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Promoting Self-Regulation with a Multitouch Experiment Instruction on the Topic of Water Analysis

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Abstract

In context of Education for Sustainable Development (ESD), the range of experiments offered by the Schülerlabor NanoBioLab at Saarland University was expanded to include an experiment on the topic of water analysis, which provided the basis of the intervention. In addition to the analogue experiment instruction, there is a digital version which is presented as a Multitouch Experiment Instruction (MEI). MEIs are digitally enriched, interactive experiment instructions that accompany the cognitive learning process of pupils and promote competencies in the digital world (Seibert et al., 2020). In this study, we analysed whether the MEI could support self-regulated learning in an indirect support approach by considering different hierarchical levels of self-regulation in the design of the materials. The results show a significant acquisition of self-regulatory competences of learners in grades ten and eleven by using the MEI compared to the analogue version.

Keywords

digital learning, ICT, interactive eBooks, self-regulation, Schülerlabor

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State of the literature

- Using digital media requires pupils' increased self-regulation behavior. They also offer a possibility of indirectly promoting self-regulated learning.
- In this context, the design of the digital medium is one of the most important aspects to be considered in order to support pupils in their use in the most effective way.
- Multitouch Experiment Instructions are interactive eBooks that can be enriched with multimedia content to enable individual learning of students not only in a school context but also in non-formal learning contexts.

Contribution of this paper to the literature

- Multitouch Experiment Instructions (MEIs) can have psychological effects on learning through a selective design. For example, the conscious structuring within such a digital learning tool can indirectly increase self-regulated learning when experimenting in chemistry lessons and in the Schülerlabor.
- The findings of this research study revealed that an interactive eBook is able to achieve exactly this psychological learning effect by using digital interfaces.
- On this basis, further influence factors of digital media on self-regulated learning can be investigated, to enable an indirect promotion of pupils' ability to experiment in a self-regulated way in science lessons.

Introduction

The European Council declared "self-regulated learning" as a key competence for lifelong learning and emphasized the importance of this competence in our rapidly changing society (EU Council 2018). It is important to already promote these competences at (pre-)school in order to prepare pupils for the transition from a more structured learning environment to a less structured one (Dörr & Perels, 2018; Dörrenbächer, 2016), whereby learners are to change from passive to active learners (Perels, 2009). The effects of self-regulated learning have already been investigated in many studies. For example, Dignath et al. (2008) found a correlation between interventions to promote self-regulation and an increase in learning performance in a meta-analysis. Over time, more and more intervention programmes based on the use of digital environment have been developed (Bellhäuser, 2016). These include Multitouch Experiment Instructions (MEI), which are preferably used in scientific experimentation and whose influence on self-regulated learning has not yet been investigated. A MEI based on the self-regulation model, according to Landmann and Schmitz (2007) was developed and evaluated in the NanoBioLab at Saarland University concerning its effects on self-regulated learning and cognition.

Multitouch Experiment Instructions to promote self-regulated learning

How to promote self-regulated learning

Self-regulated learning is a matter of the independent acquisition of knowledge, as well as the associated independent goal-setting and control, but also monitoring of learning processes to achieve different goals (Zimmerman, 2000; Perels and Dörrenbächer, 2018).

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In the course of the development of various theories on self-regulation, the components "cognition", "motivation" and "metacognition" are of particular importance, and are found in nearly all models (e.g., Landmann et al. 2015). Models of self-regulated learning can be divided into two categories. While process-oriented models focus on different phases of self-regulated learning (e.g., Zimmerman, 2000), layered models focus on different levels of self-regulation (e.g., Boekarts, 1999). Another model of this category is the hierarchy model according to Landmann and Schmitz (2007), on the basis of which the MEI was developed. Here, a process-oriented model is integrated into a layer model, focussing on the different hierarchical levels of self-regulated learning. Learners first set themselves an overriding goal (example: solving ten equations). A metacognitive strategy can already be chosen before learners proceed to the next levels of self-regulation. Now, according to the process-oriented model (e.g. Schmitz & Wiese, 2006), the pre-action, action and post-action phases are passed through, which correspond to the planning, action and reflection phase according to Zimmermann. If necessary, the cycle is repeated at the lowest level. If this is not the case, learners proceed to the next higher hierarchy level. In this way, the cyclical phase model becomes the object of regulation, and the selection of cognitive and metacognitive strategies is reflected and readjusted. At the next higher level, the object of reflection is extended over a longer period or several aspects (Zimmermann, 2000). The goal of this procedure is pattern recognition. If all these hierarchy levels do not lead to the set goal, adjustments can be made at the outermost level. The goal adaptation, as well as the whole cycle, can refer to short-term goals, such as solving several tasks, as well as to longer-term goals, such as improving a pupil's grade in mathematics by one level.

Given the relevance and theoretical models of self-regulated learning, the question arises how this competence can be promoted, especially since there is evidence that academic performance can be improved by promoting self-regulated learning. In addition to this context, self-regulatory competence is also a significant predictor of performance at school and university (Otto, 2011).

The promotion of self-regulated learning can take place holistically, or only individual aspects of self-regulation can be promoted, such as adequate goal setting. In contrast to direct support measures, indirect approaches do not focus on the learners but rather aim at training instructors (e.g. teachers or parents) so that they can promote self-regulation of the learners. Otto (2007) suggests three approaches to how this indirect support can take place:

a) Instructors design the learning environment in such a way that self-regulated learning is encouraged. Furthermore, Reinmann and Mandl (2001) propose various guidelines for designing constructivist learning environments:
   - Learning based on authentic problems
   - Learning in multiple contexts
   - Learning from different perspectives
   - Learning in a social context
   - Learning with instructional support

b) Another approach is directly related to Bandura's theories, according to which parents or teachers provide role models for children or learners. By observing positive behaviour of a role model concerning self-regulatory competencies, learners can acquire these competences themselves. Thus, teachers should use the same strategies for self-regulation that they intend to encourage in their pupils (Landmann, 2009).

Multitouch Experiment Instructions to promote self-regulated learning in chemistry education

In order to promote self-regulated learning, Multitouch Experiment Instructions (MEI) can assist students' experimentation as a digital learning tool (Seibert, Kay and Huwer, 2019). MEIs are interactive, multimedia-enriched experimental instructions, which can be either implemented as an eBook or as Augmented Reality (AR), which enriches an analogue experiment instruction (Seibert et al., 2020a). MEIs can be referred to as technology-based learning environments (TELE), a term which is more specific and better suited to describe an educational setting than ICT, which refers to Information and Communication Technology in general. Dettori et al. (2011) describe two types of TELE with regard to fostering self-regulation and contrast them with unenhanced learning environments. They differentiate between didactic TELE, a learning environment which aims at improving students' self-regulation by specifically training self-regulation strategies, and facilitative TELE. While the latter is also targeted at improving students' self-regulation, facilitative TELEs do not contain self-regulation training or content on the topic of self-regulation (Dettori et al., 2011, p. 5). For the facilitative TELE, it is rather the nature and design of the learning environment which contributes to the promotion of self-regulation strategies. Considering the features and design of the MEI, it can be classified as a facilitative TELE:

A MEI covers all phases of the experiment from preparation to reflection through exercises and individual support. Individual support for the pupils can be integrated as experimental, equipment, language, or comprehension support, which are implemented as videos, text, or sound (Huwer, Bock and Seibert, 2018). Exercises can be created and integrated using widgets from various providers, such as bookry® or learningapps®, which are interfaces that allow pupils to complete interactive multimedia activities including instant feedback. These widgets enable learners to check the solutions of the task independently. Furthermore, MEIs offer the possibility to follow an individual learning path by allowing learners to decide which content to work on and which not. This individual support is also reflected in the student-centred design of the eBook. In addition to the previously mentioned widgets, which provide assistance when experimenting, further digital features are implemented in the eBook. These are intended to help the students especially in cognitive learning processes. This includes additional tasks that are intended to promote the students' understanding of the content regarding the experiment. In addition, the digital experiment instructions are designed in such a way that the students can find their own solutions through targeted navigation and thus work autonomously (Huwer & Eilks, 2017). The widgets are intended to provide an interface between guided and structured inquiry learning depending on the student's experimenting skills. Once exported as an eBook, MEIs can be retrieved on a tablet or other device at any time without further preparation (Seibert et al., 2020b). MEIs such as the one implemented in this study offer support tools which promote students' learning process, reflection, strategy use and planning phase. This type of MEI can be described as facilitative TELE, as it not only includes various support tools but also requires students to decide for themselves whether to take advantage of these support tools and to actively seek them out.

It is evident that the focus of this study an indirect approach to promote self-regulation. This indirect approach of self-regulation corresponds to the models presented in the theory section and will be elaborated in the following chapter. Due to this focus, digital design features that are able to indirectly promote self-regulated learning will be especially considered in this study and further described in the following. Special attention is paid to the conception of the layout but also to the content and media pedagogical design of the different widget types in order to enable optimal multimedia environment while working with a MEI and to keep the extraneous cognitive load as low as possible (Mayer, 2009). Further general design principles of digital media are taken into account in order to promote self-regulated learning indirectly by taking the cognitive load theory of multimedia learning into account (Mayer, 2009):

- **Interactivity and segmenting principle:** Through the integration of buttons, the MEI becomes an interactive experiment instruction. Tasks and support can be accessed and closed as desired. Some tasks and exercises provide direct feedback, which is preferred by learners according to Miller (2009).

- **Coherence principle:** The instruction material does not contain any irrelevant information per se. As advanced learners may not require support, support tools are not displayed automatically. This reduces the extraneous load, which frees up more cognitive capacity in the working memory for the germane load, since only information that is important in a specific situation is displayed.

- **Temporal Contiguity Principle:** In order to avoid split-attention effects, elements that belong together are arranged next to each other. In MEIs this applies among other things to the arrangement of tasks and exercises in one box and help and hints in a second box. Also, the text was integrated in embedded pictures and videos at the appropriate places. For example, the technical term for an item of laboratory equipment is always displayed directly below a photo of this item.

- **Modality principle:** Visual and acoustic signals are integrated into the working memory to form a mental construct, which increases learning success. Due to the already increased noise level which results when more than twenty pupils' experiment in a laboratory when using the MEI, it was decided not to integrate audio content into the MEI.

- **Multimedia principle:** In addition to text paragraphs, the instructional material contains pictures, graphics, videos and animations. Almost every task of a station contains a video showing the execution of the respective experiment. The principle of supplantation (Salomon, 1979) enables the pupils to learn new processes (e.g. detection reaction for nitrate and phosphate) or to extend processes they already learned. In addition, animations are included which enable the visualisation of the individual experiments at particle level.

- **Image principle:** As the MEI contains relatively little text, we have refrained from highlighting individual components. Only "tasks and exercises" and "help and hints" were underlined.

- **Redundancy principle:** The degree to which MEIs enable leaners to choose their learning objectives freely is difficult to assess. In principle, pupils can determine aspects such as the number of the stations to be worked on and their sequence themselves. Even within the stations, there is a heading for each task, which is initially formulated without a research question. Theoretically, it would be possible to set goals for each task, which can be achieved with individual solutions. In contrast, the tasks and exercises provide a clear structure and direct instructions. The learners can either follow this given structure, or formulate their own goals and solutions, without being guided by support tools or a detailed instruction.

- **Segmenting principle:** The tasks and exercises, as well as the help and hints, divide the learning objective of a task into learning-compatible sections. Even with integrated videos, pupils can pause and continue watching the video according to their needs. A division of the videos into several sections for better overview was partly realised by providing individual sequences with text sections.

- **Personalization principle:** Learners can control their learning process themselves by using the MEI. With the help of information and exercises, pupils can use the material when and how often they want, under the principle of freedom of objectives.

A Multitouch Experiment Instruction for the context of water analysis

Based on the theory presented, we created a MEI for processing the experiment "water analysis" for the Schülerlabor NanoBioLab of the Saarland University. This MEI was tested in different grades with regard to the MEI's potential to promote self-regulation and its effect on cognition.

Promotion approach

The water analysis experiments to be carried out by the pupils aim to determine the chemical index of a water sample and are divided into five different experiments. Due to the broad scope of the subject matter, a direct promotion approach, in which knowledge of self-regulated learning and the associated cognitive and metacognitive strategies are imparted in addition to the specialist knowledge, did not seem to make sense in terms of time. Therefore, an indirect approach for promoting self-regulation was chosen. As mentioned in the previous section on the theory of self-regulated learning, two aspects were mentioned as to how educators can promote self-regulated learning among pupils using the indirect support approach. Educators can take on the function of a role model or directly impart strategies for self-regulation. However, these two approaches were not realized in the intervention. A positive model behaviour can be observed by the learners only during the preliminary discussion, during supervision of the experiments, and in the embedded experiment videos in the MEI. However, the focus is on the design of a beneficial learning environment. The analogue version of the experiment instruction also implements the first three guidelines for the design of learning environments ("learning based on authentic problems", "learning in multiple contexts" & "learning under different perspectives"). The use of the MEI and especially the integrated evaluation file, supports another aspect ("learning in a social context"), as the class works on a uniform document with a common goal - the determination of the chemical index of a water sample. The last guideline ("learning with instructional support") is also implemented by using the MEI.

Design of the Multitouch Experiment Instruction

To ensure that the MEI is immediately recognized in the iBook app, a cover was first designed that contains the title of the experiment and a label identifying it as a MEI. By tapping on the cover, which is displayed on the bookshelf, the eBook opens, and provides an overview of the stations (see **Figure 1**).

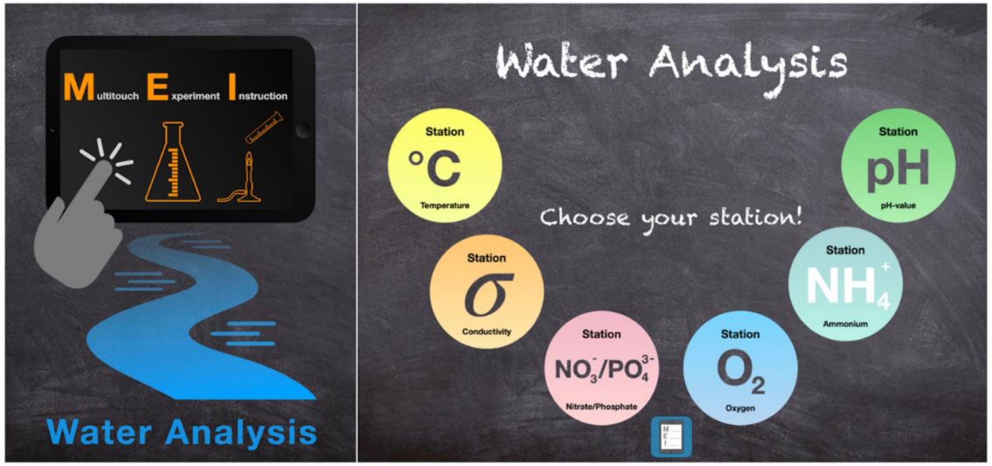

Figure 1. Book cover and navigation page

Buttons are integrated in the MEI which serve to navigate between the chapters and access widgets. The first page of a chapter opens when pupils tap on the corresponding button such as the station on the pH value of the water sample. The name of the respective task is shown in an elongated bar below the round station symbol. Various tasks and exercises can be accessed via buttons on the left-hand side, while help and support are available on the right-hand side (see **Figure 2**).

A unique feature of the MEI is the "Share button" (see **Figure 3**, bottom left). By tapping on this button, the pupils access an evaluation file, which can be edited online by all pupils simultaneously. In addition to the individual results of each group, the table calculates averages for all groups. This way, each group receives a result, which contributes to the overall result of the class and can be compared with this and other group results. Although the hierarchy model according to Landmann and Schmitz (2007) integrates a process-oriented model into a layered model, both types of the model should be considered separately.

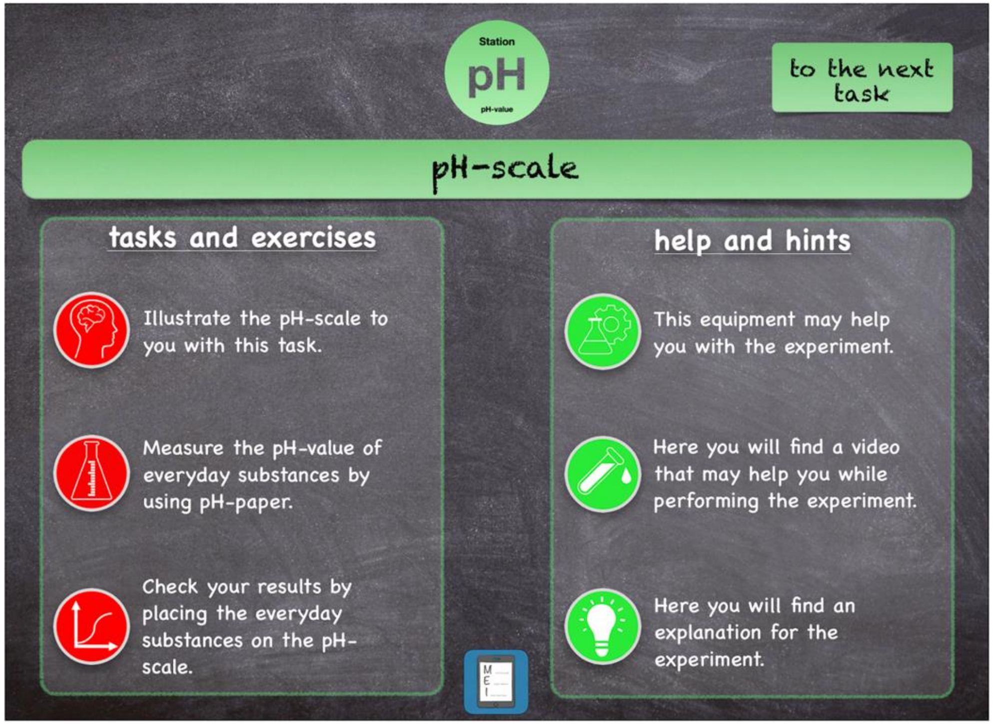

Figure 2. First page of the experiment "pHscale"

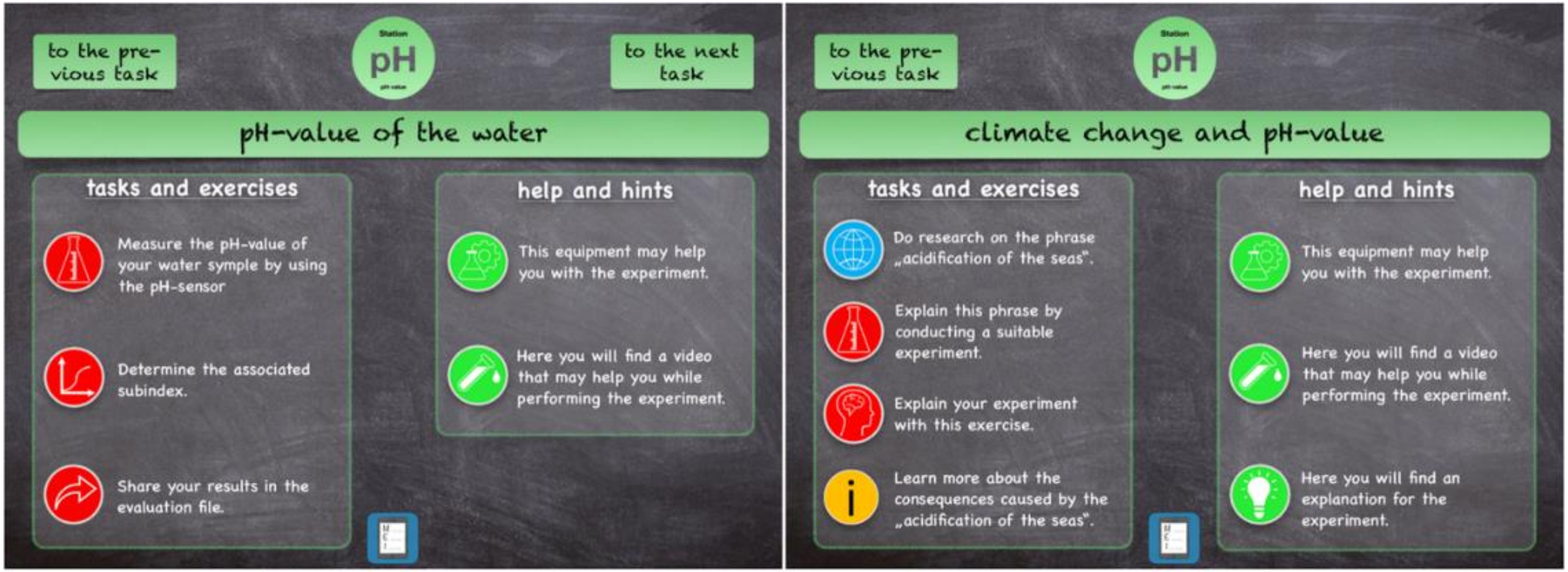

Figure 3. Second and third page of the experiment "pH scale"

Phase model in a MEI

Each task within the MEI has a heading, which is phrased without a specific question or instruction. On the basis of this heading, learners can set their own goals which are achieved through individual learning paths. The tasks and exercises support the three phases of self-regulated learning according to Zimmermann (2000).

How the pupils' self-regulation is supported can be illustrated by one of the tasks for determining the pH value

The subdivided tasks and exercises include three detailed instructions to support the three phases. The first task aims at activating the pupils' prior knowledge and thereby support the planning phase by repeating the pH scale. For this purpose, a widget from the template " Matching pairs on images" from learning apps was used which is accessed by tapping the first button. The task "Tap a pin and match it with the appropriate term" is displayed and can be hidden by tapping "Ok". If a pin is tapped, the terms "acidic", "alkaline" and "neutral" appear in a random order, from which the suitable term must be selected. Once all terms have been placed in the correct position, pupils are provided with feedback by pressing the blue button in the lower right-hand corner. If the pupils matched all terms correctly, the message "Great, you found the right solution" appears (see **Figure 4**).

The activation of the pupils' prior knowledge and the positive emotions resulting from the positive, direct feedback can be beneficial for the upcoming action phase. The action phase is initiated by the second instruction "Measure the pH value of various everyday substances using pH paper". By tapping on the corresponding button, a pop-up window opens, which directs pupils to the help and hints in case they encounter problems while completing this task. This serves to make learners aware that they can access help at any time, thus maintaining positive emotions and their motivation. Furthermore, the specific task supports the maintenance of the learning process or experimentation, as it is always visible, unlike pop-up windows. After the action phase, pupils should evaluate their results in the reflection phase.

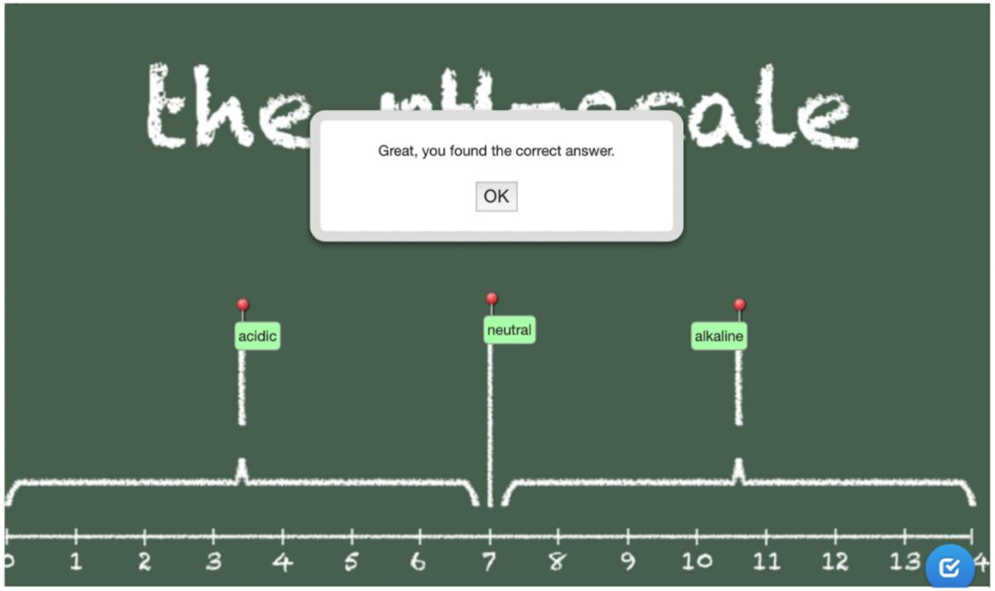

Figure 4. Interactive widget to visualize the pH scale

For this purpose, the pupils can open a widget which was created with the template "Number line" in learning apps by tapping on the last button (see **Figure 5**). In this widget, the measured pH values of everyday substances are supposed to be arranged on a pH scale on which certain positions have already been marked to which the pH of the substances should be matched. If the allocation is correct, the positive feedback appears by tapping on the blue button. The pupils can check their results from the action phase themselves. Incorrectly assigned substances are marked in red and can be re-examined for their pH value in a new cycle. In order to understand how the MEI further supports self-regulated learning in such a case, it is necessary to switch to a layer model.

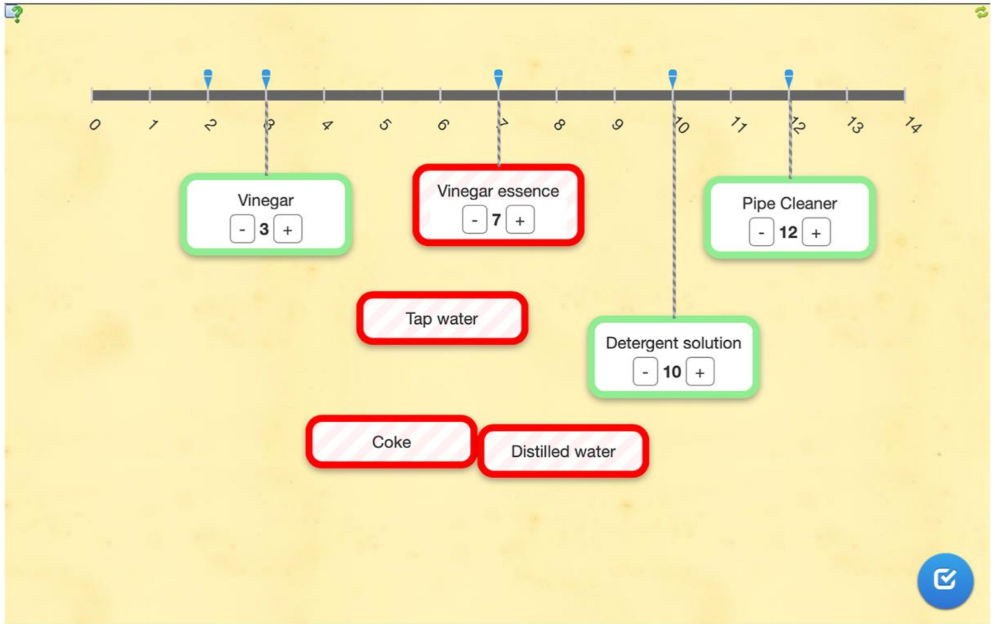

Figure 5. Widget for assigning substances to their the pH value

Layer model in a MEI

As the hierarchy model according to Landmann and Schmitz (2007) was chosen as a framework for our intervention, the implemented content is arranged in accordance with the hierarchy levels. A short overview of the four phases is provided in **Figure 6**, which assigns the different sections to the corresponding self-regulation phase (blue, cyan, pink, and green).

a) *0th order: execution regulation*

At this level, the phases of executing the experiment are planned in greater detail. The impact of the MEI on the aspects of such a process-oriented model have been elaborated in the previous chapter. In case learners achieve their goal (see **Figure 6**), they proceed to the next higher level.

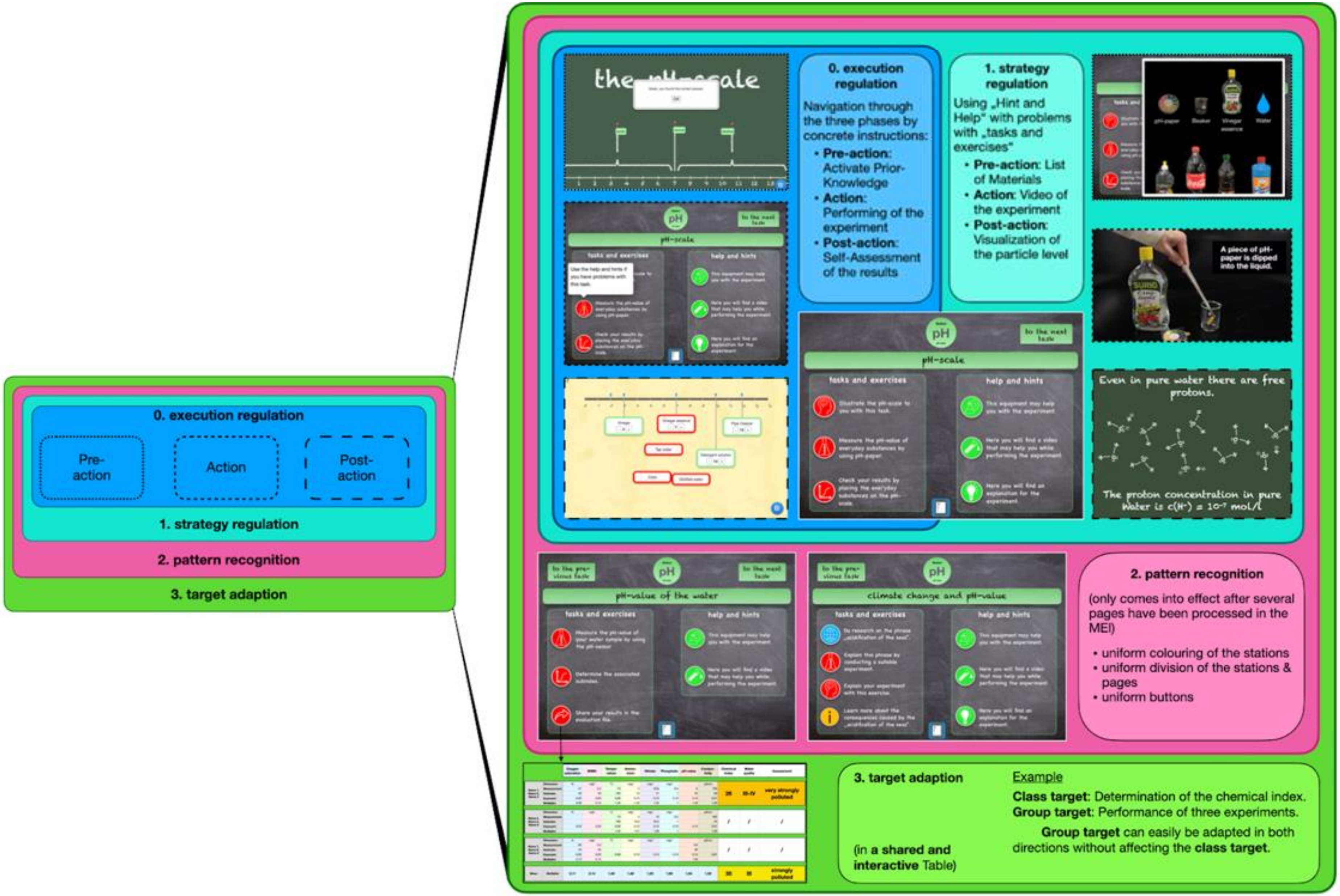

Figure 6. Hierarchy model of a MEI (adapted to Landmann and Schmitz (2007))

b) 1st order: strategy regulation

The whole level below now becomes the object of regulation. Especially individual support is essential at this point, as it promotes the three phases associated with self-regulation when going through the cycle of the lowest level again. By tapping on the "equipment button" (see **Figure 2**: top green button under "help and hints" popping up like seen in **Figure 7**), pupils access a list of images of all the required equipment, chemicals and materials, including their technical terms.

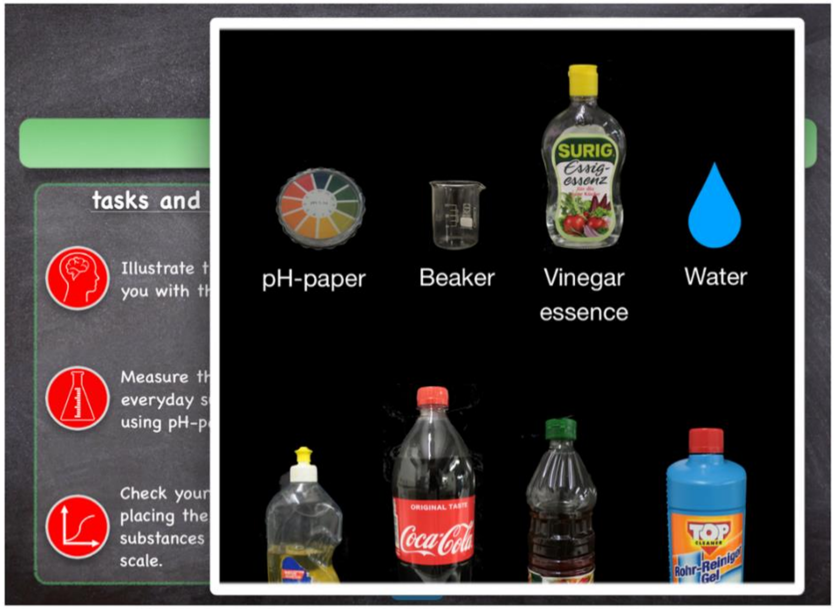

Figure 7. List of materials and chemicals pupils can use for their experiment

This list can be particularly helpful in the planning phase, as pupils may find it easier to plan their experiments when they already know which equipment, chemicals and materials they need and are entirely able to focus on the process of planning their procedure. If the pupils are not yet able to plan and successfully carry out the experiment after viewing the list, additional assistance is provided – pupils can access a video showing a part of the execution of the experiment (see **Figure 8**).

This video supports the planning phase as well as the action phase. During the experiment, students can watch sections of the video and apply what is seen to their own experiment. After the first two phases have been successfully executed, the last button supports the post-action or reflection phase by showing an animation which displays the observations made during the experiment on the particle level (see **Figure 9**). Learners recognize whether or not they interpreted the observations from the experiment correctly, which has an emotional and motivational impact on the learners. Based on the new understanding of the experiment, learners may wish to repeat the experiment to focus on other aspects, thus restarting the cycle.

Figure 8. Supporting video for the experiment "pH scale"

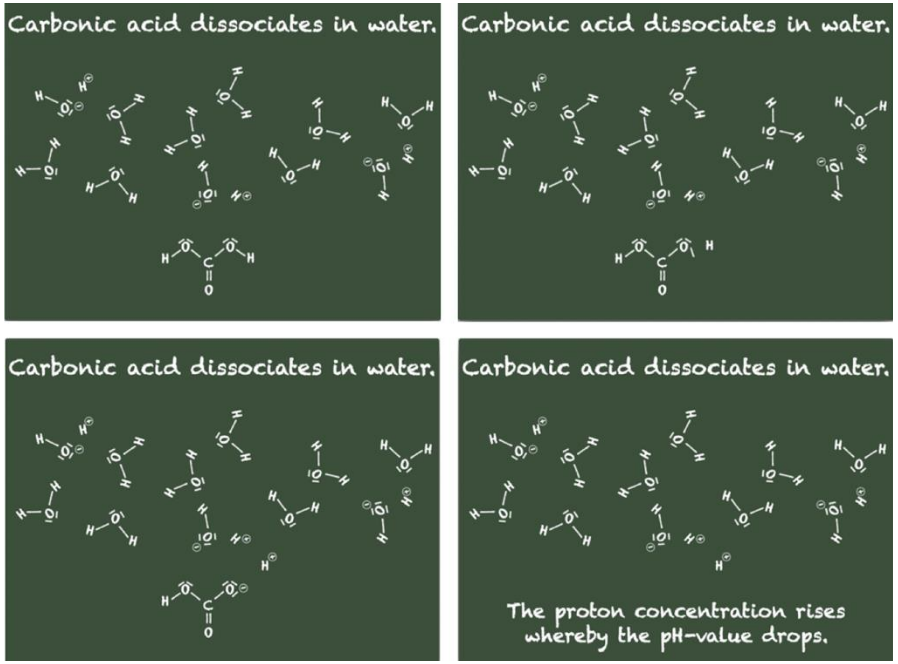

Figure 9. Supportive animation for the task "pH scale"

In addition to these three types of individual support such as pictures of equipment and chemicals, an experimental video, and an animation of the particle level, classical "support cards" have also been included (see **Figure 10**).

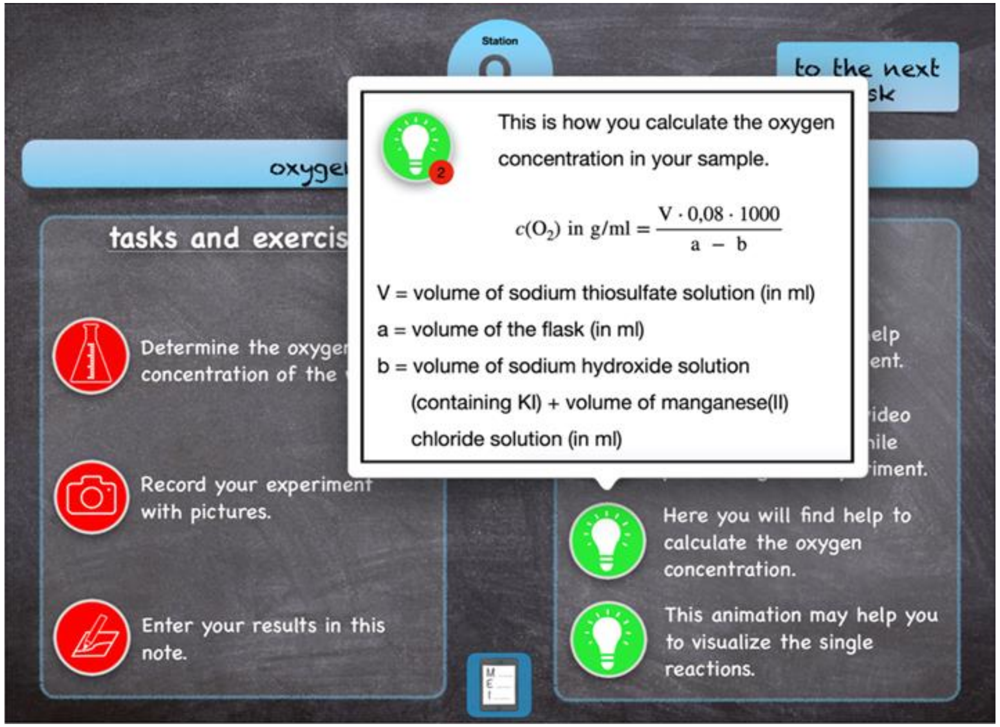

Figure 10. Written hint as pop-up for evaluating the task

c) *2nd order: pattern recognition*

This hierarchy level only comes into effect after learners have completed at least one or two tasks of a station and recognise that the structure of the MEI follows a specific pattern. The tasks of each station are structured in the same way, divided into tasks and exercises as well as individual support and the symbols are also used consistently. (see **Figure 11**).

The consistent structure and use of the symbols eases the navigation of the MEI and allows pupils to select the content they need more precisely. To additionally support orientation, each station follows its colour scheme.

Figure 11. Overview over the buttons that are used in the MEI

d) *3rd order: target adaptation*

Finally, the adaptation of overarching objectives can be facilitated by the use of a MEI. For this purpose, class goals and group goals must be distinguished from each other. The goal of the whole class could be to determine the chemical index of a water body. To achieve this collective goal, each group could decide to set a group goal of completing three experiments. If a group notices that it does not have enough time to complete three stations, it could for example reduce its goal to two stations, without jeopardising the class goal. This is made possible by the evaluation file, which calculates average values for all groups. So even if each group adapted its goal from three to two or even only one station, the collective goal would still be achieved. This allows the positive emotions and the motivation of learners to be maintained despite the failure to achieve the group goal.

Test design, sample and procedure

A total of two classes took part in the evaluation. Since the experiment water analysis is applicable starting in the tenth grade, pupils of one tenth and one eleventh grade of grammar school participated. Forty two pupils took part in the evaluation, 20 of them being in the 11th grade (average age 16.29 years) and 22 in the 10th grade (average age 17.55 years), two of whom refused to answer the questionnaires.

While the intervention took place on the same day, the tenth grade experimented in the morning and the eleventh grade in the afternoon. The pupils completed a pre- and post-test, which included a questionnaire on self-regulation and cognition each. The pre-test was completed before the preliminary discussion of the experiment to ensure the objectivity of the pre-tests. The self-regulation questionnaire was completed first in order to avoid negative emotions that might arise from filling out the cognition questionnaire. After completion of both questionnaires, each class was divided into a control group and a test group. The control group carried out the water analysis with an analogue version of the experiment instruction, while the pupils in the test group were equipped with iPads and used the MEI. To avoid any influence on the current motivation and emotion of the pupils and therefore ensure internal validity, the two groups were instructed separately and worked on the stations spatially separated in the laboratory.

The questionnaire on self-regulation

The questionnaire is comprised of items from different questionnaires that have been adapted for the use of MEIs. Selected items for the evaluation of self-regulated learning according to Dörrenbächer and Perels (2016) serve as a basis for the questionnaire. All these selected items show a Cronbachs' α between .65 and .91. Selected items were supplemented by single items from Deci and Ryan (2003a, 2003b). For the items of Deci and Ryan, but also Dörrenbächer and Perels, there has been a slightly modification to fit the experimental activities. For example, an item such as "Before I start this activity, I know exactly which goals I want to achieve" can be changed to "Before I start experimenting, I know exactly which goals I want to achieve". Especially for the items of Deci and Ryan, the authors explain that the test they present *"consists of varied numbers of items from these subscales, all of which have been shown to be factor analytically coherent and stable across a variety of tasks, conditions, and settings." (Deci & Ryan, 2003a).* After a reliability analysis (see **Table 1**), useless items were removed and a Cronbach's alpha of .5 was used. In a pilot study, correspondingly, poor items were removed and evaluated in the same questionnaire scale. The fourteen items in total cover the three phases of self-regulated learning according to Zimmerman (2000) and are to be evaluated on a scale from 1 (disagree) to 6 (fully agree) to avoid a neutral position. To ensure content validity, the questionnaire covers each of the three phases of self-regulation, therefore aiming to represent the entire construct of self-regulation. The items were tested for clarity and comprehensibility and reviewed by Perels and Dörrenbächer (2016). As the questionnaire consists of items taken from established questionnaires on the construct of self-regulation with tested validity (Dörrenbächer & Perels, 2016; Deci & Ryan, 2003a), construct validity can be assumed. Concerning the questionnaire's reliability, all values are within the acceptable range of α > .5, whereby the low values in the post-action phase are to be viewed critically. For these first investigations, these values should nevertheless be sufficient. The following list contains examples of questionnaire items for the three phases of self-regulation:

Pre-action phase:

- Before I start the experiment, I think about the materials and chemicals I need to perform the experiment
- Before I start experimenting, I know exactly which goals I want to achieve

Action phase:

- When I conduct experiments, I think about whether my approach makes sense

Post-action phase:

- After experimenting, I check whether I have reached my goals
- After experimenting I reflect on what I can improve next time

Table 1. Reliability analysis of the self-regulation questionnaire and the three subscales

	Cronbach's	
Subscale	**Pre-Test**	**Post-Test**
Self-regulation (total)	.860	.854
Pre-action phase	.763	.839
Action phase	.809	.601
Post-action phase	.665	.579

Evaluation

For evaluation, the mean values of the pupils' test results are calculated, both for the entire test as well as for the three phases of self-regulation. The mean values of pre- and post-test are compared with a dependent t-test for paired samples with a 95% confidence interval (α = .05).. After testing for variance homogeneity, a t-test is performed for independent samples of the mean differences between the variables. If variance homogeneity cannot be assumed, a Welch test is performed (t-test with Welch correction). In both cases, the t and p values, the number of degrees of freedom and the effect size d are given. The cognition questionnaire starts with a general task and then addresses the individual stations in five tasks. The six tasks are each divided into knowledge and understanding, according to the learning goal taxonomies of Bloom (1972). The evaluation of the cognition questionnaire is similar to that of the self-regulation questionnaire, with the difference that instead of the mean values, the total score for the twelve questions is calculated.

Findings

Self-Regulation

Effect of the analogue experiment instruction on self-regulation

To investigate the question whether the analogue experiment instruction promotes pupils' self-regulation, only the two test groups that performed the experiments without the MEI are considered. For this purpose, the mean values of the pre- and post-tests of the two analogue groups are compared regarding their score in the self-regulation questionnaire. In grade ten, a lower mean value is found in the post-test, while in grade eleven it is above the mean value of the pre-test. However, both results are not significant (p = .132 & p = .145). Therefore, the analogue experiment instruction seems to have no positive influence on the pupils' self-regulation.

Effect of the digital experiment instruction on self-regulation

Two test groups carried out the water analysis using the developed MEI. Whether this version leads to an increase in self-regulatory is assessed by paired t-tests for the two digital groups with regard to the overall self-regulation score. Both groups showed a significant increase in self-regulation with a large effect size (p = .010 & p =.002, d = 0.84 & d = 1.24), which indicates that experimenting with the MEI has a positive effect on pupils' self-regulation (see **Table 2**).

Table 2. Results on the relation between self-regulation and Multitouch Experiment Instructions, *p < .05, **p < .01, df = degrees of freedom. d = Cohens d.

				Pre-Test		Post-Test		t-Test			
Grade	Group	Pupils	Type	*M*	*SD*	*M*	*SD*	*T*	*df*	*p*	*d*
10	Analogue	9	Pre-action phase	3.19	1.03	3.15	0.94	0.17	8.00	.436	0.06
			Action Phase	3.22	1.37	3.17	1.22	0.18	8.00	.433	0.06
			Post-action Phase	3.78	1.24	3.54	1.18	1.40	8.00	.099	0.47
			Self-Regulation (Total)	3.44	1.12	3.32	0.91	1.20	8.00	.132	0.40
10	Digital	11	Pre-action phase	3.45	0.76	4.08	0.63	-2.88	10.00	.008*	0.87
			Action Phase	3.41	1.18	3.18	0.51	0.59	10.00	.284	0.18
			Post-action Phase	3.77	0.80	4.27	0.69	-2.87	10.00	.008*	0.87
			Self-Regulation (Total)	3.58	0.70	4.03	0.53	-2.79	10.00	.010*	0.84
11	Analogue	10	Pre-action phase	4.65	0.56	4.92	0.87	-0.82	9.00	.218	0.26
			Action Phase	4.35	1.31	4.15	1.08	0.53	9.00	.303	0.17
			Post-action Phase	4.18	0.66	4.42	0.67	-1.58	9.00	.074	0.50
			Self-Regulation (Total)	4.41	0.47	4.59	0.69	-1.13	9.00	.145	0.36
11	Digital	10	Pre-action phase	4.02	0.87	5.27	0.65	-4.26	9.00	.001**	1.35
			Action Phase	4.55	1.32	5.05	0.64	-1.34	9.00	.107	0.42
			Post-action Phase	4.22	0.64	4.58	0.57	-2.18	9.00	.029*	0.69
			Self-Regulation (Total)	4.18	0.73	4.94	0.41	-3.90	9.00	.002**	1.24

Differences between digital and analogue experiment instruction

The final question is whether the use of the MEI promotes the acquisition of self-regulatory competences to a larger degree than the analogue version. An unpaired t-test reveals that the digital version is superior as the test group which experimented with the MEI achieved a significantly higher self-regulation score compared to the analogue test group (p = .006 & p =.018, d = 1.09 & d = 0.92). Accordingly, the use of the MEI promotes the pupils' self-regulation to a larger extent than the analogue version (see **Table 3**).

Table 3. Results on the differences between self-regulation in using a Multitouch Experiment Instructions and an analogue instruction, *p < .05, **p < .01, df = degrees of freedom. d = Cohens d.

			Difference analogue		Difference digital		t-Test			
Grade	Pupils	Type	*M*	*SD*	*M*	*SD*	*T*	*df*	*p*	*d*
10	20	Pre-action phase	-0.04	0.66	0.62	0.72	-2.12	18.00	.024**	0.88
		Action Phase	-0.06	0.95	-0.23	1.27	0.34	18.00	.371	0.15
		Post-action Phase	-0.24	0.51	0.50	0.58	-2.99	18.00	.004**	1.13
		Self-Regulation (Total)	-0.13	0.32	0.45	0.53	-2.84	18.00	.006**	1.09
11	20	Pre-action phase	0.27	1.03	1.25	0.93	-2.24	18.00	.019**	0.91
		Action Phase	-0.20	1.18	0.50	1.18	-1.33	18.00	.101	0.58
		Post-action Phase	0.23	0.47	0.37	0.53	-0.60	18.00	.279	0.27
		Self-Regulation (Total)	0.19	0.52	0.76	0.62	-2.26	18.00	.018**	0.92

Knowledge acquisition

Impact of the analogue experiment instruction on knowledge acquisition

The two control groups that performed the experiment without the MEI are considered first. The question arises as to whether the analogue experiment instruction of water analysis leads to an acquisition of knowledge on the corresponding topic. A paired t-test revealed a significant knowledge acquisition both in grade ten and eleven with strong and medium effect size respectively (p = .008 & p = .018, d = 1.02 & d = 0.78). Thus, the analogue version of the experiment instruction has a positive effect on pupils' knowledge acquisition (see **Table 4**).

Table 4. Results on the relation between cognition and Multitouch Experiment Instructions, *p < .05, **p < .01, df = degrees of freedom. d = Cohens d.

				Pre-Test		Post-Test		t-Test			
Grade	Group	Pupils	Type	*M*	*SD*	*M*	*SD*	*T*	*df*	*p*	*d*
10	Analogue	9	Knowledge	1.67	1.12	2.56	0.88	-2.53	8	.018*	0.84
			Comprehension	2.17	0.93	2.67	0.61	-1.90	8	.047*	0.63
			Total	3.83	1.87	5.22	1.3	-3.05	8	.008**	1.02
10	Digital	11	Knowledge	1	1	1.73	0.79	-1.70	10	.060	0.51
			Comprehension	1.91	0.54	2.55	0.79	-2.51	10	.016*	0.76
			Total	2.91	0.94	4.27	0.82	-3.82	10	.002**	1.15
11	Analogue	10	Knowledge	1.6	1.35	2.5	1.58	-1.87	9	.048*	0.59
			Comprehension	2.65	1.53	3.35	0.46	-1.65	9	.067	0.52
			Total	4.25	2.12	5.85	1.49	-2.48	9	.018*	0.78
11	Digital	10	Knowledge	1.7	0.82	3.3	1.34	-4.71	9	.001**	1.49
			Comprehension	2.15	1.01	3.55	0.37	-3.38	9	.004**	1.07
			Total	3.85	1.11	6.85	1.29	-10.06	9	.000**	1.49

Impact of the digital experiment instruction on knowledge acquisition

Whether the digital version leads to knowledge acquisition can be answered by a paired t-test for the two test groups which carried out the water analysis using the MEI. In both groups a significant knowledge acquisition with high effect strength was observed (p = .002 & p =.000, d = 1.15 & d = 1.49), which demonstrates the positive impact of using the MEI on the pupils' knowledge acquisition.

Differences between digital and analogue version of the experiment instruction

Finally, the question arises whether the use of the MEI has a stronger impact on pupils' knowledge acquisition than the analogue version. A paired t-test revealed lower mean value difference in the digital group for grade ten. However, as this difference is not significant (p = .483), the digital version has no greater effect on knowledge acquisition than the analogue version of the experiment instruction. In comparison to the control group, a higher mean value difference in the digital group can be observed for grade eleven. The difference is significant with a large effect size (p = .036 & d = .82) (see **Table 5**). Therefore, the use of the MEI in grade eleven promotes knowledge acquisition to a larger degree than the analogue version.

Table 5. Results on the differences between cognition in using a Multitouch Experiment Instructions and an analogue instruction, *p < .05, **p < .01, df = degrees of freedom. d = Cohens d.

			Difference analogue		Difference digital		t-Test			
Grade	Pupils	Type	*M*	*SD*	*M*	*SD*	*T*	*df*	*p*	*d*
10	20	Knowledge	0.89	1.05	0.73	1.42	0.28	18.00	.390	0.13
		Comprehension	0.50	0.79	0.64	0.84	-0.37	18.00	.358	0.17
		Total	1.39	1.36	1.36	1.19	0.04	18.00	.483	0.02
11	20	Knowledge	0.90	1.52	1.60	1.07	-1.19	18.00	.126	0.53
		Comprehension	0.70	1.34	1.40	1.31	-1.18	18.00	.127	0.52
		Total	1.60	2.04	3.00	0.94	-1.97	12.67	.036*	0.82

Discussion

Our data showed positive results for the use of a Multitouch Experiment Instruction regarding cognition and self-regulation compared to an analogue experiment instruction for both age groups (grade ten and eleven). These results were found for self-regulation overall as well as for the planning phase as a subscale of self-regulation. This suggests that MEIs are able to promote self-regulated learning through their intentional structure and content. Bernacki et al. (2011) conclude that TELEs must meet two conditions in order to promote self-regulated learning effectively: a domain-specific objective and a responsive adaption to students' needs. Both conditions apply to this MEI, which accounts for its general ability to promote students' self-regulation. However, no significant difference was found for the action phase, while only one group (grade 10) showed a significant increase for the reflection phase in comparison to the analogue group. According to the three phases of self-regulation described by Zimmerman (2000), there was one type of media for each phase which was targeted to support students in this phase. The material lists, which were tailored to assist students in planning their experiments, seem to have been effective, as a significant increase in self-regulation in planning phase was found for the digital version. In contrast, the videos on the execution of the experiment and its interpretation on particle level did not achieve the expected outcome, that is, to improve students' self-regulation in the action and reflection phase. Students might have consulted the videos for planning their experiments or might have been overwhelmed and therefore reluctant to consult the videos as they contained even more information to process.

As Bernacki et al. (2011) highlight, the relationship between didactic and facultative TELEs and self-regulation needs to be further investigated. Only few studies feature facilitative TELEs which aim to promote self-regulated learning without explicitly training self-regulation strategies or including information on self-regulation. Even fewer focus on the effect of such environments on students' self-regulation while many investigate the effect on students' learning outcome. However, the findings of this study can be compared to an intervention which compared a didactic TELE with self-regulation training to a facilitative TELE, both implemented as an interactive eBook (Seibert et al., 2020c). Interestingly, the enriched version of the MEI, which included self-regulation training, showed no benefits compared to the MEI which only featured the content-related support tools. This emphasises the MEI's ability to promote self-regulated learning due to its structure and content without explicitly addressing self-regulation strategies or other aspects.

However, it should be noted that both test conditions can not be considered as fully equivalent due to the complexity of the multimedia content present in the MEI. Integrating this content into an analogue experiment instruction is only possible to a certain degree, especially when it comes to the support tools such as interactive widgets with instant feedback. Also, the self-regulation strategies students might have applied due to the interaction with the MEI require a certain amount of training and automation in order to be fully effective, which students could only benefit from during a longer intervention period. Some studies on TELEs have investigated the effect of support by human tutors on self-regulation and cognition. Azevedo (2008) describes how prompts provided by tutors resulted in a more effective interaction with the learning environment and higher degree of self-regulation on regard of the students. This finding indicates an important limitation of our study because the support provided by the tutors might have influenced the learning outcome of the students as well as their use of self-regulation strategies.

The findings have provided a valuable insight into the indirect promotion of self-regulation through technology-enhanced learning environments for the context of science education. This is especially the case as the effect of facilitative TELEs on self-regulated learning is a topic only few studies address, which is why intentional future research on the topic is required to improve our understanding of the relationship between TELEs, SRL and learning outcomes.

One issue which can be derived from our investigations is how specific phases of self-regulation can be promoted more effectively by the medium or prompting. This raises the question which types of media might be ideally suited to promote certain aspects of self-regulation. Also, the questionnaire could be modified to collect data on which media and tools students actually interact with and whether the degree of help-seeking is related to their self-regulation strategies and motivation. Due to a tendency towards gender bias in the natural sciences, gender effects should be investigated in future studies.

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Declaration of Conflict of Interests

The authors have no competing interests to declare.

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