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Re-Experiencing Chemistry with Augmented Reality: New Possibilities for Individual Support

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Abstract Based on the example of Augmented Reality (AR) this article examines the use of digital media over tablets in chemistry lessons. The structure of an AR-centered learning environment for chemical experiments is explained against the background of learning success, motivation and self-determination. The results of an empirical case study for comparison with analog media are presented, according to which AR can be regarded as a promising tool for visualization in chemistry lessons.

Keywords: *augmented reality, general public, middle school science, high-school, graduate education, research, collaborative/cooperative learning, computer-based learning, self-instruction, inquiry-based/discovery learning, multimedia-based learning, misconceptions/discrepant events, informative and cooperative technology, ICT*

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1. Introduction

Digitization is increasingly finding its way into the most diverse areas of our everyday lives, e.g. the latest smartphone or smart TV, intelligent voice control or the 3D film experience at home. For many of these technical innovations we are only too happy to incorporate them into our daily lives and welcome the comfort they bring with them. Certainly, it is only a matter of time since this development will also have taken over the remaining areas of our lives. This also gets apparent for educational institutions in our country (Germany). This is evidenced through numerous educational initiatives by school authorities and education ministries, including the announcement by the Federal Minister of Education of the so called "Digital Pakt#d", which primarily provides budget for the expansion of the digital (hardware) infrastructure. With "Competences in the digital world", the Conference of Ministers of Education and Cultural Affairs also created the interdisciplinary framework to promote the digitalization of the German school system [1]. Therefore, concrete application scenarios for subject-related media education have to be developed to combine them with existing specialist methods and to evaluate them in order to actually generate additional value in (scientific) education by using existing potentials.

The still quite new technique of "Augmented Reality" (AR, extended reality) can - when used appropriately - represent such an additional value in research experiments in chemistry lessons [2]. This article aims to show possible concepts for supporting the learning process in terms of learning success, motivation and self-determination.

2. Tablets in Science Classes

The purposeful use of digital media in educational institutions should always aim to enable pupils to use digital media responsibly in the sense of "competences in the digital world" [1]. This should give every student the opportunity to actively participate in the technological change and thus to participate in society [3]. It should always be noted that the use of digital media is reflected and adapted to the respective learning group and learning situation. When used appropriately, digital media can support the learning process of students through self-directed, cooperative learning environments [4]. Computers are currently the most commonly used digital media in educational institutions. In addition, the use of tablets in teaching and learning situations is constantly increasing. Compared to permanently installed computers, the strength of tablets lies in their handy size, the interactive touch interface and the wireless use [5]. Tablets therefore own great potential in science education, especially in chemistry, as they have three didactic functions:

As learning tools they enrich the cognitive learning process in the concrete learning situation. As experimental tools they expand the possibilities for experimenting by enabling learners to actively explore or document their surroundings with the technical sensors of the device, such as the camera or the microphone [6]. Furthermore, as learning companion they can enrich learning beyond the concrete learning situation or lesson and over a longer period by "accompanying" all learning processes [7,8,9]. Some national and international studies on the use of tablets in chemistry teaching provide evidence that this has a positive influence on motivation, attention and independence of learners [10].

3. Interactive Learning with Augmented Reality (AR)

Using augmented reality technology, the user's real environment is superimposed with digitally generated information presented as virtual overlays. This allows the viewer to observe both real and virtual content at the same time. He or she can also interactively control the digital content [11]. Either glasses with integrated display (e.g. Google Glass or Microsoft Holo Lens) or smartphones or tablets are used as hardware. The latter is done through corresponding apps, which now also use their own development environments (e.g. Apple ARKit).

In this case, the camera of the tablet serves as a sensor to capture the real environment. This creates an image of the environment on the tablet's screen, which is enriched with digital content by the AR app. The principle of such an AR application is shown in Figure 1 using the example of a digitally extended worksheet.

Due to the free accessibility and wide availability of mobile devices, such as tablets, this technology is also becoming increasingly interesting for the area of education. It offers the possibility to create interactive and individualized learning environments. A particular strength of this technique in chemistry lessons lies in the visualization of non-visible or non-observable phenomena, such as processes at the particle level. By the simultaneous optical presence of the real environment (chemical experiment) and the virtual AR content (visualized explanation of chemical processes), the learning process of the students can be specifically supported [12].

At Saarland University, in cooperation with Kaiserslautern Technical University, such an AR environment was developed and it has been empirically investigated how the AR environment affects students' performance. To analyze the effect of the AR environment on relevant variables accompanying the learning process, intrinsic motivation, self-efficacy expectations and self-determination of the students were assessed before and after working on the AR-supported learning environment. Intrinsic motivation is understood as the execution of an activity due to pleasure in the matter itself. In particular, external pressure or a reward is not decisive for the execution of such actions [13]. The expectation of self-efficacy describes the self-perceived competence of a pupil to be able to solve a task successfully [14]. In the context of chemical experiments for which the AR environment was developed, the successful solution of a task can be seen in the execution of the experiments [15]. The self-determination of the students was evaluated with regard to the components "experience of autonomy", "experience of competence" and "relatedness" [16]. These three components are regarded as basic human needs. The fulfilment of these components is of the greatest relevance for a person's intrinsic motivation.

4. Making the Invisible Visible

The developed AR environment is embedded in the field of electrochemistry for the upper secondary level and for the transition between lower and upper secondary level. The experiments "The Lemon Battery" and "The Volta Column" [17] and "The Lithium-Ion Battery" [18] are discussed. The AR environments are intended to support the students in carrying out the experiments by offering targeted assistance and visualizations where they are actually needed. Using the AR app, students can interactively discover the respective experimental instructions and processes at particle level. All you have to do is open the AR app and position the camera of your tablet above the test instructions. On the screen of your tablet, the help appears in the form of an interactive menu. Students can navigate intuitively through the menus by touching the content displayed.

The graphical user interface (GUI) is started with a "play button" known to the learner, which then starts the corresponding menu offering virtual information at the places where one would expect help or information.

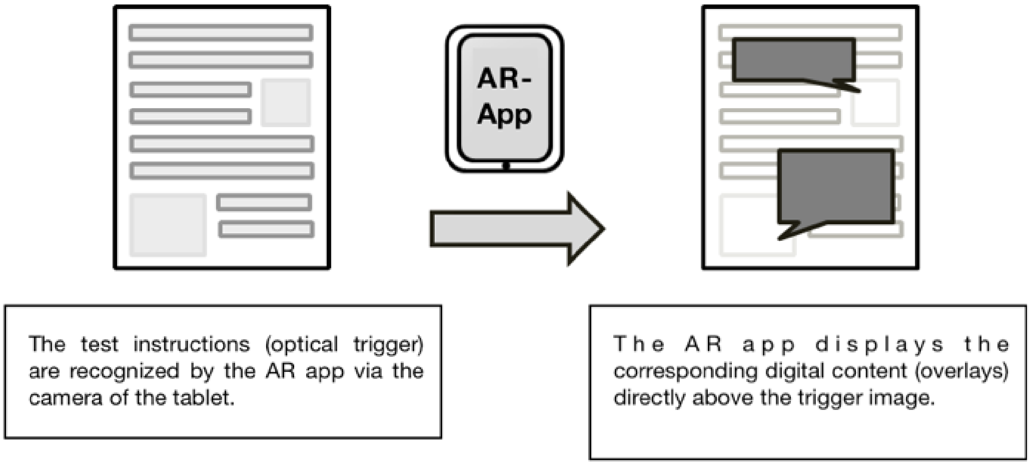

Figure 1. Operating principle of an AR worksheet

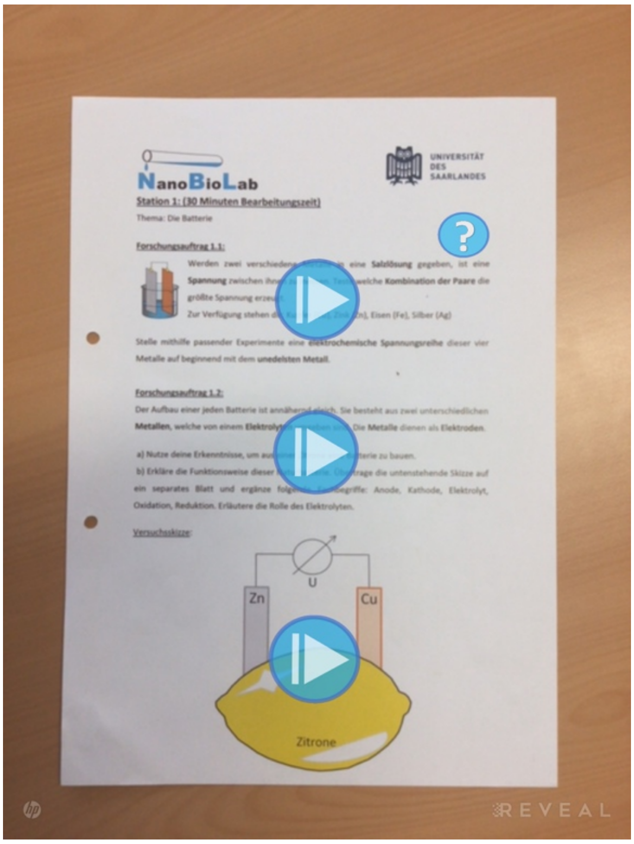

Figure 2. Virtual GUI - Start of interaction on the AR-Interface

Within the AR application, the help is presented in form of digital help cards, which are identical to the analog versions used so far. All help was implemented in the form of image or video files. The aids are always linked either to a specific work order or a test sketch. When linked to a work order, the help maps are displayed in form of a help menu. The helps are presented in a structured and easy to find manner and are divided into different help categories (Figure 3).

Figure 3. Concept of the AR interface and categories of support (left) - Real implementation (right)

Through this classification of the aids, the students can make use of either hints for sources of error, understanding, test evaluation or the operation of devices. A glossary is also available in which important technical terms are explained. If one of these help categories is selected, the first help card related to this category appears. With the navigation icon "Next" the students immediately know that further help maps are available. By clicking on the navigation icon "Back to selection" the students can close the currently displayed help. If the aids are linked to a test sketch, they are displayed directly next to the corresponding test sketch (Figure 4).

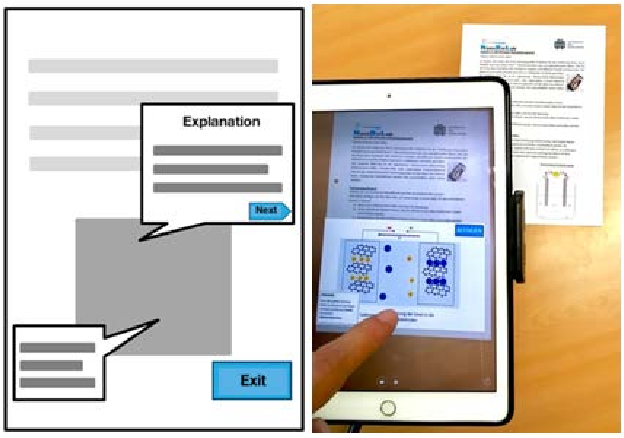

Figure 4. Concept of the AR of an illustration (left) - Real implementation (right)

This allows students to view both the experimental sketch and the explanation at the same time and to relate the contents much better to each other. Overall, it should be emphasized that the help can be displayed successively at the student's instigation. For this reason, students can decide for themselves how much help they need to solve a task. Freedom of choice in terms of assistance should have a positive influence on the self-determination of pupils in particular by promoting their experience of autonomy. The visually appealing and highly structured presentation of the aids should arouse interest and curiosity of the pupils and thus contribute to the increased development of an intrinsic motivation.

The strength of AR in the presentation of aids lies in the already mentioned site-specific visualization of non-observable chemical processes at the molecular level. Electron flows and ion migrations can be shown directly on the experimental sketch. This can reduce pupils' misconceptions and make it easier for them to understand the facts. By merging the two sources of information, a split-attention effect is avoided on the one hand and information interaction is used on the other. This should improve the students' performance and increase their self-efficacy expectations through experiences of success. In the AR environments developed here, the visualizations include the electron flow and the reactions at the electrodes of the lemon battery and Volta column as well as the storage and retrieval of ions at the electrodes of the lithium-ion battery. This can be done either via images (static, identical to analog help cards) or animations (dynamic).

5. Results of an Empirical Study: First Successes Recorded

A total of n = 100 students from the 10th grade of high schools in Saarland participated in the empirical study. The newly developed AR environments were examined with regard to their effects on learning success, intrinsic motivation, self-efficacy expectations and self-determination. A control group design was used in which students received either the AR help, a tablet with a PDF help document (no AR) or analog help to edit the underlying tests in each class. The analogous support represented the usual procedure. The influence of the tablet should be assessed separately through the tablet PDF help, since this tablet caused effect also occurs when using AR due to the required hardware. With regard to the AR help characteristics, a further distinction was made between static help (images) and dynamic help (animations). A total of four groups were therefore distinguished. All groups received the same support of the stuff of the Schülerlabor. The help available to the pupils differed only with respect to the form of presentation. The data were collected using various paper-pencil questionnaires: In the knowledge tests on student performance, multiple-choice tasks had to be solved. All other data were collected using self-report questionnaires with a graduated, interval-scaled response format [19,20,21]. Performance and self-efficacy were evaluated at two points in time, i.e. before and after the intervention. The questionnaires on intrinsic motivation and self-determination were collected solely after the intervention.

An ANOVA (see Table 1 & Table 2) was calculated for the evaluation of student performance, which led to the following result:

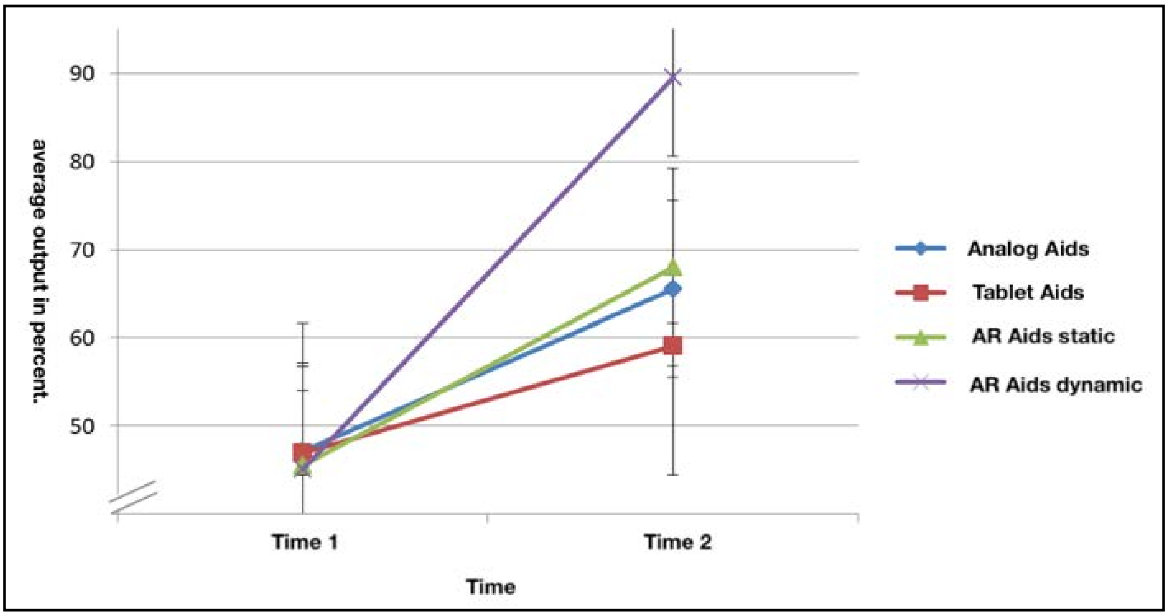

Figure 5. Results of the empirical study on the use of AR applications in research experiments on cognitive-knowledge learning outcomes

Table 1. Overview of the average total scores for the cognitive-knowledge learning test in the pre-test (time 1) and retest (time 2)

Group	Measurement Point	Mean	standard deviation
Control Group	1	47.095	1.767
	2	65.505	1.757
Experimental Group Tablet	1	46.913	2.762
	2	59.092	2.748
Experimental group AR	1	45.518	2.105
	2	68.037	2.094
dynamic Help AR	1	45.062	2.762
	2	89.562	2.748

Table 2. Scheffé Post-hoc comparisons for the cognitive-knowledge learning test (* Significance at p ≦ 0.05, ** at p≦ 0.01 and * highly significant at p≦ 0.001)**

	Group				
		CG	EG Tablet	EG AR	AR dyn.
Group	CG		3.30 (.550)	-0.48 (.996)	-11,01 (<.000***)
	EG Tablet	-3.30 (.550)		-3.78 (.483)	-14,31 (<.000***)
	EG AR	0.48 (.996)	3.78 (.483)		-10,53 (<.001***)
	AR dyn.	11.01 (<.000***)	14.31 (<.000***)	10.53 (<.001***)	

The study could not show any significant differences between the static AR aids, the aids in PDF format on the tablet and the analog aids, but a tendency that AR aids seem to be better than simple digital conversions on the tablet or the analog execution. Representatively for the other measurements for which similar results were found, the results of the student performance survey are shown in Figure 5. At the beginning of the study, all groups show an almost identical performance level; the analysis of intermediate subject effects (group membership) is significant $F = 9.138$, $p < .001$*, $n^2_p = .204$.

While the groups "Analog aids", "Tablet aids" and "AR aids static" do not differ significantly from each other in the retesting of performance, the student performance in the group "AR aids dynamic" is significantly higher and differs significantly from all other groups ($p < .001$*). With regard to the evaluation of self-efficacy expectations, intrinsic motivation and self-determination the results were in the same direction but did not reach significance at any time. Advantages have been found for the table groups on a descriptive level. In the following we discuss the results and give an outlook on the consequences our study may have for the use of digital media in schools.

6. Discussion and Preview

Based on these test results on student performance, there is a tendency for aids in the form of ARs to be superior to "normal" analog and digital use, especially if they use dynamic presentations. Even if the results of the three groups "Analogue aids", "Tablet aids" and "AR aids" are not statistically significantly different (increasing sample size could help to clarify this), it has been shown that the use of digital media does not seem to lead to cognitive overload in students experimenting and thus does not negatively affect their learning performance, as is often assumed. This means that new media potentials can be used without any disadvantages relevant to learning and motivational sectors. And it also means that they can promote the development of competences in the digital world without disadvantages with regard to motivational factors and learning performance. Furthermore, it has been shown that the user interface (GUI) developed by us is of high quality, that it can be used for learning without being overstrained and that its principles and concepts can serve as a template for further AR applications in research experiments. In terms of cognitive and motivational aspects, the GUI enables a "lossless" learning process and thus seems to be usable without friction effects.

Furthermore, the clear superiority of dynamic aids has shown how big the learning performance and motivational effects can be when changing from static to dynamic media. Tablets or AR applications enable young researchers experimenting to access these media that are not available in a completely analog learning situation (e.g. analog support for researchers experimenting) and also cannot be used individually.

Particularly interesting in this context is the visualization of dynamic, chemical processes at particle level. The support with AR opens up completely new possibilities in this field to visualize chemical processes at the particle level and to change the system levels according to the yo-yo learning principle with AR [22]. In our case, we achieved this by augmenting experimental sketches, e.g. the lemon battery, with the processes at the particle level. At this point we would like to point to the great potential that could be achieved by augmenting real objects, such as a real lemon battery.

This technique also proved to be a promising tool for promoting more motivational aspects of learning. Various AR programs for mobile devices are available for use in teaching practice. On the one hand, they enable teachers to create suitable learning environments. On the other hand, students can use the applications to explore the AR environments individually and integrate them into their own learning process according to their needs. With the progressive use of tablets or smartphones in schools, AR can also gradually find its way into school life. As the AR field is still undergoing constant development, it is to be expected that further technical innovations will appear on the market in the near future, which will make the AR experience even more diverse and lively.

Technical reference:

The AR application presented here was created with the cross-platform "HP Reveal" app and can be used on all common mobile devices.

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