Digitisation in chemistry lessons

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An experimental digital learning environment with universal accessibility

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Abstract:

Today, digital media are an integral part of most people's daily routine. Therefore, tablets, smartphones and the internet have become increasingly important at school, as well. At the same time, digitisation offers great potential for teaching highly heterogeneous learning groups individually and comprehensively. However, the use of digital media at German schools is still in its infancy. In order to create a basis for the successful implementation of digital media in teaching, it is necessary to generate profound knowledge about the effectiveness of digital learning environments regarding heterogeneous learning groups. Within this framework, we develop and evaluate a digital learning environment for lower secondary classrooms (age group 13–14) in this project. The aim of the study is to determine the effects of the use of tablet computers in different teaching phases on the students' learning outcome. In order to analyse the effectiveness of the tablets in the classroom, we assess the expertise knowledge of the students before and after the teaching unit as well as the students' attitude towards the teaching unit and towards working with tablet computers. With the help of a screen-capture-software, it is possible to retrace the students' action steps while working with the tablets. Additionally, the lessons are filmed to compare the work behaviour of the learners with and without tablets. Furthermore, the cognitive abilities and the self-concept of the students are determined. This paper focuses on the development and design of the study, as the evaluation has not yet been completed.

Keywords: digitisation, tablet computer-based chemistry lessons, universal accessibility

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Introduction

Just like society, educational institutions are in a constant state of change as they are under the influence of changing frame conditions. There have been different developments in education policy over the last two decades that have had a decisive influence on German schools. The most notable of these are the School Act NRW of 2005, which obliges every teacher to promote each student individually (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2005), and the ratification of the *UN Convention on the Rights of Persons with Disabilities* (United Nations, 2006), which grants every student equal participation in school life. Consequently, joint learning has finally found its way into the German education system. Teachers are thus facing the great challenge of dealing with increasingly heterogeneous learning groups.

At the same time, another topic is coming to the fore: digitisation. Today, digital media have arrived in almost all areas of life, becoming an indispensable part of our everyday lives. That is why the Internet, and thus tablets and smartphones as well, are becoming more and more important in schools, too. Learning with digital media and via digital media is therefore not only extremely important, but is also explicitly demanded by the strategy paper "Education in the digital world" published by the *Conference of Education Ministers* (KMK, 2016). The Federal Government also sees a need for action here and wants the "DigitalPakt Schule" [Pact for digitisation in German schools] to be established by the end of 2018, which includes financial support for German schools (Bundesministerium für Bildung und Forschung, 2018).

In view of the increasingly heterogeneous learning groups on the one hand and the simultaneously growing digitisation of schools on the other hand, our interest is to generate knowledge about the use of digital media in heterogeneous learning groups. We focus on chemistry lessons.

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Theoretical background

Due to the central role of digital media for this project, it is first of all important to briefly define the term. “Media” is a relatively vague term because there is no universally accepted definition. Technical hardware devices such as computers, beamers and mobile devices, software such as computer games, media formats like online newspapers, but also simple texts, images, audio and video files are referred to as media. For the fields of media didactics Petko (2014) defines digital media on the one hand as cognitive and on the other hand as communicative tools for processing, storing and transmitting symbolic information.

In addition, we have to distinguish digital media from analogue media. Analogue media generally refers to books, posters, newspapers, etc. but also to audio or video cassettes. Digital media include the internet, mobile devices such as smartphones, tablets and computers, as well as e-books and video games (Petko, 2014). They are also classified according to the sensory channels they address: the auditive, visual and audio-visual channels (Barke & Harsch, 2011; Reiners, 2017).

In this context, the concept of multimedia should be emphasised. Nowadays, multimedia is an essential feature of both printed and digital media and describes the combined presentation of linguistic and pictorial representation formats. These can be static, for example in the form of written texts, diagrams or illustrations, or dynamic, as in spoken text, videos, animations or simulations (Scheiter & Richter, 2015). Overall, multimedia systems are characterised by the fact that they use different symbolic systems – this is called multicodality – or address several senses simultaneously – this is called multimodality. Multimedia-based teaching and learning materials are frequently used to convey scientific content, as it is hoped that the visualisation of facts and processes will provide a special learning potential (Girwidz & Hoyer, 2018; Weidenmann, 2002).

Theories of digital learning

The use of digital media bases on various theories. For this project, three theories in particular are to be highlighted. The first of these relates to the design of digital media and is called *Cognitive Theory of Multimedia Learning* (Mayer, 2005, 2014). This approach firstly bases on the assumption of the working memory having a limited capacity and secondly on the fact that auditive and visual perception, i.e. hearing and seeing, fall back on independent capacities. Information presented in multimedia, which address several channels simultaneously, is therefore more likely to lead to a learning success than exclusively visual or auditive presentations. Digital media in particular are expected to have great potential for the combination of auditive and visual access to information (Paivio, 1990). However, despite the use of different cognitive structures, the human information processing system has only limited resources such as attention and memory capacity. Hence, there is still a risk of a high cognitive load (Mayer, 2005).

Another approach known as *Cognitive Load Theory* (Sweller, 2005; Sweller, Ayres, & Kalyuga, 2011; van Merriënboer & Sweller, 2005) deals with the load of cognitive structures, also concerning the design of learning materials. This theory assumes that the human brain has certain limits, but that the cognitive load required to learn a skill can be divided into three areas:

- The first area covers the complexity or scope of the actual content to be learnt. This is called *intrinsic cognitive load*. The more difficult the learning material, the higher the *intrinsic cognitive load*.
- The second area relates to the design of learning content and is called *extraneous cognitive load*. Learning material characterised by superfluous and irrelevant information, repetitions or numerous references leads to a higher *extrinsic cognitive load*.
- The third area, the *germane cognitive load*, comprises the understanding and linking of the information to be learnt. The *germane cognitive load* must be promoted for the learning to take place. This means that the learner has to build up new schemes and activate existing schemes in the working memory.

The goal of every good instruction is to keep the *extraneous cognitive load* as low as possible so that the working memory has enough resources to maximise the *germane cognitive load*. Particularly when using digital media, there is a risk of overloading the working memory with an excessively large *extraneous cognitive load*, since the learning content here often has a higher information density and complexity in the representation. Multimedia learning material should therefore be designed in such a way that learners can use their resources for the learning process as efficiently and effectively as possible. There are different recommendations for text and image design. These equally apply to both analogue and digital media and serve to avoid overloading the working memory (Clark & Mayer, 2011; Hartley, 2014; Meier et al., 2016).

In addition to the design of digital teaching materials, the way in which they are used is of decisive importance for their successful implementation. This can be described using Puentedura's SAMR model (2006). In the following, however, Bastian's concept (2017) based on Puentedura will be introduced (see Figure 1). Unlike the original model, it does not refer to digital media in general, but to the use of tablets specifically. The model comprises four ladder-shaped steps. The lowest level at which a digital device can be used is that of *substitution*. Here, the tablet acts as a direct replacement for an analogue tool without any functional changes. This is the case, for example, if a PDF-file is read on the tablet or the device is used to type in a text.

Figure 1: Adaptation of the SAMR model according to Puentedura (2006) for the use of tablets in class (cf. Bastian, 2017).

The second stage is the *augmentation*. At this stage, the tablet also serves as a direct replacement for an analogue tool, but adds functional improvements. For instance, when a spell checker can be performed for a designed text or when in simple knowledge tests, for example in multiple-choice format, feedback is given as to whether the answer to a question is correct or incorrect.

Both of these levels are summarised under the term *enhancement*. The use of the tablet at these levels does not mean an increase in the quality of teaching, but rather an expansion of possible working methods.

The two upper levels indicate a *transformation* of learning. Thus, the use of tablets on the third level, *modification*, allows a substantial redesign of learning arrangements. Here, for example, the tablet can ensure that the students do not simply write down the learning content, but expand it with their own sound, images or video documents, which enables learning via other sensory channels. Additionally, there is the possibility to edit the content and to use it for further learning.

Finally, on the fourth level of *redefinition* the medium is used to design tasks that would have been inconceivable without the technology. As an example, Bastian (2017) cites collaborative and synchronous writing projects or the extension of self-created weblogs, i.e. diary-like websites that are accessible to all students and offer the opportunity to supplement with comments or notes. The knowledge content produced can thus be adapted and expanded again and again in further learning. This creates an interactivity that enables new learning tasks.

Overall, the SAMR model provides an opportunity to make a statement about how the technical equipment can be integrated into school teaching. However, this does not necessarily mean that at the same time a statement can be made about the quality of teaching or the learning success of the students. Although the model aims to use digital media at the higher levels, this is not a prerequisite for good teaching and learning. According to Bastian (2017), the goal should therefore be to reach the higher levels in the sense of a more varied use of the devices. Teachers should aim not to remain at the lower levels, but to enable new learning tasks and thus to redefine teaching and learning in the sense of the fourth level.

Experimenting with digital support

Often presented in literature, experiments are an elementary part of chemistry education (i.a. Eilks, 2015; García-Martínez & Serrano-Torregrosa, 2015; Hüing, 1984; Lister, 1995). This is still the case in times of digitisation. Digital media offer special added values that can be used for experimenting in schools. Starting with the introduction to the experiment, digital media can have a motivating and introductory function. Possibilities include playing a video or trailer, the digital presentation of newspaper or online articles, but also the presentation of comics, which can be created relatively easy by the teachers themselves with the help of digital templates (Huwer, Seibert, & Brünken, 2018; Kuhn & Müller, 2014; Sieve & Schanze, 2015).

Video instructions or animations can also be used to plan and guide experiments. At the same time, it is possible to compile overviews of the required materials and equipment and to present the construction of more

complex experimental apparatuses both visually and animatedly (Ardac & Akaygun, 2004; Huwer et al., 2018; Sieve & Schanze, 2015).

Furthermore, there are different possibilities of using digital media during the performance of experiments. Nowadays there are various providers offering so-called virtual labs in which experiments can be simulated. Digital devices such as smartphones or tablets make it much easier to carry out a wide variety of measurements, to evaluate the collected data extensively and have it graphically displayed. For experiments that cannot be carried out at school, classic video demonstrations of experiments are of course suitable. However, digital media can also have a supporting and differentiating character during the experiment, for example by offering additional help and information (Bresges et al., 2014; Huwer et al., 2018; Irwansyah, Lubab, Farida, & Ramdhani, 2017; Kuhn & Vogt, 2013; Sieve & Schanze, 2015).

Finally, there are useful application possibilities for the documentation of experiments. Smartphones or tablets can extend experimental protocols with the help of their photo function. The audio recording function provides auditive storage of experimental documentations. At the same time, phenomena that happen too fast for the human eye can be recorded and slowed down with the slow motion function, just as particularly slow chemical processes can be recorded and shortened with the time lapse function (Hilfert-Rüppell & Sieve, 2017; Klein, Kuhn, & Müller, 2017; Mähler & Pallack, 2014; Sieve, Ehlers, & Struckmeier, 2015).

Universal accessibility

Finally, the aspect of universal accessibility should be emphasised. Even today, regular instruction is often planned for imaginary average students, so that only one common access to learning is created for all students. For some learners, however, this can create barriers that cannot be overcome without support. A learning environment with universal accessibility offers different ways to overcome these barriers or creates alternatives so that each learner can choose his access to successful learning individually.

In this context, for several years we have been working on the approach of Universal Design for Learning (UDL; Center of Applied Special Technology (CAST) (2011)) from the USA, which is a concept for designing inclusive teaching. The UDL is characterised above all by the use of flexible and varied teaching materials. Lessons that have been designed according to the principles of the UDL are both challenging and supportive and aim to minimise unnecessary barriers that all learners may encounter in class. Basically, the UDL is divided into three principles, each with three subordinate guidelines (see Figure 2).

Principles		Provide multiple means of engagement	Provide multiple means of representation	Provide multiple means of action & expression
Guidelines	Access	1. Recruiting interest	4. Perception	7. Physical action
	Build	2. Sustaining effort & persistence	5. Language & symbols	8. Expression & communication
	Internalize	3. Self regulation	6. Comprehension	9. Executive functions
Goals		Purposeful & motivated	Resourceful & knowledgeable	Strategic & goal directed

Figure 2: Summarised table of the UDL (cf. CAST, 2018).

The first principle concerns the students' engagement to learn, because learners can differ substantially in their interests in different contents. Thus, largely autonomous and authentic learning should be made possible, so that the students can work perseveringly on different learning subjects. In particular, measures to promote self-regulated learning play an important role.

The second principle involves the provision of different formats and means to present information for the teacher, as learners can also clearly differ in the way they perceive and understand the information presented. For example, information should not only be presented visually, but also audibly. The language should be

comprehensible to all students and additionally supported by symbols. Furthermore, in order to help learners understand, it may be helpful if particularly important information is highlighted and the content is presented in a structured way.

The third and final principle of the UDL is to offer multiple means of action and expression, which means that students can present their knowledge in various ways. They should be offered different motor actions and choices when creating and presenting their learning outcomes. Additionally, they should be supported in learning executive functions.

In a conclusion, the UDL table can be used as a kind of checklist when designing inclusive teaching, whereby it is not always necessary to follow all guidelines, because often this is not possible. Consequently, each teacher can decide for himself which elements are feasible for his individual learning group and which may initially be neglected. With regard to the use of digital media in teaching, these play a special role for the implementation of the UDL, as they offer a higher degree of flexibility compared to analogue media. Thus, they have the potential to be used in schools for more equal opportunities and in the sense of a more individual promotion. However, it has to be said that the use of digital technologies does not guarantee the implementation of all UDL guidelines *per se* (CAST, 2011; 2014).

Interim conclusion

The insights gained from the theoretical part can now be summarised as follows. Firstly, it can be stated that digital media can serve as knowledge mediators due to their versatile presentation formats and their multimedia character. Their quality, as with analogue media, strongly depends on their design and the way they are used. However, digital media are also able to serve as various support tools for experimenting, specifically in relation to chemistry lessons. In addition, they are particularly suitable for increasing the universal accessibility of learning content. The effectiveness of these individual aspects has already been investigated in various studies (Baumann & Melle, 2018; Kuhn & Vogt, 2013; Pietzner, 2014), but their interplay has not yet been evaluated. In this project we developed a digital learning environment that combines these aspects within an iBook. This way the iPad on the one hand functions as a mediator of knowledge and on the other hand serves as a supporter in experiments. All the while accessibility for every learner is to be guaranteed in the different learning phases.

Research questions and design

In the course of this project, we pose the following research questions:

Q1: How do students rate iPad-based instruction?

Q2: Do the learning units increase expertise?

Q2.1: Does the effectiveness of the use of iPads vary in different phases of the lesson?

Q2.2: Are there differences in the increase in expertise when learning with digital or analogue teaching materials only?

Q3: How do students use the teaching materials?

Q3.1: How do students use the teaching materials in different phases of learning?

Q3.2: How does the use of iPads affect learning behaviour?

Q4: To what extent are the learning units suitable (a) for learners of different cognitive levels, (b) for female and male learners?

In order to investigate the research questions mentioned above, we chose a research design as shown in Figure 3. The intervention is carried out within one day at the schools with a sample of $N = 105$ in the pilot study and an estimated sample of $N \approx 300$ in the main study. Based on the results of the pre-test in expertise knowledge and cognitive abilities, the students of the same class are divided into two comparable groups (G1 and G2) for the intervention. At the beginning, both groups receive a digital introduction via a motivating introductory video. After that, the groups differ in the way that G1 receives the digital working materials in the experimental phase and in the theoretical phase, while G2 works with analogue working materials. Various test instruments are used for the investigation: One week in advance of the intervention an expertise knowledge test is used as part

of the pre-testing to record previous knowledge of the chemical content (multiple-choice test with 23 items; see Figure 4). In addition, the CFT 20-R test (Weiß, 2006) is used to determine cognitive skills and the DISK-GITTER questionnaire (Rost, Sparfeldt, & Schilling, 2007) serves to estimate the school self-concept in mathematics and chemistry. Within the intervention, an attractiveness test (10 items, 6-step Likert scale; see Figure 4) as well as a cognitive load test (10 items, 6-step Likert scale; see Figure 4) in the form of assessment sheets are used after the individual teaching phases to assess to what extent the learners find the respective teaching phases motivating and how they perceive their cognitive load after each teaching phase. Moreover, after the experimental and theoretical phase, the expertise knowledge test is carried out again in order to determine the effects of the individual phases on the learning growth of the students. Three weeks after the intervention the follow-up test to evaluate the long-term effects takes place. Additionally, the individual actions of the students on the iPads are captured by means of screen recordings and the entire classroom teaching process is recorded on video, too. In order to make statements about the use of digital material in heterogeneous learning groups, the results of the CFT test, the self-concept questionnaire as well as the data regarding expertise knowledge, attitude and the handling of the tablets will be linked.

Figure 3: Research design.

Example of the **expertise knowledge test**:

You want to get alcohol out of wine. Which separation method do you use?

- ☐ Filtration
- ☐ Distillation
- ☐ Extraction
- ☐ Fermentation
- ☐ Sedimentation

Example of the **attractiveness test**:

I liked the last learning phase.

Agree ☐ ☐ ☐ ☐ ☐ ☐ Disagree

Example of the **cognitive load test**:

The explanations in the last learning phase were too complicated.

Agree ☐ ☐ ☐ ☐ ☐ ☐ Disagree

Figure 4: Example items of the expertise knowledge, attractiveness and cognitive load test.

The learning software

As part of the project, we developed a learning software in the form of an interactive iBook on the topic of separating mixtures for lower secondary classrooms (age group 13–14). We used the programme “iBooks Author” (Apple Inc., 2018) which provides the necessary internal functions and offers the possibility to add external functions, so-called widgets. The iBook consists of three phases: A short introductory phase, an experimental and a theoretical phase, that are described in the following.

In the beginning, all students watch the introductory video by the use of a beamer. This is intended to provide a motivating and prefacing introduction to the topic, but does not yet include contents. The story of the learning environment is presented in the video. The students are included in the story, within which they are on their way to a chemistry excursion. Their airplane gets caught in a storm and they are forced to perform an emergency landing on a deserted island. Having arrived on this island, the students have to overcome different challenges, which can only be mastered with the help of material separation. The separation processes discussed in the following part are experiments commonly carried out in schools.

After the video introduction, the experimental phase, in which the learners independently carry out the individual separation processes, takes place. Here the students work individually. They each receive their own experimental box and the corresponding teaching materials at their workplace. The treatment of each separation process is divided into three sections. At the beginning of each experiment, the students first receive a problem-oriented impulse on how to approach the experiment. For example, this can be an article from an in-flight magazine or stimulating pictures or videos. Afterwards, the independent planning and execution of the student experiments takes place with the support of staged learning aids. These aids can be opened by simply tapping on the corresponding symbol. Students are encouraged to decide for themselves whether they need the help or not. The first tip contains only the visual representation of the materials required for the experiment, while the other tips increasingly guide the experiment. Finally, the most comprehensive tip contains the complete experimental instructions, which can be used by the learners like a cookbook and is also offered in multimedia form in video sequences. For documenting the experiments, the students use the photo function of the iBook to create a before-and-after comparison. This is supposed to support them when writing down their observations. With the help of the “Apple Pencil” the students enter their observations into the iBook by hand.

The experimental phase is followed by the theoretical phase, in which the students get deeper information about the experiments they carried out before. Also in this phase the students work on their own. This phase can also be divided into three parts for each separation process. First, the learners receive general information about the respective separation process. An information text is provided, which can also be played back as an audio file, stopped at will and listened to repeatedly. Furthermore, the students receive additional interactive information, for example in the form of an interactive picture, as well as animation or video. In addition, learners can receive help in the form of previous knowledge as well as extra information. Secondly, after the information transfer, different tasks take place on three levels. Learners are encouraged to complete at least two tasks. Of course, they can also complete all three. The task types differ by topic. Finally, the learners summarise their newly acquired knowledge. This is done in the form of an article for the school homepage as well as through an online interview and a “WhatsApp” chat. Here, the students can receive support in the form of staged learning aids, too.

With a view to the design of the study, the iBook described up to this point is not used by all students, but only by the students of group G1. In contrast, the students of group G2 work with analogue learning materials that we developed for the comparison. These materials were designed in the form of a regular workbook, which have identical content as the iBook. Understandably, not all functions of the iBook can be transferred 1:1 into the analogue workbook. For example, videos and animations had to be replaced by sequences of pictures and instead of the photo function, students have to make drawings. In order to ensure comparability between the two groups, each learner of G2 receives an extra booklet with corresponding learning aids for additional help.

Conclusion and outlook

In the course of a pilot study the developed learning environment and the corresponding test instruments were tested in five classes ($N = 105$). The data collected will be evaluated in the following months, which is why there are no quantitative results currently available. At present, only a qualitative assessment of the pilot study can be made. First of all, we can say that the learning environment generally works and that there have not been any serious structural or technical problems. The students of both groups were able to work individually with their teaching materials during the project day, despite of being unaccustomed to this very independent way of working. In addition, the experimental boxes prepared for each learner were highly appreciated by the students.

Especially in the experimental phase, the analogue group proved to be working faster than the digital group. This could be due to some functions of the iBook being initially unfamiliar to the students of the digital group and therefore first having to be internalised. Interviews with individual learners have not yet been able to show whether the teaching materials of one group were rated better or worse than those of the other. Overall, we observed a visible decrease in motivation in both groups when transitioning from the experimental phase to the theoretical phase. Although they rated both the analogue and the digital learning material positively, the teachers involved in the project noted that the development of such materials is hardly feasible in everyday school life.

After the evaluation of the data collected within the pilot study and the subsequent revision of all materials and test instruments, the main study with a sample of $N \approx 300$ is scheduled to begin in autumn 2019. In addition, the development of suitable coding manuals for the evaluation of screen and video recordings is still pending.

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