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Multitouch Experiment Instruction for a Better Learning Outcome in Chemistry Education

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Abstract Multitouch Experiment Instructions (MEI) are interactive multimedia eBooks as a full-digital or Augmented Reality (AR) Instructions as a digital-augmented material for the individual promotion of learning while experimenting in chemistry lessons. They provide a digitized experimental instruction, which is made to support both cognitive weak and strong pupils in the sense of individualization. The aim of the MEI project is to improve pupil's self-regulated learning using a digitized experimental manual which is based to main results of didactic and scientific learning. Initial research results have shown that the presentation of information follows a structured learning process. To connect the promotion of self-regulated learning, digital competences and experimental skills an existing experiment "Characterization of Alkanes" has been digitalized as one Multitouch Experiment Instruction.

Keywords: *ICT, science education, digital media, chemistry education, middle school, high school, multimedia learning*

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1. Introduction

Digital media has become essential tools in all aspects of life including education. In 2016, the Standing Conference of the Ministers of Education and Cultural Affairs in Germany (KMK) already adopted the "Competences in the Digital World" [1] and the German government implemented the Digital Pact. This regulation intends to make schools fit for the digitalized future and provide financial support for their digital equipment. In the future, all types of schools can be equipped with information and communication technology (ICT). Unfortunately, there still is a lack of adequate applications. Mainly responsible for this is a lack of practical and easy-to-use materials. Since ICT should not replace but more remain a tool that supports way of teaching, we will describe a competence-oriented method that can be used with or without digital input.

2. Multitouch Experiment Instructions as a Learning Tool in Science Education

Digital media can be included in teaching in many different ways. The competences in the digital world demanded by the KMK promotes the necessity to use digital media in schools. However, such use should be directly targeted and not only reflected, which is why the benefit for the classroom is paramount in all our research projects. Digital media can fulfil three functions in science education. As *learning tools*, they enrich learning in the current teaching situation and support cognitive processes. These include, for example, explanatory videos created by pupils or Augmented Reality (AR) applications [2,3]. As *learning companion*, they support learning over a longer period of time and beyond the classroom at the same time. These companions furthermore help to link the different learning locations - formal, informal and non-formal. Multitouch Learning Books, an example for a learning companion, are also designed to accompany the learning process [2,3]. A sub-category of these -socalled Multitouch Experiment Instructions (short: MEI) -place the actual experiment in the foreground and further integrate it into the ongoing lessons [4]. As *experimental tools*, ICT can aid pupils while experimenting, for example, when using wireless measurement sensors or thermal imaging cameras.

2.1. Characterization of Multitouch Experiment Instructions

Well-known representatives of digital learning companions are the Multitouch Learning Books (MLB), which are enriched with various digital/interactive tools [5,6]. As Huwer, Seibert & Brünken [7] have shown, a Multitouch Learning Book consists of various smaller "modules" that can also be used individually. Such a module can be an interactive, medially enriched experimental instruction, a Multitouch Experiment Instruction (MEI). Technically there are different forms of Multitouch Experiment Instructions. There are two options to design a MEI: The instructions can be completely digital or a combination of digitally enriched analogue experiment instructions (e.g. with augmented reality). Both variants have specific advantages that can be used depending on the situation. The completely digital variant is easier to integrate into a multitouch learning book and serves primarily to document the learning process. The Augmented Reality and the eBook variant have the advantage that it delivers information, on demand ‘and can reduce split attention effects. With both variants, additional small widgets can be integrated, e.g. as learning success control, or visualizations, which can be edited.

The experiment is indispensable in chemistry lessons and is usually the central element of them. The additional multimedia materials, such as worksheets, animations or step-by-step aids, are integrated directly into the eBook or AR-learning environment in the course of individual support for tasks and experiments, so that the risk of a split attention effect is minimized [8]. The special feature of the Multitouch Experiment Instruction is the possibility of new learning formats. In addition to a classic linear representation, this eBook variant can also be non-linear or modular in structure, which enables the selection of individual learning paths or thematic contexts [9]. Progress in the book can also be linked at a certain point to a condition, such as solving a problem. This promotes research-based-learning for example because results are not anticipated. Through the opportunities for personalization, such as the documentation of learning outcomes, the creation of a glossary, the integration of interactive tasks, training, assistance, games or multimedia content, this eBook or augmented version becomes a learning companion that can adapt to the learner depending on the scope of functions [10]. Our studies have shown that it is helpful from a learning psychological point of view to provide the widgets with a different interface so that unimportant information is hidden [5]. In addition, a number of new widget categories have been developed in previous research projects (e.g. learning target differentiating, individual assistance, communication, collaboration…). Huwer & Eilks [11] critically describe the use of didactically non-reflected media could result out of many advantages of such a learning companion.

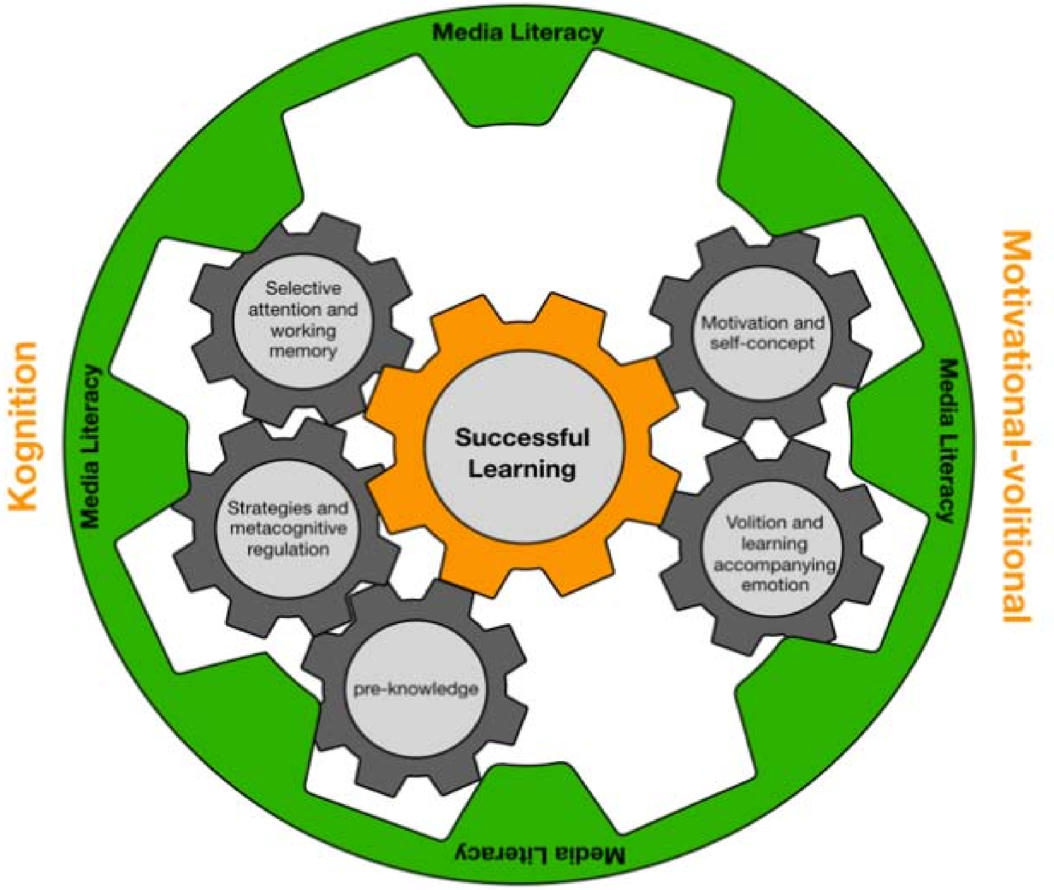

Figure 1. D-INVO-model adapted to the INVO-model [13]

2.2. Multitouch Experiment Instructions in School

2.2.1. MEI in Self-Regulated Learning Settings in School

Especially due to the increasing diversity in German schools, the focus should be tailored to individual learning processes. Here in particular, digital media can play to their full potential [2]. Our project *MEI* aims to create digital teaching material with the focus on competence acquisition in the digital world, taking into account empirically founded aspects such as the Cognitive Load Theory of Multimedia Learning (CLTML) [12]. Ideally, this could lead to a promotion of self-regulated learning (SRL) in consideration of CLTML and the didactic functions of digital media for deeper cognitive processing and a more sustainable acquisition of competence. The *D-INVO model* establishes the connection between Digital, Individual prerequisites (German: Individuelle Voraussetzung) and successful learning [13]. [S] trategies and metacognitive regulation, 'elective attention and working memory 'and, prior knowledge' are the three defined cognitive prerequisites. In the area of motivation and volition, predictors are also mentioned: "motivation and self-concept "and "volition and emotions accompanying learning". Accordingly, learning situations should be motivating, stimulate prior knowledge and also ensure that the pupils' attention is focused on the object of learning. A pleasant atmosphere during work also promotes successful learning and experience a positive self-concept, following this model. In addition, the pupils' learning process is supported even more if they can apply meta-cognitive strategies. As a direct consequence, pupils have unequal chances of successful learning due to their different preconditions, partially caused by the diversity of the learning group. The use of digital media opens up the opportunity to offer every learner the same learning success. The learning offer must therefore be adapted to the pupils competence and prior knowledge [13]. The differences between pupils should be perceived and valued [14,15]. Experiments, therefore, can be differentiated according to various criteria. Differentiations according to performance (adjusting the degree of difficulty of tasks), learning speed (having several tasks processed) or interest (independent selection of tasks from a task pool) are feasible [14,15]. The D-INVO model can thus be used to describe the promotion of successful learning with the help of digital media. Due to the diversity of digital media, it can help to improve the individual factors of this model in a targeted way. Figure 1 illustrates this potential.

Conceptually, learning science aspects can thus be related to digital tools and chemical didactic aspects. With the help of ICT various tools could be made available to promote motivation and (meta-)cognition processes. The experimental input contains three basic aspects that can furthermore be divided into the three phases of self-regulated learning [16].

2.2.2. Didactical Functions of MEI

When preparing the materials, both scientific learning and media-pedagogical aspects are taken into consideration. On the basis of already published research results on digital functions of tablets in chemistry classes and Schülerlabors as well as the use of multitouch learning books as learning guides, the MEIs are specifically tailored to an experiment [5]. The cognitive learning processes are given special attention when creating individual tools in the eBook. Basic aspects of CLTML [12] play a central role in the arrangement and structuring of digital materials. Particular importance is attached here to the fact that a clearly structured user interface and clear presentation of the assistance avoid a split attention and instead generate an overlay attention. Overall, the implementation of MEIs is intended to promote self-regulated learning by pupils. This self-regulated learning can be divided into three main phases, which are very similar to the planning, implementation and evaluation of one's own experimentation. In the *preexperimental phase* the focus is on the theoretical preparation of the experiment. For the *experimental phase*, the pupils should experiment independently and monitor and document their results. The *post-experimental phase* involves the evaluation of the results, with the pupils receiving direct feedback on their experiment in order to be able to analyze and reflect on the results. To promote one important meta-cognitive component of SRL - self-monitoring and self-reflection of the experiments a learning diary is used which additionally contributes to the evaluation of the course through regular feedback to the teacher.

2.2.3. Educational Use of MEI

A Multitouch Experiment Instruction is an interactive eBook or an Augmented Reality on an experimental instruction paper. In addition to the eBook or the AR, the pupils are provided with the standard laboratory equipment for experimenting. The MEI serves as a learning tool to support the pupils in case of difficulties. This support can be experimental, device-, speech- or comprehension-driven. In addition to these individual (possibly stepped) support, the pupils* have the opportunity to document and explain their results from the experiment directly in the eBook. The chemical experiment is by no means replaced, but merely supplemented by a digital learning tool to promote cognitive but also motivational processes. A MEI is a digital and above all interactive experimental instruction for improved individual support in research experiments. Apart from the normal experimental effort, no further preparations have to be made at school or in the Schülerlabor. The finished MEIs are stored as eBooks on iPads and can be retrieved at any time.

2.2.4. Added Value of MEI for Self-Regulated Learning

The experiment, planned in the form of a MEI, is intended to motivate and inspire pupils to study chemistry. This goal is to be achieved by means of predominantly pupil-centered, independent work, the use of the experiment as a central component of chemistry teaching in the individual subunits and the use of digital media. Through the only isolated teacher-centered phase, the teacher is available to the learners as an (additional, analogue) learning companion in a large part of the experimental free-work or exercise phases and can thus also provide individual support and differentiated individual counselling. The design of the MEI in the form of a "research journal" with instructions, experimental instructions, support, exercises, tests, feedback forms as well as logging and documentation functions enables self-responsible, self-regulated and thus missing evidence. By incorporating various feedback functions into the MEI, such as the self-assessment form for work organization and experimental competence or for technical competence, feedback can be immediate, situational, multidimensional and transparent an therefore supportive for self-reflective processes. In addition, a further feedback tool ensures that the learning progress of the individual pupils remains transparent and that any comprehension or experimental problems can be recorded directly.

This high level of individualization is reinforced by the fact that diagnostic tools are made available to the teacher on the basis of the feedback functions and the creative learning products of the pupils, enabling the implementation of a support cycle.

The "main innovation" of the planned teaching unit, besides the almost exclusively digital implementation, is the already mentioned self-evaluation feedback tools for the pupils. The self-evaluation questionnaire on work organization and experimental competence was conceived in two variants, which differentiate between linear and the much more complex, non-linear learning path. The evaluation of these feedback questionnaires can provide both the learner and the teacher with information on which competences can still be promoted in experimenting and evaluating experiments.

The self-assessment questionnaire on professional competence is the most complex feedback tool to be used in this teaching unit. Can-lists were developed, with the help of which the pupils can assess their level of knowledge and understanding in each subunit of the Alkane topic. In order to check the "Can - statements", the pupils are provided with appropriate examples of tasks including solutions; solving and comparing their own solution with the sample solution increases the significance and objectivity of the feedback. If learners are unconfident enough about a certain topic, additional offers are available to them in the form of tips for repetitive activities and exercise possibilities (with solutions) as learning aids. This combination of self-evaluation and self-diagnosis tool promotes reflection on one's own learning (metacognition). From the joint discussion of the results, agreements can be made to optimize the learning process with objectives. Both for the self-evaluation and especially for the peer and lesson evaluation, binding rules have to be developed and practiced together with the pupils in order to avoid problems concerning the communication and relationship level of the feedback provider and receiver and to implement a trusting feedback culture in the course. This can prevent problems that may arise in the course of feedback events.

3. Characterization of Alkanes with the help of a Multitouch Experiment Instruction as an interactive eBook

For the completely digital version, the program eBooks Author® is a good choice. It functions as a classic WYSIWYG editor (what you see is what you get), making it the tool of choice for inexperienced users. Many ready-made widgets are available to the user, which can be scaled, positioned and edited analogously to the standard text processing tools. The program also offers the opportunity to add several widgets as interactive tools This additional flexibility allows the content to be prepared and visualized in a variety of ways, e.g. multicoded, multimodal and/or interactive [17]. Thus, one combines an analogous experiment manual with the advantages described by Weidenmann [18], which multimedia content can bring with it. These contents or aids can be texts, pictures, videos and animations which are presented at the places where the pupils need them.

Using a relevant content, which is anchored in the curriculum of the tenth grade, the pupils themselves research the properties of gaseous and liquid alkanes. In addition to the relevant context for the pupils, the experiment itself and the explanation at the particle level will be at the forefront of the lesson.

The aim in creating the materials was a consistently structured design of the materials in order to keep the cognitive load as low as possible through the presentation of the materials. The center of the eBook is the navigation page (see Figure 2). From there, the pupil can select his task and choose his own learning path. Figure 2 presents the center side. The figures show which action can be triggered on the page. By clicking on information button (see Figure 3, Tap 1.), the available materials are shown in text and image. These pictures are shown in the complete course of the eBook at the appropriate places as material aids.

By clicking one of the four experiment buttons (see Figure 3, Tap 2., 3., 4 and 5.), the pupil can navigate to the experiment of his own interest. All experiment pages have the same structure. In the lower right corner, the pupil can navigate back to the main page any time. When working with a Multitouch Experiment Instruction for the first time, the icons should be thematized with the pupils. On page 1 there is a short overview of the buttons that appear in the book (see Figure 4.). The color of the icons plays an important role in using the MEI. Red icons define tasks that have to be done. Green icons are used for differentiation with the help of various (possibly staggered) hints. At least two required steps must be completed on each task on page. On the one hand the experimental instruction and on the other hand the documentation and explanation of the respective experiment. Figure 5 shows an example of one of the pages.

On the left half (marked blue) are the exercise for the experiment (see Figure 6). The experiment should always be documented. By clicking the camera button, the camera opens and up to five pictures of the experiment can be taken to document the progress (see Figure 6, Tap 1.). The pupil can also import images from the tablet image gallery. On the one hand this task has the function to document the experiment and on the other hand the execution can be reflected afterwards. Thus, only this simple but effective exercise can promote self-reflection processes of the pupils. Besides the documentation and observation of the experiment, the experiment has to be explained. For this purpose, the second button (see Figure 6, Tap 2.) is provided. Behind this exercise there is a gap text, which explains the chemical content on particle level, realized as by a drag-and-drop widget.

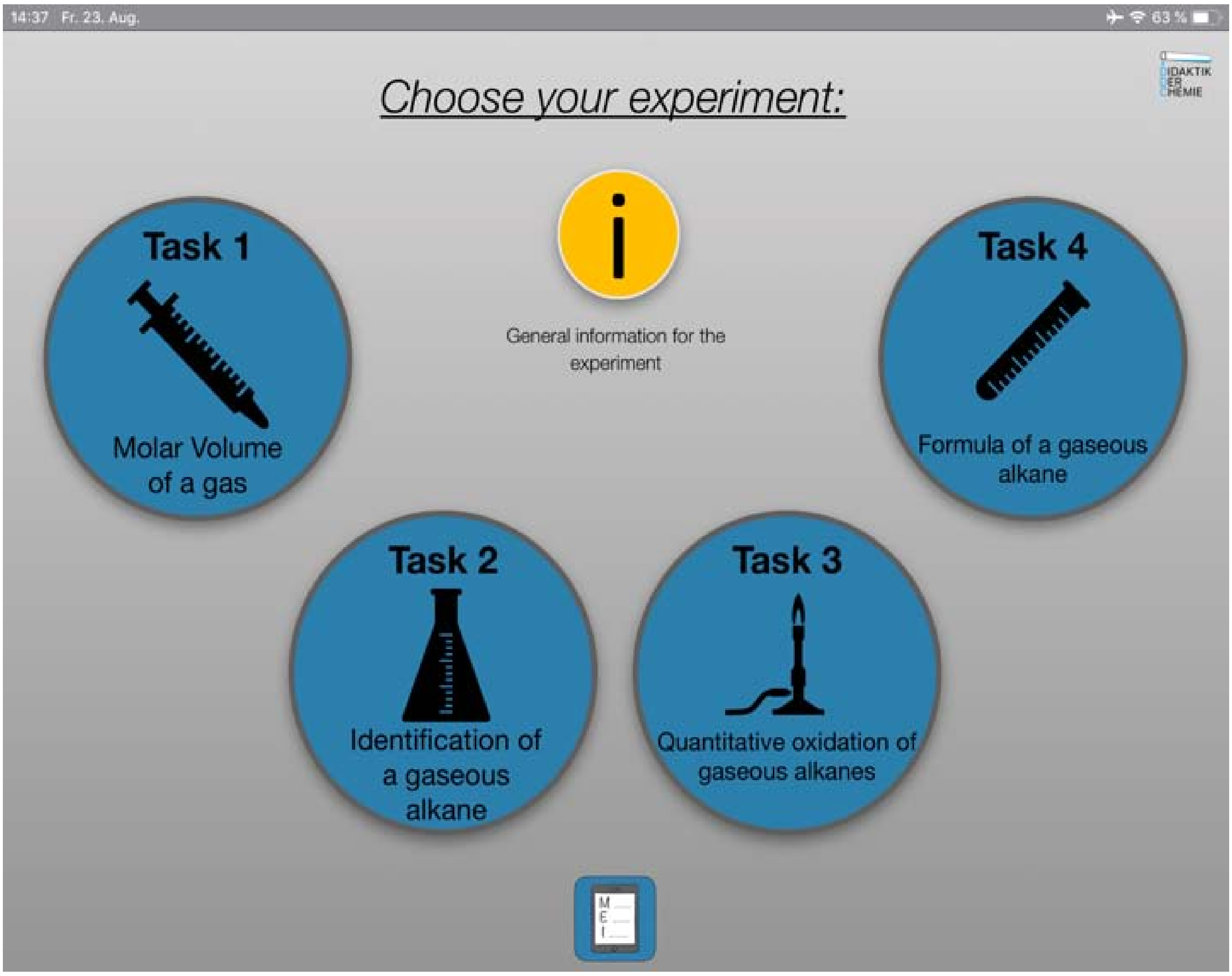

Figure 2. Overview of the experiments

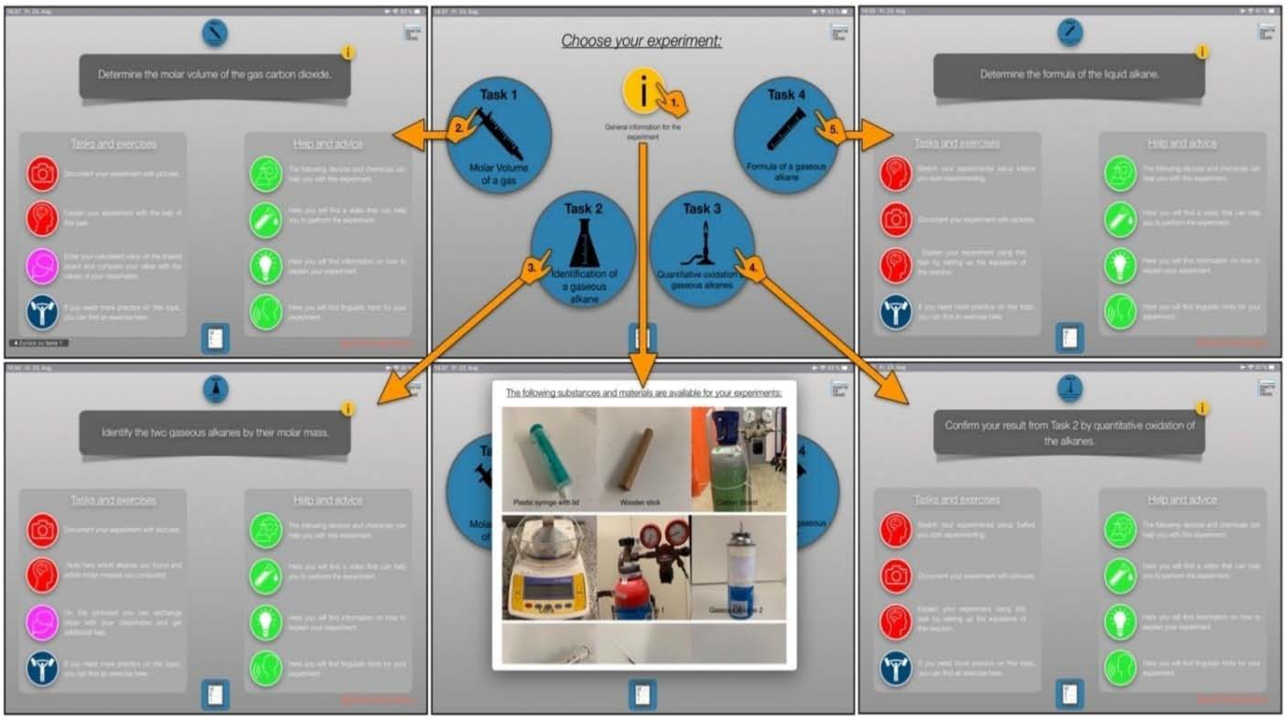

Figure 3. Structure and overview of the eBook

Figure 4. Buttons in a Multitouch Experiment Instruction

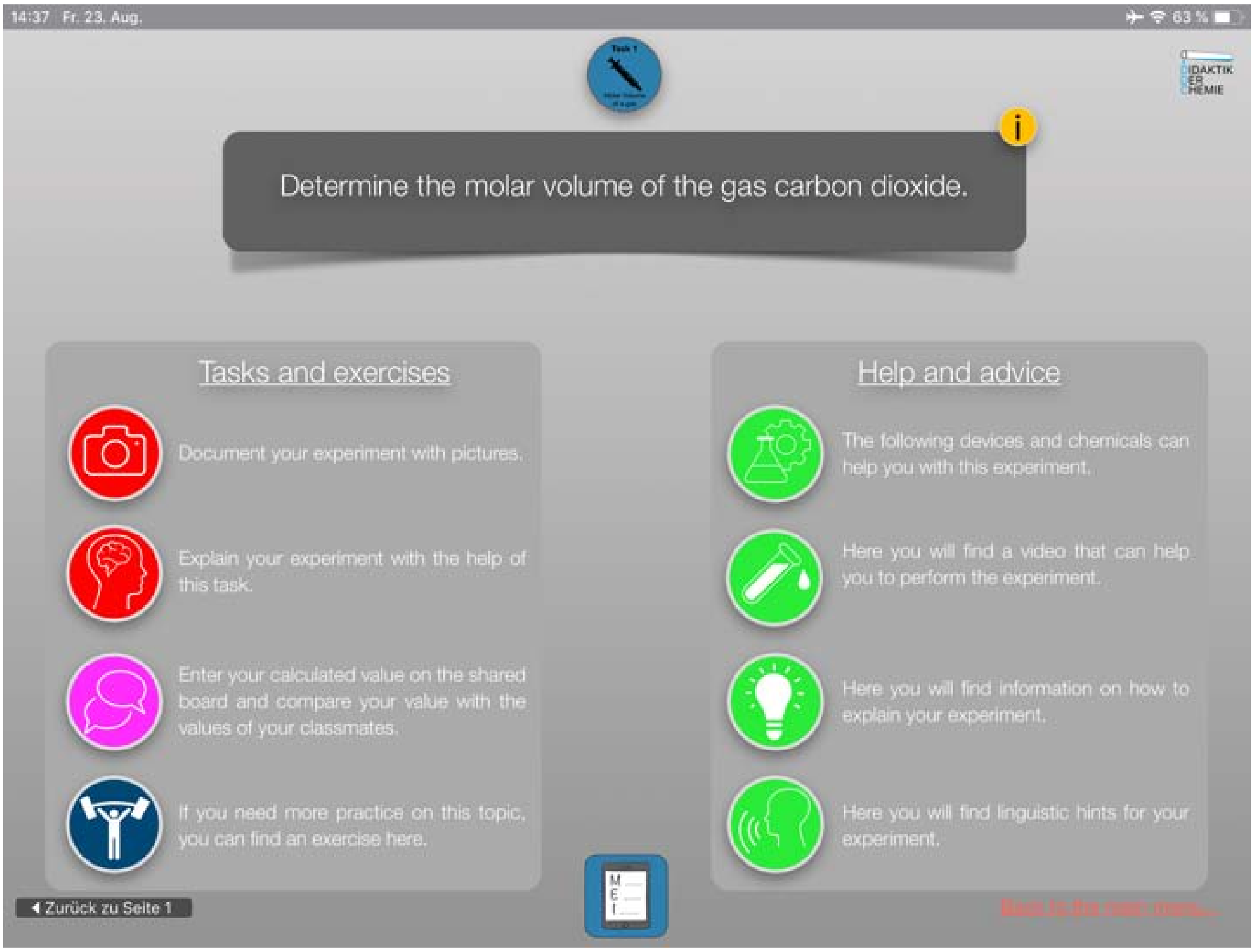

Figure 5. First experiment page with all tasks and helps

Figure 6. Design and arrangement of one experimental task (here task 1)

After the pupils have performed this experiment, it is corrected by a Peer-2-Peer feedback. To promote communication and collaboration between the pupils, the pink button (see Figure 6, Tap 3.) opens a split pinboard that can be edited by any device. Thus, the pupils can share the results on demand and get additional ideas and control. The pupils will find a further possibility for differentiation behind the training button (see Figure 6, Tap 4.). This task can be done by pupils who have already completed and by pupils who are weak and want to repeat the content. This exercise repeats the basic knowledge necessary to complete the main experiment. After completing these three tasks and the experimental instruction, this section is finished. If, however, the pupils need further assistance in planning, conducting and explaining the experiment, they have the opportunity to obtain additional information. The right half of the page (marked green) is intended for this purpose. On all four experimental pages the pupils will find four different ways to help them. Behind the button for equipment help (see Figure 6, Tap 5.) pictures of the equipment is given. For the semantization, pictures and words of the equipment are used in order to enable an optimal individualization. If the pupils have problems with the actual execution of the experiment, they get a short video by clicking the experimental help button (see Figure 6, Tap 6.), which shows a possible procedure of the experiment. Here the pupil can reflect on his own experiments and correct them if necessary. In order to promote the ability to explain the chemical experiment, there is also a short video behind the comprehension help (see Figure 6, Tap 7.) to understand, which repeats or explains the chemical content of the experiment. In this case, the focus is on the help for the preparation of the gap text (see Figure 6, Tap 2.). This help focuses above all on the promotion of cognitive processes, so that the connection between the experimentally observed and the cognitively explained is enhanced. In the context of individual language training in chemistry lessons, a series of specialist vocabulary is provided behind the button for language aids (see Figure 6, Tap 8.) to explain the experiment correctly. Here the vocabulary can help with the observation, as well as with the explanation of the experiment. This kind of help not only supports pupils who have a weak command of the language, but also native speakers who do not have a sufficient specialist vocabulary.

4. Conclusion

Multitouch Experiment Instructions have the advantage for the teacher that digital aids, tasks and visualizations can be well organized. This means if the materials are used again, there is no need to sort them, check them for completeness or even replace them like the analogue equivalents. In this case the temporal advantage becomes noticeable with regard to the administration of the materials. This temporal advantage also results on the part of the pupils, who can specifically seek help, since the system behind the help types and symbols remains unchanged and the help is offered with the respective exercises. The organizational advantage of the materials also makes it possible to individualize them more effectively without making them confuse for the pupils with a stack of help cards. For the learner this means on the one hand that the experiment can be made more open and that the pupil can receive help in small steps if necessary, without the experiment having to be interrupted by leaving the workplace and searching through the help cards. We designed it to initiate cognitive processes, and to support mental models by a wide variety of presentation options and contents. Also, the possibility of varying representations can thus promote cognitive flexibility, enabling pupils to choose suitable forms of representation while solving problems. At the same time competences in the digital world are promoted, whereby the category "Use digital tools and media for learning, working and problem solving" is in the foreground.

In general, one can offer many different types of help at the appropriate places without the pupils having to search for the suitable help (e.g. help cards) first (information on demand). Pupils have a single document and the help is displayed in the appropriate places if the tablet so desires. A defined, memorable symbolism ensures that pupils who need language help, for example, can also specifically select them. A further advantage of the MEI is that dynamic content can also be displayed dynamically on the experiment instructions, whereas previously one had to resort to an image sequence.

First experiences have shown that through the use of MEI the pupils are much more motivated and interested in performing the experiment. However, it was also noticed that the first time using MEI in a class, a certain amount of introduction is necessary in order to minimize the cognitive load caused by the "new" materials.

Supporting Information

All materials including the interactive MEI in English 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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