Different half cells are tested against each other and the respective potentials are measured. For this experiment, self-made 3D-printed half cells are available with which the pupils can experiment independently in small groups (see section 3.3.2). The aim of this sequence is to enable the pupils to measure different voltages in order to sequence the different metals (here: aluminum, copper, zinc and iron) and thus to predict further reactions. This serves as a transition to cover the topic of the electrochemical series.

This experiment must also be documented and explained. Up to five pictures of the experiment should be taken for documentation purposes. At this point, the learning companion is linked to an experimental tool, because the measured values are recorded with the help of an App, called Measure® by Phywe, and then transferred to the E-Book (see Section 3.3). After the results of the experiment have been documented, the findings must be explained. On the following page pupils find technical

vocabulary and a task for this purpose. In this exercise, the pupils should classify their results in a predefined grid and thus describe the occurrence of various potential differences (see Figure 9).

### 2.1.1.4. Chapter 4: Serious Games for a Better Differentiation in Class

Games in class? If games are used profitably in class, they are called Serious Games. Pupils are offered games that contain the chemical context. This is particularly suitable for differentiation in a class. Especially when experimenting, some pupils need more time due to their different abilities. This aspect is taken into account by encouraging fast pupils by offering Serious Games to consolidate their knowledge. In this book, there are included two different kinds of Games, shown in Figure 10. Likewise, these tasks offer to cognitive weaker pupils additional help and the opportunity to improve their skills. The use of playful aspects in lessons can also increase motivation [5].

### 2.1.1.5. Chapter 5: Pupil Feedback on the Materials

Since this method of teaching does not correspond to conventional teaching methods, it was important to find out how the pupils responded to dealing with the "new" materials in the course of the study. For this purpose, a feedback session was also implemented in the E-Book, allowing pupils to express their personal opinions on this type of teaching. The results of this evaluation are described in more detail in Section 4.

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**Investigate the influence of different redox-pair combinations on the potential.**

**REDAKTIK  
ER  
HEMIE**

### Research task

- Use pictures to document the experiment.
- Record the results that you measured in the Measure App in this table.
- If you are already finished, solve this task.

### Help and hints

- Here you will find a list of chemicals and devices as well as initial help for performing them.
- Here you will find a video that can help you perform the experiment.
- Here you will find information on how to explain individual specialist words.
- On this pinboard you can exchange information with your classmates and get additional help.

[Continue...](#)

Figure 8. Chapter 3: Pupil-centered experiment with 3D-printed half-cells

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**Calculate the potential differences**

**REDAKTIK  
ER  
HEMIE**

Redox Pair	Potential (V)
$Al/Al^{3+}$	0
$Zn/Zn^{2+}$	0,92
$Fe/Fe^{2+}$	1,27
$Cu/Cu^{2+}$	2,02

### Research task

- Calculate the missing potential differences.

### Help and hints

- Here you will find information on how to explain individual specialist words.

[Conclusion](#)

Figure 9. Chapter 3: Explanation of the pupil-centered experiment

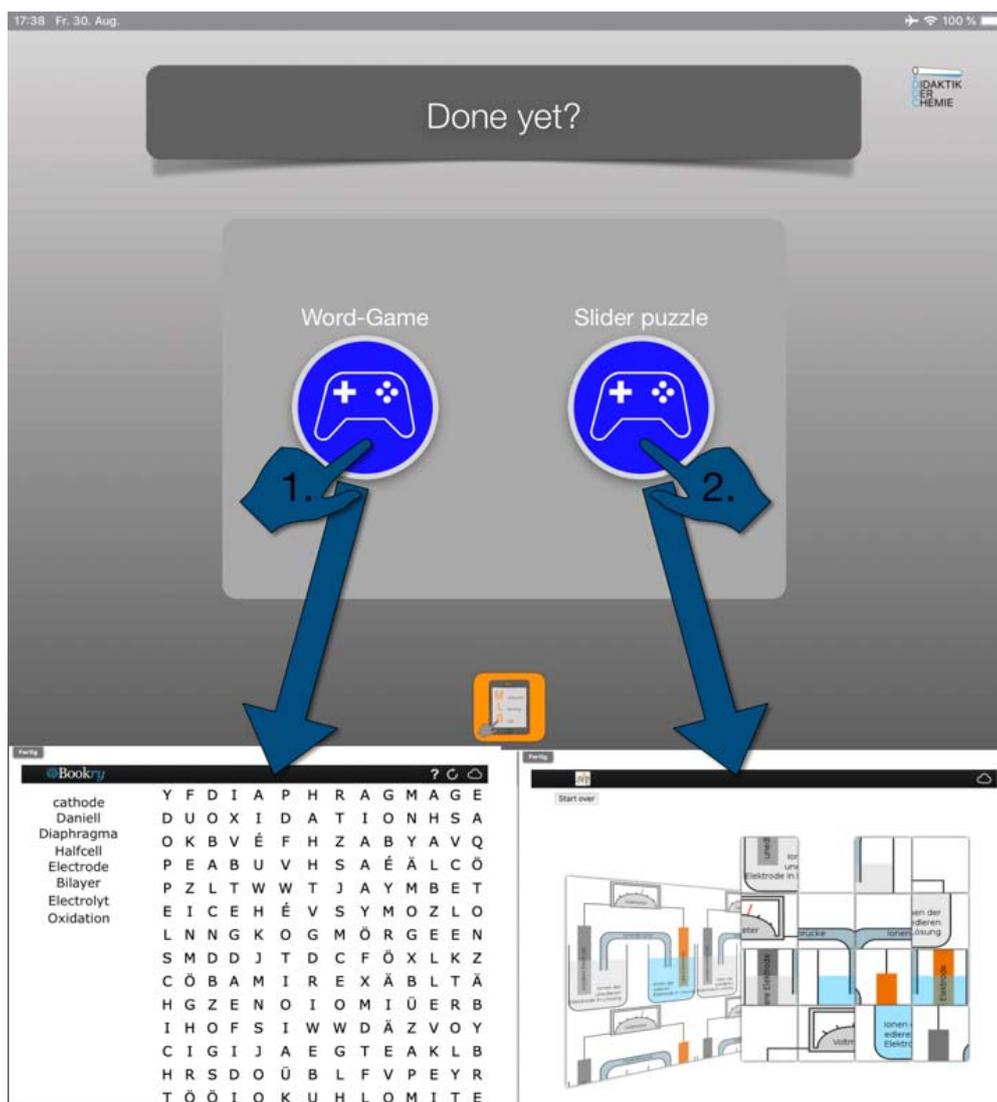


Figure 10. Chapter 4: Serious Games to promote differentiation in class

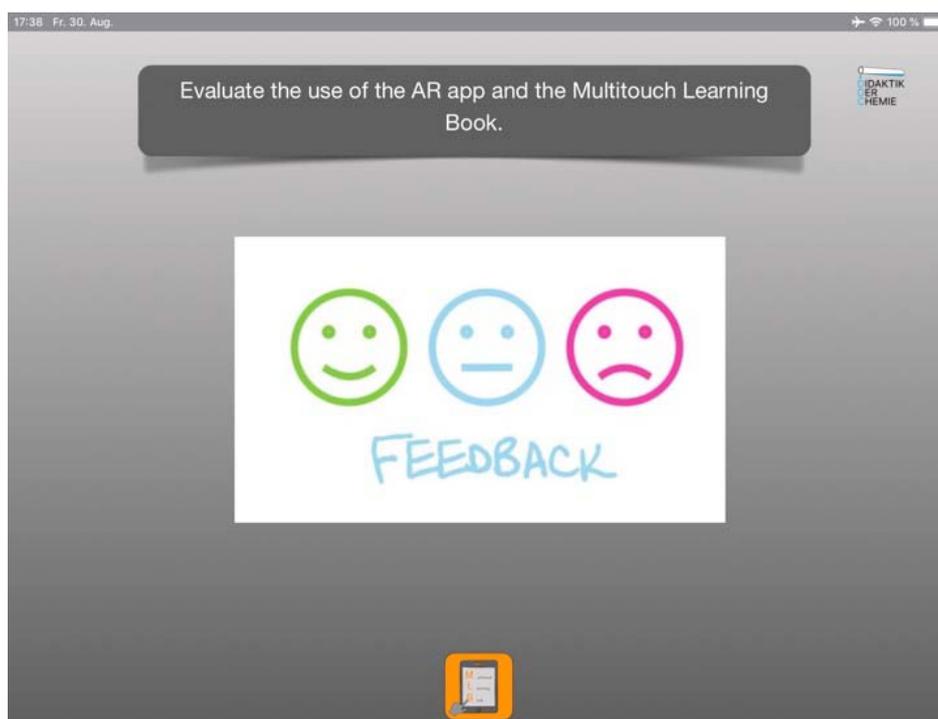


Figure 11. Chapter 5: Pupil feedback about the presented materials

### 2.1.2. Didactically Added Value of a Multitouch Learning Book

Multitouch Learning Books promote learning across an entire series of lessons. In this case, the entire series and especially several functions of ICT are anchored in one E-Book. This results in different added values for the lessons:

- More pupil-centered working phases in the classroom
- Active involvement of pupils in the classroom, including experiments performed by the teacher
- Individualized textbooks
- Differentiation possibilities in the classroom
- Structured use of different digital methods

In summary, it can be said that the use of a MLB can provide the structural and content framework to combine different functions of digital media. In this context, it is important to ensure that the content of digital materials is presented in a way that is appropriate for the addressees.

## 2.2. Learning Tool Content

The contents, which are used in a particular classroom situation, promote the current learning process. In the teaching unit described in the previous section, individual learning tools are specifically implemented for this purpose. Individual situations are enriched with Augmented Reality materials in order to initiate the development of selective cognitive processes.

### 2.2.1. Augmented Reality as a Chemical Magnifier

AR is currently used less frequently in chemistry lessons, although the coexistence of virtual and real objects offers various possibilities for teaching practice. AR itself differs from other techniques by its three characteristics, such as the linking of digital and real content, real-time interactivity and linking in three-dimensional space [6]. It is precisely this connection with positions in real space that allows digital content to be connected with the real objects themselves. The connection can be realized in different ways: Marker-based and image recognition-based triggers can be used in the classroom or to support pupils to conduct experiments. On this basis, experiments and their structure can be provided with site-specific information. This content can consist of static images, text, animations or videos. According to Johnston, chemistry contains three levels of representation, the macro-, submicro- and the representational level, of which only the macro-level can be perceived by the pupil. [7]. Augmented Reality offers the possibility to extend the experiment to the submicroscopic and representational level in order to provide an idea of chemical reactions at the particle level, or to gain insight into a black box such as the battery. A detailed description of the underlying didactic approach is included in the following section.

### 2.2.2. Didactically Added Value of Augmented Reality as a Learning Tool

It may be tempting to apply new techniques in the classroom for purely motivational reasons. However, the educational value of the technique is not in itself [8]. Under certain circumstances, the unreflected use of AR materials can even be a barrier. The simultaneous

consideration of the three levels according to Johnston would, for example, overload the workspace [7]. For this reason, AR cannot be used for many fast-moving experiments. In contrast, more static experiments would be suitable for AR-supported teaching material, as it would be possible to examine the different levels step by step.

The aim of the teaching series is the consideration of the galvanic cell and the electrochemical voltage series. Mahaffy extended the Johnston triangle by the human element to a tetrahedron [8]. As a context for the series of lessons and thus as an introduction to the topic, the mono cell is a good choice as it is a familiar example from everyday life. Pupils are able to view the sections of the battery they receive through the AR app on the iPad (see Figure 12). The form of representation of the battery can be changed via control elements. The composite battery is displayed as a rough sectional image as the start display. Using a control element, the battery can be dismantled into its components which are displayed with their technical terms. In order to be able to fall back on analogies in the later course of the series, a similar set-up to the galvanic cell is chosen. Due to this similar set-up, the functioning principle of each component is revisited at the end of the lesson series, integrating the newly acquired knowledge.



**Figure 12.** Augmented Reality mono-cell to explore the components

The subsequent attempt at the Daniell element was augmented in such a way that all three levels of the Johnston triangle are made visible to the pupil in a manner linked to the experimental set-up. The advantage of the Daniell element compared to other experiments is its static existence, giving pupils sufficient time to deal with the different levels of the Johnston Triangle one after the other. It is intended that at the beginning of the experiment the focus will be on the experiment, i.e. the observation on a macroscopic level, and the engagement with their prior knowledge. It is only in the second step that AR is added in order to explore missing technical terms on the representative level. Pupils who would otherwise fail to interpret the experimental results on the particle level benefit from the combination of macroscopic level and real experiment in AR: Part of the AR is the representation of the processes at the electrodes in the currentless state of the Daniell element (see Figure 13). In an implied "magnification", the pupils can observe how, depending on the electrode material, different numbers of cations dissolve, and form the Helmholtz double layer. Pupils which were previously unable to explain the occurrence of the voltage, can do so with the help of the AR. In this representation they have after the animation expired the

possibility to look at all three levels again in connection and to connect these levels again consciously with each other. After the animation expires, pupils are able to examine the three levels again which enables them to consciously connect those levels with each other. Apart from the experimental setup on the macroscopic level, the pupils observe the measured values on the symbolic level. The measured values in combination with the pupils' knowledge from physics serves to deduce which electrode is more negatively charged. Additional to the macroscopic and symbolic level, pupils engage with the submicroscopic level by observing the animation of the electrode from which cations go into solution (see Figure 14).

As described at the beginning, AR as a technology has no added didactic value in itself. However, the development itself took place along the contents of the teaching series and thus with consideration of the competences in the digital world to be acquired. So, in combination with the other didactic functions of the tablet, a didactic added value can be attributed to this AR within the teaching series.

## 2.3. Experimental Tool Content

In the process of creating these materials it becomes important to combine all three functions of digital media with each other. The third function "the experimental tool" describes the function of a tablet during active experimentation. In this case, the tablet is used to record measured values. For this purpose, the App Measure® from Phywe is used. The values measured in this way can then be entered into the MLB and subsequently evaluated. In addition to the use of digital data logging, this pupil-centered experiment uses 3D-printed materials.

### 2.3.1. Didactically added value of digital data logging

The didactic functions defined by Huwer and Seibert (2017) allow for mixed forms. In this article, the tablet is described as an experimental tool, depending on the design of the experimental set-up, but at the same time cognitive learning processes are initiated and supported, which is why the experimental tool cannot always be separated from the learning tool:

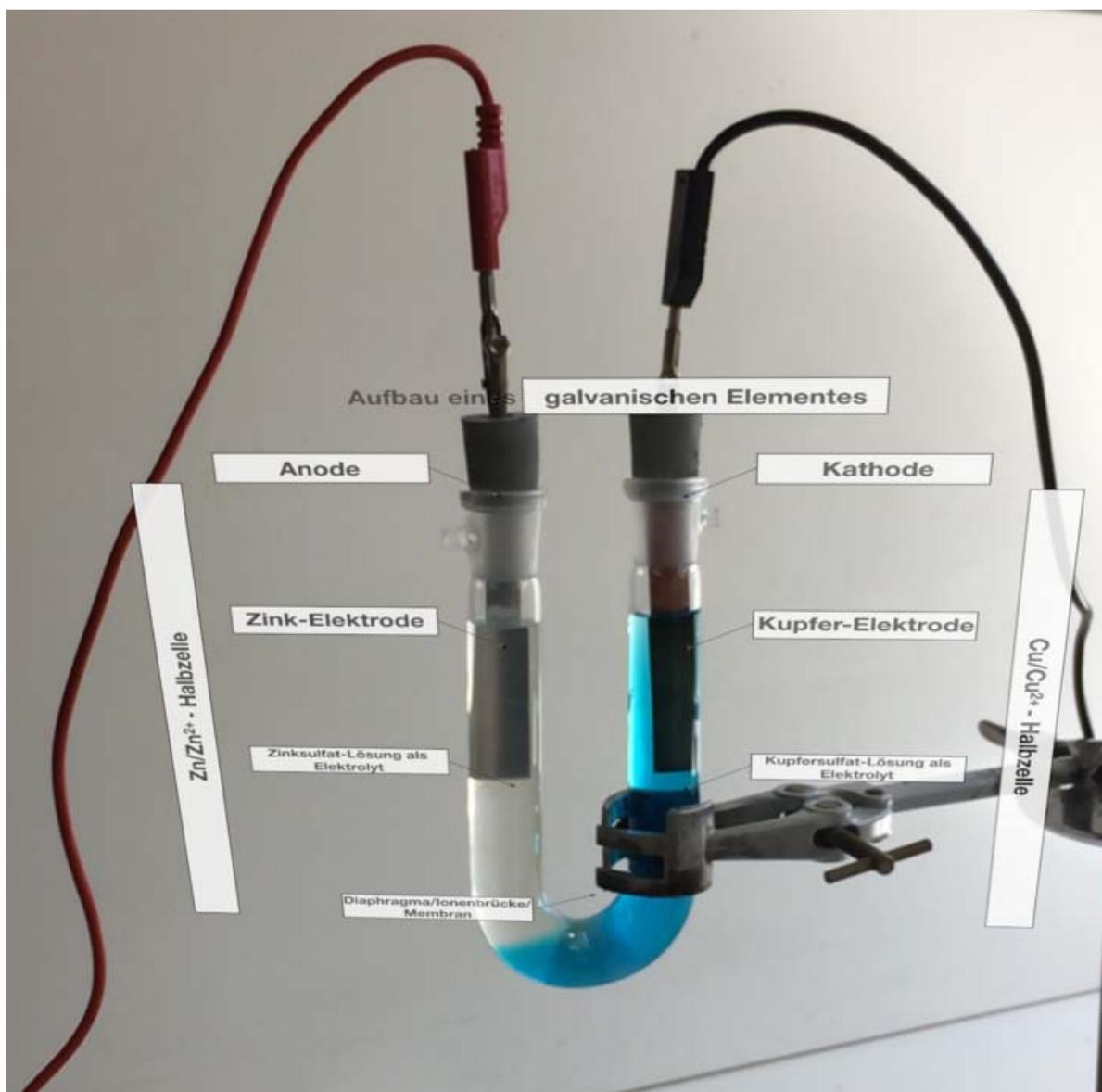


Figure 13. Augmented Reality of the components of the Daniell element on microscopic level



**Figure 14.** Augmented Reality of the microscopic level in a Daniell element

Even if the tablet is used as a tool for data processing only, because the data is logged by the pupil it is visually processed which includes cognitive processes.

Even if the tablet is used as a tool for data processing only, cognitive processes take place because the data logging by the pupil requires visual processing. This processing to support learning situations is part of the function as a learning tool. If considering the simultaneous processing of measured values or the calculation of other quantities from the measured values, the tablet is more of an experimental tool at the moment.

### 2.3.2. Didactically Added Value of 3D-printed Materials in Chemistry Lesson

Low Cost materials are particularly suitable for pupil experiments. In the course of this work, 3D-printed half cells were prepared in such a way that they can be used in experiments as often and variably as desired. For this purpose, four metals were inserted into the provided opening and fixed with hot glue. The corresponding salt solutions were filled into the small cubes (6 mL solution in each box).



**Figure 15.** 3D-printed Low Cost half-cells for a pupil-centered experiment

Magnets were installed on two sides, so that the half cells hold together like in a modular system.

## 3. Findings

The presented teaching unit was used and tested in two classes. A total of 49 pupils took part in the test. Individual statements were taken from the oral feedback of the pupils:

### 1) Feedback of the pupils:

- Helpful in complicated situations and experiments through the illustration by videos (“Hilfreich bei komplizierten Sachverhalten und Versuchen durch die Veranschaulichung durch Videos”)
- Provided variety in the lessons (“Abwechslungsreich im Unterricht”)
- More motivating than gap-fill activities on paper (“Motivierender als Lückentext auf Papier”)
- as fun to work with something new (“Es hat Spaß gemacht mit etwas Neuem zu arbeiten”)
- I felt more like interacting with the content in chemistry class. (“Ich hatte mehr Lust mich mit dem Inhalt im Chemieunterricht zu beschäftigen”)
- The Augmented Reality was great for improving understanding (“Die Augmented Reality war super für das Verständnis”)

The two teachers involved also included feedback on the implementation and changes in the perception of the pupils.

### 2) Feedback of the teachers:

- While some of the pupils are clearing away the experiments, the rest of the class is voluntarily occupied with the additional task of setting up the reaction equations. (“Während ein Teil der Schüler die Versuche wegräumt, beschäftigt sich der Rest der Klasse freiwillig mit der Zusatzaufgabe: Aufstellen der Reaktionsgleichungen”)
- Pupils who otherwise would not have dealt with the content immediately start the assignment and fill in the gaps. (“Schüler, die sich sonst nicht mit den Inhalten beschäftigt hätten, beginnen sofort mit dem Arbeitsauftrag und ergänzen die Lücken”)
- Especially with the gap text higher motivation than on paper (“Insbesondere beim Lückentext höhere Motivation als auf Papier”)
- Due to the pictures they take, students are more likely to recall their experiments (compare holiday pictures). (“Durch die Bilder ist es möglich, dass sich die Schüler das Gemachte besser behalten (vergleiche Urlaubsbilder)”)
- No need to change the medium in the classroom (“Kein Wechsel des Mediums im Unterricht mehr notwendig”)
- No independent unit which can be implemented easily and makes no sense without progress plans (“Keine freie Einheit, die einfach so durchgeführt werden kann und macht ohne Verlaufspläne keinen Sinn”)
- Two games, even when the pupils drift off they still engaged with chemistry (“Zwei Spiele, wenn die Schüler abdriften, haben sie sich trotzdem mit Chemie beschäftigt”)

- Components of the battery are clearly displayed and this method is more time-efficient than cutting open an actual battery. (“Bestandteile der Batterie werden anschaulich dargestellt und zeitlich effektiver als das Aufschneiden der Batterie”)

The classes and teachers were without any exception satisfied with the new materials. The new effects of the materials can be excluded, as the classes have been working with their own tablets in class for two years already. However, the pupils learned for the first time with a Multitouch Learning Book and a lesson enriched with Augmented Reality. All in all, it can be said that the use of an MLB has led to a higher motivation in chemistry lessons. In addition, the knowledge gained in the lessons could be consolidated deeper than with conventional materials, which was confirmed by the teachers. The preparation of the materials took about a week. In the eyes of the authors, this describes a good time-benefit ratio.

## 4. Conclusion

All in all, it can be said that the use of a Multitouch Learning Book is ideally suited to link the three didactic functions of a learning companion, a learning tool and an experimental. As one of the teachers also noted, the variation of the media is no longer necessary in the classroom, since linking individual components results in a mix anyway. The evaluation of the materials created a basis for optimization, revealing that some aspects of the materials are worthy of improvement. Especially the built-in learning tool contents in the form of Augmented Reality show a strong motivational, but also cognitive character/nature. In particular, the bundling of individual learning tools of this kind into a complete MLB has many advantages for teaching, just as described in the chapters above.

## Supporting Information

All materials including the interactive E-Book in English



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and in German can be seen and downloaded from our homepage <https://www.uni-saarland.de/lehrstuhl/kay/ag-didaktik/downloads/>.

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