Multitouch Experiment Instructions to promote self-regulation in inquiry-based learning in school labs

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ABSTRACT
Multitouch Experiment Instructions (MEIs), implemented as interactive eBooks, are learning tools for pupils, which offer various digital support tools and enable pupils to individualise their learning. They may be applied to contexts such as inquiry-based experiments in school labs, which involve highly demanding cognitive processes and require a high level of self-regulation. Self-regulation has been shown to be reliably promoted by interventions which include the targeted training of self-regulation strategies. A MEI was designed as interactive eBook on experiments on the topic “Analysis of Cola”, suitable for an inquiry-based learning environment such as a school lab. The MEI’s potential to promote self-regulated learning was investigated by comparing it to a MEI with digital, integrated self-regulation training. The data revealed a significant increase of self-regulation in the control group, which consisted of pupils experimenting with the MEI on its own, and one experimental group, which included pupils that were supported by the MEI with an additional self-regulation training. It can be assumed that the MEI’s ability to promote self-regulated learning is comparable to the results achieved by an additional self-regulation training which explicitly addressed self-regulation strategies. This highlights the MEI’s potential to promote self-regulated learning in an indirect approach.
GRAPHICAL ABSTRACT

KEYWORDS
Elementary/ Middle School Science, High School/ Introductory Chemistry, Interdisciplinary/ Multidisciplinary, Curriculum, Hands-On Learning/ Manipulatives, Inquiry-Based, and Multimedia-Based Learning

INTRODUCTION
While self-regulation has long been a research interest in the field of psychology, its relevance to education has also been widely recognized. This has been highlighted by its definition as across-curricular competence which equips pupils for life-long learning by the PISA consortium\(^1\). This development is accompanied by the challenge of incorporating Information and Communication Technology (ICT), whose increasingly significant role in the classroom has been recognized by the publication of guidelines for the development of digital competences by the Standing Conference of the Ministers of Education and Cultural Affairs\(^2\). School labs, especially those which offer an inquiry-based learning environment, may represent a sensible complement to established teaching methods.

In order to support individualised learning in such an environment, Multitouch Experiment Instructions (MEIs) serve as learning tools for pupils which offer various digital support tools aimed at different categories of experimental problems and provide individual, targeted support. This article focusses on the implementation of MEIs as interactive eBooks and elaborates on their potential to promote knowledge acquisition and self-regulation by comparing them to a MEI with self-regulation training (SRT).
THEORETICAL BACKGROUND

Self-regulation

The relevance of self-regulation is manifold: high-achieving students apply more self-regulation strategies than lower-achieving students which shows its impact on academic performance\(^5\), is a key competence in relation to life-long learning\(^4\), a cross-curricular competence\(^1\), and may enable pupils to independently acquire knowledge and skills to meet unprecedented challenges regarding their future on the labour market.

Zimmerman\(^5\) (p.14) defines self-regulation as follows: “Self-regulation refers to self-generated thoughts, feelings and actions that are planned and cyclically adapted to the attainment of personal goals”. Self-regulation in the context of learning can be described as self-regulated learning, which aims at the reflected use of appropriate strategies in the respective learning situation and also includes motivational and metacognitive regulation on part of the pupils.

Zimmerman emphasises the cyclical character of self-regulation in his social-cognitive model and divides the underlying processes into three phases, which form a cycle.\(^5\) The initial step is a forethought phase which includes self-motivation and task analysis, involving not only an analysis of requirements and potential difficulties but also aspects of goal setting and strategic planning. Intrinsic interest in the action or task leads to a high level of motivation, which can be decisive for the actual execution of the action.

If this prerequisite is met, pupils initiate the performance of the task or action, exercise self-control to focus on the task at hand, identify and prioritise action steps they should take and apply and optimize their problem-solving strategies. At a metacognitive level, pupils also monitor certain aspects of their performance to assess its effectiveness, which enables them to detect patterns which they take into consideration when it comes to the next forethought phase.

This aspect already refers to self-reflection of the performance, which constitutes the last phase of the self-regulation cycle. Pupils carry out a self-assessment by comparing the information gathered during self-observation with the goals they set out to achieve as well as by ascribing their success or failure to a cause as part of causal attribution. This self-assessment triggers an emotional reflection of the performance outcomes, which has consequences for future learning processes and Zimmerman
refers to as self-reaction. The outcome of the pupils' self-reaction has an impact on the motivation for future actions, including their choice of learning strategies, and on how ambitious future goals are set. Overall, the reflection determines how the learning process is adapted in the future, meaning that the self-reflection process undergoes an iteration as feedback on the performance phase is harnessed for optimising future actions.

Self-regulation has been shown to be successfully promoted by interventions for learners in different age groups, especially those which are integrated into actual subject content.

The effectiveness of these interventions also applies to primary school pupils and is not subject-specific.

Interestingly, successful interaction with educational multimedia environments requires a certain degree of self-regulation on part of the learners. As empirical studies have shown, a high degree of self-regulation therefore has a beneficial effect on learning with digital learning environments. Pupils who fail to regulate their learning may lose their motivation when dealing with a complex learning environment or might not be able to focus their attention in the degree required to solve complex task. This shows that especially when it comes to multimedia learning environments, the pupils' self-regulation needs to be taken into account. While digital learning environments do not in themselves promote self-regulated learning, educators should consider the requirements of hypermedia environments and design the environment accordingly such as by integrating support tools or prompting as they provide new ways to promote self-regulated learning. Digital media proves to be successful in promoting self-regulation through forms such as individual eLearning via online platforms or multimedia learning environments which are also enriched with support tools or employ prompting. A well-designed digital learning environment may enable even pupils with a low level of self-regulation to successfully interact with the content it provides.

In addition to multimedia design principles, the cognitive load pupils are confronted with needs to be taken into account when constructing multimedia learning environments. Thus, a cognitive overload should be avoided as it may affects the effectiveness of the intervention. Multimedia learning environments are an attractive realisation of self-regulation training in the context of experimentation since a combination with a digital experiment instruction is possible.
Multitouch Experiment Instructions: interactive multimedia content as experimental tool

Information and Communication Technology (ICT) in science education can generally fulfil three didactic functions.\(^{17}\) ICT can be harnessed as an experimental tool in order to facilitate experimentation, for example by using a pH electrode with digital data acquisition. In the role of a learning companion, ICT accompanies the learning process over a certain time period to promote cognitive and individual learning processes, such as a unit in the curriculum.\(^{18,19,20,21,22}\) One implementation is the Multitouch Learning Book (MLB), an interactive eBook consisting of several modules which connects formal and non-formal learning environments.\(^{23}\) This connection defines one of the major advantages for a successful learning in a non-formal learning environment.\(^{24}\) In contrast to learning companions, learning tools are tailored to support cognitive learning processes in a specific situation such as a visit of a school lab.

Multitouch Experiment Instructions (MEIs), interactive, digital experiment instructions, are one way of creating a learning tool and may be implemented as interactive eBook or Augmented Reality. For example, iBooks Autor, a free software for macOS, enables the creation of interactive eBooks which can be used on an iPad as a terminal. In the eBooks we create, interactive interfaces are implemented. From a technical point of view, those are referred to as widgets. MEIs cover a wide range of interactive content by the integration of widgets on top of content such as videos, documents or presentations. MEIs are especially suited for inquiry-based instruction. Inquiry-based learning is in stark contrast to the mere replication or verification of findings, it rather aims at the individual construction of knowledge and skills through interaction with the learning topic.\(^{24}\) In this non-formal, inquiry-based learning environment, MEIs offer pupils individual support due to interactive tools, called widgets, which focus on one hand on individual tasks depending on their knowledge and on the other hand on supporting tools for experimental problems, comprehension problems and language support. How pupils choose to use the provided support tools determines the degree of openness of the experiments. In addition to support tools from which particularly weaker pupils may benefit, high-performing pupils are encouraged by additional challenging exercises. Widgets can fulfil various functions such as activating prior knowledge, documenting experimental setups and measurement
data, evaluating measurement data, verifying pupils’ results and may also promote pupils’ digital media literacy.

Therefore, MEIs also serve to implement ways of using digital media such as the ones described by the SAMR-Model by Puentedura. Puentedura describes how teaching and learning can be improved by the use of digital media which can enhance or even transform the learning process. On the lowest level (substitution), conventional tasks or teaching material are simply replaced by digital media while the task remains the same. Enhancement of the learning process is achieved by augmentation of tasks and teaching material which leads to functional improvements due to harnessing technical possibilities of digital media. However, digital media can also lead to a transformation of learning and teaching which includes redesigning tasks by integrating digital media (modification) or even enabling new tasks and learning paths which would not have been possible without digital media (redefinition). Especially the last two aspects of the model, namely modification and redefinition of exercises and teaching methods, can be achieved by MEIs. Rather than simply providing a digital version of a conventional experiment instruction, the widgets which MEIs are enriched with enable novel types of exercises. For example, a matching task with instant feedback helps pupils to confirm the results of an experiment without disclosing them to the pupils in advance. Thus, MEIs pave new learning paths by enabling the redefinition of methods and exercises.

These benefits are by no means theoretical as MEIs have also been deemed effective in interventions. The implementation of MEIs as interactive eBooks and Augmented Reality on the topic of “Analysis of Alkenes” by Seibert and colleagues showed the promotion of motivational aspects of learning and led to an equally positive feedback from pupils and teachers alike.

Support of inquiry-based learning in non-formal learning environments by Multitouch Experiment Instructions

Learning is not limited to the school context which is why a cross-linking of formal, non-formal and informal learning environments may be beneficial for pupils to prevent the formation of inert knowledge. As non-formal learning environment, school labs are understood to be places of learning outside the school context which allow pupils to conduct experiments on topics which may or may not be relevant to the school curriculum and concern their everyday life.
In addition to non-formal learning contexts, inquiry-based learning may increase pupils’ grasp of chemical concepts and comprehend the methods of scientific knowledge acquisition. Inquiry-based learning does not equal learning by random discovery but also differs from confirmation inquiry, which requires pupils to confirm findings by following “recipe-like” experiment instructions. Pupils are provided with a research question, develop theories, form hypotheses and test them by planning, conducting, and evaluating experiments. This is especially beneficial in a non-formal learning environment which provides specialised laboratory equipment as well as targeted support by tutors, which a single teacher would not be able to provide in a formal context.

However, inquiry-based learning requires complex cognitive processes because pupils need not only to plan and conduct their experiments but also develop hypotheses and interpret their findings accordingly. This is accompanied by strategies which concern self-regulation such as elaborative, motivational or metacognitive strategies.

MEIs as a learning tool may provide the necessary framework for a learning environment which enables the promotion of self-regulated learning. To boost the pupils' motivation, topics are chosen which demonstrate the relevance of chemistry for their everyday life. The cognitive processes related to experiments are supported, for example by exercises to activate the pupils’ prior knowledge or widgets to individualise the assistance pupils are provided with. One aspect, which needs to be taken into account during the development of the MEI is of course the cognitive load pupils process during the experiment. Overall, MEIs are ideally suited for use in non-formal learning situations as they enable individualised learning.

The objective of our intervention was to investigate the following research questions:

1. How does experimenting with a MEI and a MEI with integrated self-regulation training affect pupils’ self-regulation?
2. Does a MEI without self-regulation training have the potential to promote pupils’ self-regulation to the same degree as a MEI with an additional self-regulation training?
3. How does interacting with a MEI and with a MEI with self-regulation training affect cognitive aspects such as pupils’ knowledge acquisition?
As self-regulation training has been shown to be successful in analogue as well as digital learning environments, a self-regulation training which is integrated into the subject content should be able to promote pupils’ self-regulation. Therefore, a positive impact on pupils’ self-regulation score is an expected outcome for experimenting with a MEI with added self-regulation training.

Research question (2) aims at investigating the central issue whether multimedia learning environments may under certain conditions promote self-regulation. This may be due to their structure, support tools for individualised learning and demands on pupils’ ability to interact with the multimedia environment, which could indirectly train pupils’ self-regulation. If this were the case, it could enable teachers to foster pupils’ self-regulation without reserving time to explicit self-regulation training while also promoting their digital competences. Concerning research question (3), it should be considered that interacting with a MEI with self-regulation training presents a higher cognitive load compared to the MEI on its own. This is why knowledge acquisition may be compromised due to the additional input provided by the self-regulation training.

**IMPLEMENTATION OF MULTITOUCH EXPERIMENT INSTRUCTION AND SELF-REGULATION TRAINING**

**Design of Multitouch Experiment Instruction as interactive eBook**

Multitouch Experiment Instructions can be described as interactive, multimedia experiment instructions which are tailored to assist pupils of different levels of performance. An implementation of MEIs as interactive eBook includes not only the experimental tasks that would be present in an analogue experiment instruction but enriches them with further tasks and individual support to address problems of various types which pupils can access at their own discretion.

Pupils are provided with tablets including the MEI after completing the safety instructions in the school lab and are then free to conduct experiments with assistance of the MEI. When opening the eBook on their tablets, pupils are directed to an overview page and navigate between the experiments with the help of buttons. Each experiment is represented by a page in the eBook which contains the title, the research objective and digital media such as videos and presentations as well as widgets, which pupils access over buttons. The MEI “Analysis of Cola” includes four mandatory experiments, which cover the analysis of density, carbon dioxide concentration, and sugar content of cola drinks and their sugar-free counterparts, as well as an optional experiment on phosphoric acid in cola. In
order to examine the structure of the MEI in detail, the third experiment on carbon dioxide will be considered in the following.

The research objective is presented in a grey box on the upper part of the page beneath the heading (see Figure 1). On this basis, pupils develop hypotheses and test them by planning and executing experiments. In order to guide the pupils, a distinction is made between research tasks and support tools, which is highlighted by the spatial separation of these aspects on the overview page.

Figure 1. Experiment 3: Tasks to analyse carbon dioxide concentration. Marked in blue: Research tasks guide pupils towards answering the research objective. 1Camera widget. 2Widget to assist data collection and evaluation. 3Multiple-choice Quiz. 4Pinboard. Marked in green: Support tools to individualise pupils’ learning process. 5Overview of chemicals and materials 6Drag-and-drop widgets to assist experimental setup. 7Video supporting the execution of the experiment.

While the research tasks are mandatory for pupils as they serve to document, evaluate and compare their results, pupils are free to choose the support they wish to take advantage of. Pupils document their experiment with a camera widget (Button 1) which allows them to take pictures of their experimental setup and their observations, which may be used to evaluate the experiment. In order to support the evaluation of the experiment, the next widget (Button 2) covers the calculation of
the carbon dioxide concentration by dividing it into several calculation steps and pupils are provided with a worked-out example. The third widget includes a multiple-choice quiz (Button 3) with instant feedback on the properties of carbon dioxide and the detection of carbon dioxide. As these topics are part of the Saarland curriculum for grade 5, 6, and 8, this serves as a revision to activate pupils’ prior knowledge and sets the experiments into perspective. As each federal state in Germany has its own curriculum for the respective subjects, it is difficult to choose a comprehensive topic that can be transferred to other federal states. Moreover, the various curricula are designed differently. In the federal state of Saarland a competence-oriented curriculum is used, whereas in other federal states, e.g. Rheinland-Pfalz, a context-oriented approach is chosen. However, the learning requirements for this experiment are, on the whole, already taught in the lower grades, which is why the assignment to the curriculum specific to the federal state hardly plays a role. After conducting their experiments, pupils communicate their results with their classmates on a pin board (Button 4) with the research teams forming a scientific community which provides feedback and discusses experimental problems.

Apart from research tasks, pupils are also provided with support in order to individualise their learning. The support tools are aimed at several categories of problems pupils might face, such as language support, experimental support and comprehension, which are each represented by a special icon throughout the eBook. An overview of materials and chemicals which pupils can use for their experiments is provided by means of pictures and text (Button 5). This allows pupils to identify the laboratory equipment they need even when they are not familiar with the technical terms. When it comes to experimental problems, pupils are supported with three widgets which offer different levels of support. Two drag-and-drop widgets (Button 6 and 7) support pupils in planning the experimental setup of the two subtasks of the research objective. The last step of experimental support is a video which includes instructions for the execution of the experiment (Button 8). Once pupils have completed the task and conducted their experiments, a hyperlink on the right-bottom corner lets pupils proceed to the next experiment.

Conception of Self-regulation training in a Multitouch Experiment Instruction

As already pointed out, it has been shown that the effectiveness of self-regulation training can be enhanced by presenting it in relation to the subject matter, which is why the modules on self-
regulation were merged with the MEI. As an introduction, an instructional video is shown, so pupils gain an overview of structure and contents of the MEI. The individual modules on self-regulation, which cover six selected subscales of self-regulation, were arranged between the experiments (see Figure 2). Taking the phases of self-regulation by Zimmerman into consideration, a distinction between forethought, performance and reflection was made. After covering the subscales of self-regulation in theory, pupils apply the acquired strategies in exercises and then put them into practice in connection with their experiments. For example, before progressing to the first experiment, pupils are guided to a section on setting goals, which encourages them to carefully plan their experiments before carrying them out. In the context of inquiry-based learning, organisational learning strategies enable pupils to be persevering and solve the research questions independently, despite the drawbacks they might experience.

Figure 2. Integration of self-regulation training in Multitouch Experiment Instruction
Also, the phases of self-regulated learning are structurally similar to the phases of experimenting. Neber and Anton elaborate three main phases of inquiry-based experimentation. The pre-experimental activity includes the identification of tasks, the activation of prior knowledge, the formulation of questions, the presumption of answers and the planning of the procedure. In the experimental phase, the actual experiment is carried out, the respective findings are analysed and interpreted. In the post-experimental activity, the pupil should link the newly acquired knowledge with existing structures and evaluate it in a feedback loop with the pre-experimental activity. These three phases correspond almost directly to the three phases of self-regulation according to Zimmerman. For exactly these three phases, a MEI offers the possibility to promote the phases of theoretical preparation, independent experimentation and evaluation as well as explanation of the experimental findings through the targeted implementation of digital tools. This accounts for why strategies of self-regulation can easily be integrated in the process of experimenting. When it comes to the self-regulation training, certain specific strategies were selected in order to cover a reasonable amount of input and avoid a cognitive overload. The focus was set on the subscales of goal setting, motivation, strategic planning, dealing with mistakes, causal attribution and reflection.

To instruct these strategies, the training includes input which is provided by videos, short texts and presentations, as well as exercises, which require pupils to apply the provided information to the context of experimenting in the school lab. This aims at facilitating the actual application to the pupils' individual learning processes. One specific strategy included in the self-regulation training, for example, is intrinsic motivation. Input about the distinction between intrinsic and extrinsic motivation is provided by a short text with examples. In an allocation exercise, pupils then identify examples of intrinsically motivated actions from a pool of everyday examples which are relevant for the pupils and receive instant feedback on their allocation. In order to apply the content to themselves, the next exercise requires them to advise an unmotivated pupil how to motivate himself to carry on experimenting (transfer). Notably, the feedback loop of self-regulation is covered as well by means of an exercise which asks pupils to write an “e-mail to the past” to reflect their strategies, mistakes and results, including planning what they would like to improve if they had the chance to resume their experiments.
Research method
The MEIs as interactive eBook on the topic “Analysis of Cola” were tested on 88 pupils (52% female) in grade 7 and 9 who experimented in the context of a school lab. Twenty-three seventh-grade pupils participated in the intervention (N = 23, average age 12.78 years, SD = 0.59) while the remaining sixty-five pupils were in grade 9 (N = 65, average age 14.69, SD = 0.71). A total of four classes took part in the evaluation and were allocated to control and experimental intervention group. Pupils allocated to the control group (CG) conducted their experiments with assistance of the MEI, while the experimental group (EG) experimented with the MEI with integrated self-regulation training.

As one class consisted of seventh grade pupils, a distinction is made between the first experimental group, comprising ninth-grade pupils, and a second experimental group, which the seventh-grade pupils were allocated to. The intervention took place at the “NanoBioLab”, an established school lab located at Saarland University (Germany), which provided an inquiry-based learning environment. The pupils visited the NanoBioLab with their teachers in the morning and had a time frame of three hours for their experiments. Before experimentation, the pupils received a safety instruction as well as information on the topic of their experiments and the structure of the MEI by means of a pre-recorded video to standardize the input the groups were provided with. Data on the effect of the intervention on pupils' knowledge acquisition and self-regulation was collected using a pre-post design. For this purpose, a questionnaire to assess knowledge acquisition was constructed with multiple-choice items and a maximum score of 10 points. To evaluate self-regulation, a questionnaire was constructed based on the social-cognitive model by Zimmerman\(^5\), with 14 items based on items from Deci and Ryan (2003)\(^31,32\), which were adapted to the context of experimenting in a school lab. Pupils used a forced-choice scale of 1 to 6, with 1 being “strongly disagree” and 6 being “strongly agree”. The self-regulation questionnaire had a high internal consistence (Cronbach’s α = 0.88).

Comparison of the interactive eBook material for “Analysis of Cola” including a self-regulation training
The experimental conditions, namely experimenting with or without an integrated SRT, was set as independent variable. The influence of the independent variable on the pupils' knowledge acquisition, which was set as dependent variable, was investigated by calculating paired t-tests to compare pre- and post-test data (Table 1). A statistically significant increase was observed for all groups (p = 0.000)
compared to the control group (CG) consisting of 9th graders, including the second experimental group (EG2), which consisted of pupils from grade 7 who had less prior knowledge on the topic than the pupils in grade 9 (EG1). The effect size can be considered as high with Cohens d = 2.18 for the control group (CG), 2.07 for the first experimental group (EG1), and 2.94 for the second experimental group (EG2). After testing for variance homogeneity, unpaired two-tailed t-tests were performed to determine the difference in knowledge acquisition between the groups. Experimental groups showed no significant difference in knowledge acquisition compared to the control group.

A significant increase in self-regulation overall was found for CG as well as for EG2 with an effect size of d = 0.75 and 0.87, respectively. For EG1, only a descriptive increase was observed. Notably, this increase among pupils who received self-regulation training applies to EG2 which consisted of pupils in grade 7. Even prior to the intervention, the pre-test data indicates the CG as exhibiting the highest degree of self-regulation compared to the experimental groups (see Table 1).

Table 1. Comparison of T-test Pre- and Posttest Data for Multitouch Experiment Instruction with and without Self-Regulation Training

<table>
<thead>
<tr>
<th>Variables (Grade)</th>
<th>Test Conditions</th>
<th>Mean Scores (SD)</th>
<th>t (df)</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge acquisition (9)</td>
<td>CG^a</td>
<td>4.59 (1.46)</td>
<td>6.41 (1.74)</td>
<td>-6.27 (33)</td>
<td>0.000^h</td>
</tr>
<tr>
<td></td>
<td>EG1^b</td>
<td>3.74 (1.06)</td>
<td>5.23 (1.56)</td>
<td>-3.34 (30)</td>
<td>0.000^h</td>
</tr>
<tr>
<td>Self-regulation (9)</td>
<td>CG^a</td>
<td>4.48 (0.81)^f</td>
<td>4.75 (0.80)^f</td>
<td>-2.15 (33)</td>
<td>0.020^i</td>
</tr>
<tr>
<td></td>
<td>EG1^b</td>
<td>4.03 (0.95)^f</td>
<td>4.18 (0.68)^f</td>
<td>-0.87 (30)</td>
<td>0.197</td>
</tr>
<tr>
<td>Knowledge acquisition (7)</td>
<td>EG2^c</td>
<td>2.74 (1.18)</td>
<td>4.52 (0.85)</td>
<td>-6.89 (22)</td>
<td>0.000^h</td>
</tr>
<tr>
<td>Self-regulation (7)</td>
<td>EG2^c</td>
<td>4.20 (0.95)^f</td>
<td>4.50 (0.89)^f</td>
<td>-2.04 (22)</td>
<td>0.027^i</td>
</tr>
</tbody>
</table>

^aControl group, grade 9. ^bExperimental group, grade 9. ^cExperimental group, grade 7. ^dTotal N = 88. ^eScores for the cognition questionnaire have a scale range of 0-8. ^fScores for the self-regulation questionnaire have a scale ranging from 1 (fully disagree) to 6 (fully agree). ^gDegrees of freedom. ^hP < 0.01. ^iP < 0.05. ^jCohens d: High effect size for |d| > 0.8; Medium effect size for 0.8 > |d| > 0.5; Small effect size for |d| < 0.5.

No significant difference was found between knowledge acquisition of male and female pupils (p = 0.260, d = 0.29, df = 63). However, while male pupils showed an increase in self-regulation (p = 0.000, d = 1.78, df = 27), this increase differs significantly (p = 0.000, d = 1.22, df = 38) from the self-regulation of female pupils (p = 0.140, d = 0.50, df = 63). This suggests that male pupils benefit more
from the inquiry-based experimental setting regarding self-regulation in contrast to their female classmates. Interestingly, this effect applies to pupils regardless of which experimental group they were allocated to.

**DISCUSSION**

It was the aim of the study to analyze the impact of MEIs as interactive eBooks regarding their potential to promote knowledge acquisition and self-regulation by comparing them to a MEI with self-regulation training (SRT). With the help of the presented study the research questions (1), (2) and (3) can be answered:

1. Self-regulation was increased in all pupils except for EG1. Overall, the study also shows that the use of a MEI with or without integrated self-regulation training leads to an increase in self-regulation regardless of the grade. It is also obvious that the use of a digital learning environment per se can lead to an increase in self-regulation. The integration of a separate training changes the learning and the effect on self-regulation neither negatively nor positively.

2. A MEI without self-regulation training also has the potential to promote self-regulation, as does a MEI with integrated self-regulation training. Based on the presented study, it can be shown that the digital learning environment can promote self-regulation in students when they experiment and that, first and foremost, no additional training is required for this.

3. Similarly, it was found that in both variants the cognitive acquisition of knowledge as a partial aspect of self-regulation was significant. In both cases it was shown that a corresponding increase through the additional integration of a training course does not provide any significant added value for the increase in knowledge. It can therefore be said that a MEI, as a digital learning environment, has a positive effect on learning in chemistry but also promotes knowledge acquisition.

It seems that a successful interaction with the hypermedia environment provided by a MEI combined with the cognitive processes involved in inquiry-based learning might already promote self-regulatory aspects. Several aspects might have influenced our findings. For example, strategies to promote self-regulation need not only to be implemented by the pupils but are also only used
efficiently after a certain period of practice and automation, which would have only come into effect
during a longer intervention period.\textsuperscript{33}

Furthermore, prompting provided by tutors might have promoted certain aspects of self-regulation. However, the support provided by the tutors was a prerequisite for safety and technical support during the experimentation process. Both experimental groups and control groups received the same support from the tutors, thus a specific influence on the results of one group is unlikely. Also, additional input as part of the self-regulation training might have resulted in focus on understanding subject-relevant contend over self-regulatory strategies which would account for our findings.

It should also be considered that awareness of the aspects associated with self-regulation might have led pupils to a better understanding of the questionnaires which is why they might have focused on their shortcomings in the post-test. This could have caused a bias towards a lower score in the self-regulation questionnaire. A multi-method approach might be more beneficial for future research than self-report instruments, in order to document the stages of strategy implementation and enhance objectivity.

**CONCLUSION**

Overall, the intervention showcases the MEI’s ability to promote self-regulated learning in an inquiry-based learning environment. Knowledge acquisition was increased both in control and experimental groups which shows that the cognitive load generated by the additional training did not have a negative effect. This demonstrates the effectiveness of inquiry-based learning using a MEI. In contrast to our hypothesis, experimenting with a MEI as an interactive eBook promotes self-regulation as effectively as experimenting with an enriched version of the MEI, which includes self-regulation training. Therefore, MEIs have the potential to promote self-regulated learning even without explicitly addressing aspects of self-regulation. This might be the case because due to the complexity of a multimedia, interactive MEI, experimenting with the MEI might already require students to apply self-regulation strategies in order to achieve a successful interaction with the MEI. Also, the nature of inquiry-based learning requires pupils to regulate their learning processes, which could have led to a promotion of organisational strategies, regardless of the experimental condition. It might be the case that a MEI with integrated self-regulation training results in a cognitive overload due to the amount of
information to be processed by the pupils. This may lead pupils to focus their cognitive capacities on solving the research questions rather than engaging with the self-regulation training and applying the strategies the training introduces. However, this raises the question if the integrated self-regulation training showed no effect because the pupils’ interaction was inefficient or at least not sufficient due to a cognitive overload caused by the material or the aspects and strategies covered in the self-regulation training were already promoted through the interaction with the MEI. In further research questions it would be interesting to examine whether the results obtained can be transferred to other learning scenarios. The interactive ebook may be found at

https://www.dropbox.com/s/fapwh96mxr82e1g/MEI%2BSRT_Cola_final%20Kopie.ibooks?dl=0.

ASSOCIATED CONTENT

Supporting Information
The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

https://www.dropbox.com/s/fapwh96mxr82e1g/MEI%2BSRT_Cola_final%20Kopie.ibooks?dl=0

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