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Digitalchemlab—Digital and Complexity-Differentiated Learning Modules in an out of School Student Laboratory

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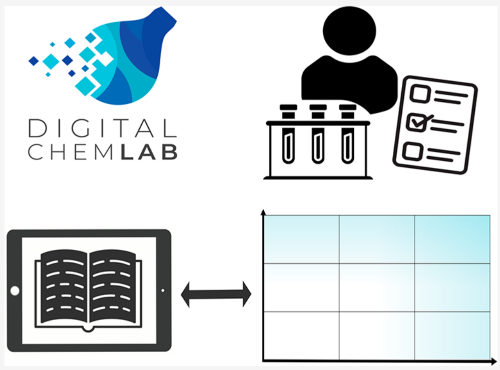
ABSTRACT: Digital media can help students in a variety of ways. For example, they can support students in managing their own learning by choosing the order and level of difficulty of tasks themselves, thereby providing structure and autonomy. At the Friedrich Schiller University Jena, a platform called *digitalchemlab* is being established, dedicated to the use of and research into digital media in chemistry teaching. The platform and its aims and goals will be presented in this paper. A first research project investigates the integration of digital media in an out of school student laboratory while supporting individualization of the learning experience. For this purpose, we developed a digital and complexity-differentiated learning module. This learning module was evaluated in a pilot study with $N = 65$ students from three-eighth grade high-school classes, gathering quantitative and qualitative data. Using a pre-post-follow-up design, we examined students' knowledge gain, thematic interest, and academic emotions. In addition, students rated different aspects of the learning module. We finally examined how students used the learning module. First results indicate positive effects of the intervention on knowledge and learning emotions. The concept itself as well as results of the pilot study are presented in this article.



KEYWORDS: *General Public, Out of School Student Laboratories, Chemical Education Research, Multimedia-Based-Learning, Acids/Bases*

1. INTRODUCTION

Digital media have long since arrived in chemistry education research. Various research projects are dedicated to digital teaching concepts,[1] digital data measurement,[2] or, more recently, the use of artificial intelligence, augmented and virtual reality[3] in the classroom. This research is often linked to the goal of improving the teaching process and the understanding of chemical content for students. Particularly, the potential of digital media to individualize the students' learning process[4] offers great advantages for education. Digital media could (a) help students to freely shape their own learning, (b) change the role of the teacher toward a learning guide and thus allow for more effective learning time, and (c) possibly increase the understanding of the learning content by offering autonomy and structure.[5] If this could be achieved, the usage of digital media in everyday lessons can contribute to the much-needed differentiation in heterogeneous learning groups.

The goals of this paper are two-fold: On the one hand, it aims to introduce a platform for digital media research called *digitalchemlab* that seeks to link different areas of chemistry education. On the other hand, our first research project for this platform will be shown, which focuses on the integration of digital media in an out of school student laboratory, while supporting individualization of the lab day. Initial results of the respective pilot study will be presented along with implications and limitations of these results. Finally, a conclusion and an outlook will be given, underlining the importance of further research into the matter.

2. THE PLATFORM *DIGITALCHEMLAB* AND ITS POTENTIAL FOR CHEMISTRY EDUCATION

The new platform *digitalchemlab*[6] intends to implement digital media and its research into regular university offers. Perspectives of students, student teachers, and university and school teachers (see Figure 1) are incorporated with the goal of transferring the results into everyday chemistry school lessons.

These four areas can contribute symbiotically to a heightened understanding of the usage of digital media in chemistry education and the development of new digital teaching concepts. An out of school student laboratory can create new concepts and courses on how to combine digital media with real life experiments and may benefit from the usage of digital media by possibly enhancing students' motivation and learning

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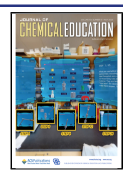

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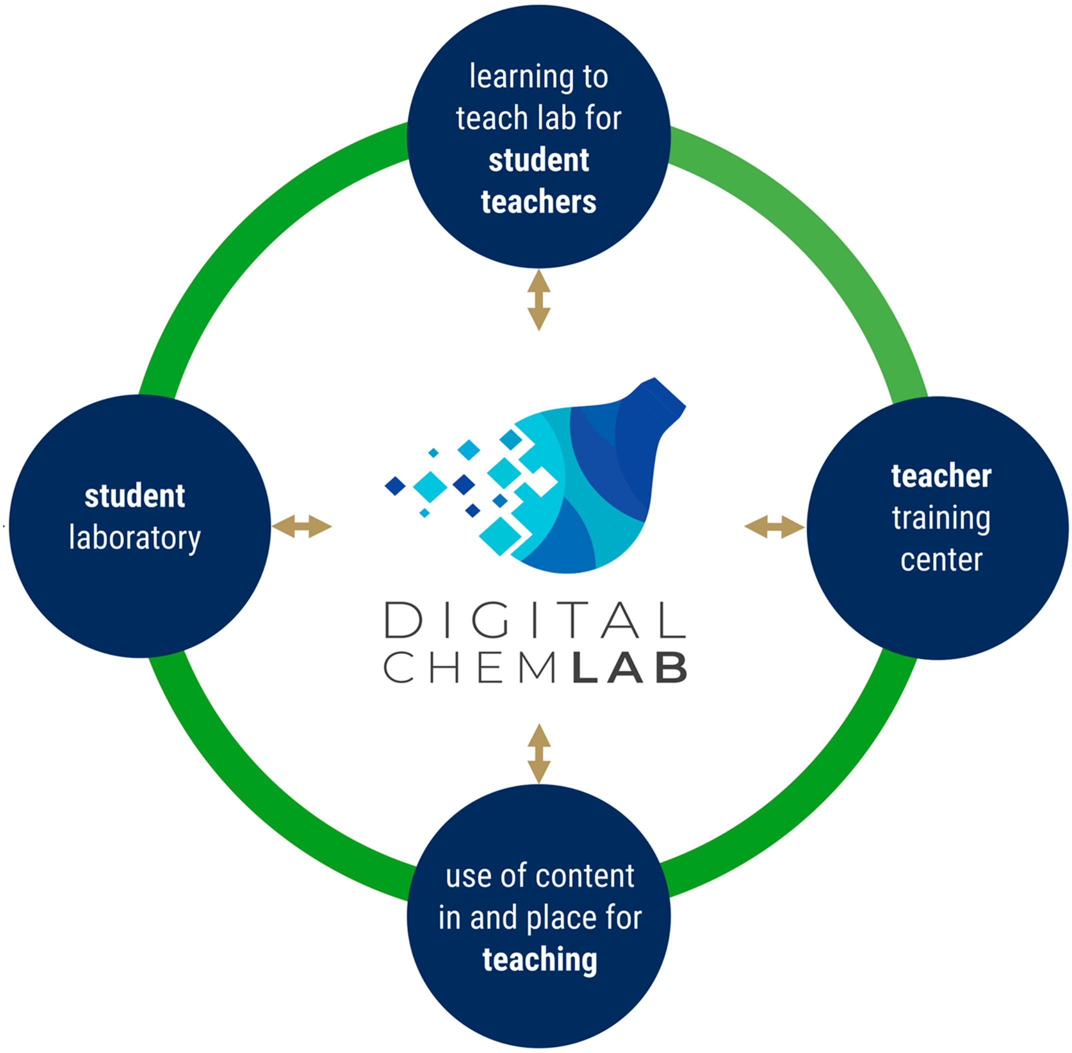

Figure 1. *Digitalchemlab* and its connection to regular university offers.

outcome.[7] The protected environment of a learning-to-teach laboratory offers student teachers the opportunity to gain practical teaching experience with digital media and to test them in everyday situations with students.[8] Teaching at the university can be improved by developing and testing new digital methods with student teachers, while implementing digital media usefully into everyday teaching aspects.[9] Finally, a teacher training center can communicate results of research on digital media as well as their practical application and further the implementation of new digital teaching concepts in everyday school lessons by addressing already practicing teachers.[10] The platform *digitalchemlab* aims to synergistically link these offers and train digital competencies[11,12] of student teachers and teachers in the process. It also tries to further current digital media research topics in chemistry education like digital measurement,[13] mixed realities,[14] machine learning[15] or gamification.[16] Included in this idea is the possible creation of a maker space,[17] where teachers, students, student teachers and researchers can experience and explore digital media directly. This maker space will include all aspects of a modern digital classroom: a 3D-printer, iPads, Smartboards, and possibly VR-Glasses. New digital tools, teaching- and learning formats can thus be developed right there, used all over the *digitalchemlab* cosmos and be evaluated in the process. This favors their research and their optimization for practice.

3. THE PROJECT "DIGITAL AND COMPLEXITY-DIFFERENTIATED LEARNING MODULES IN AN OUT OF SCHOOL STUDENT LABORATORY"

For our first research project, we developed a concept for the fruitful integration of digital media into our out of school student laboratory. From a chemistry education research point of view, the integration of digital media into the student laboratory offers possible advantages: (1) The impact of out of school student laboratories on students' interest,[18] academic self-concept,[19] and knowledge[20] could possibly be enhanced by integrating digital media and their inherent motivational potential. (2) The linkage between schools and student laboratories could be improved by developing digital and hybrid learning opportunities,[21] such as online or flipped-classroom arrangements.[22] This may make it easier to visit the student lab multiple times and favors the organic integration of the student lab contents into the regular school lessons and thus may lead to better results.[23,24] (3) Furthermore, out of school student laboratories are excellent places to study new digital tools or teaching-learning formats since they offer "well-controlled, authentic and

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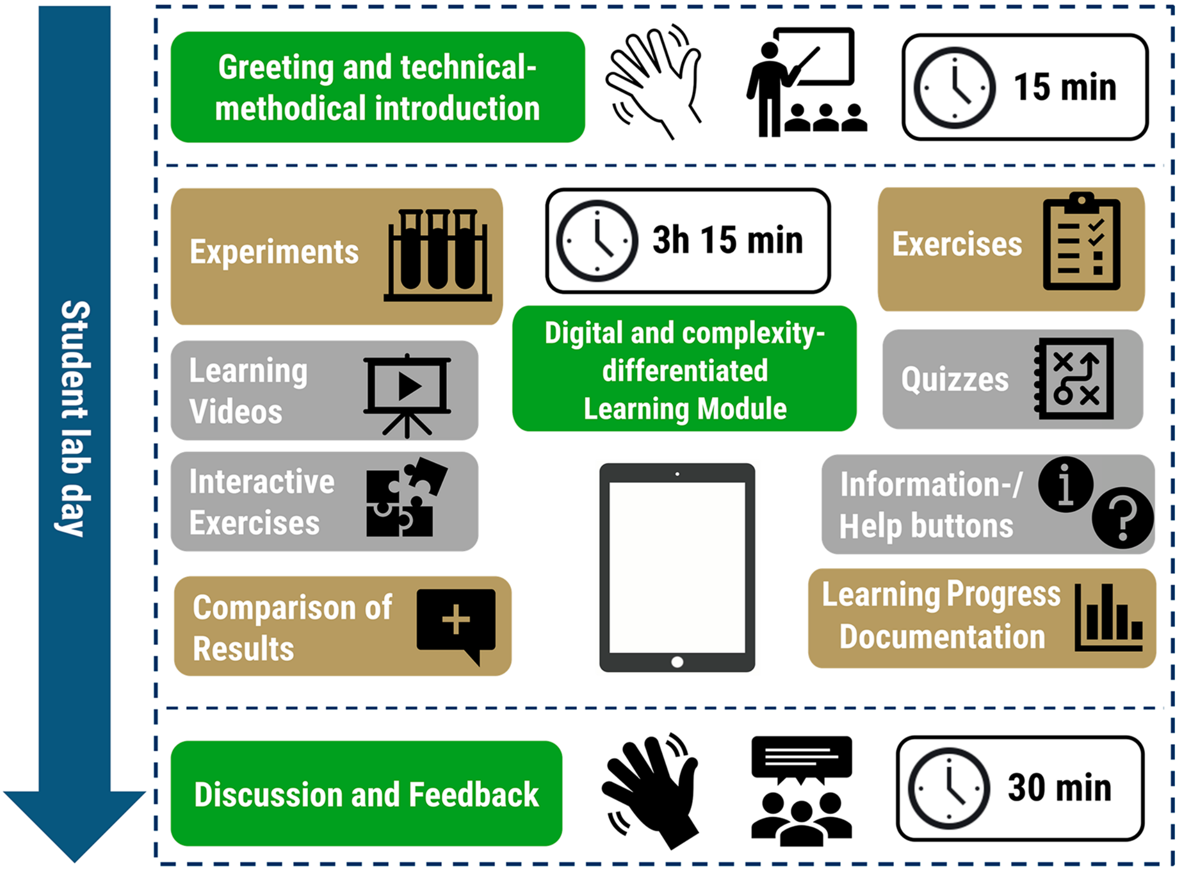

Figure 2. A day in the student laboratory according to the new concept.

realistic teaching-learning-situations".[25] The classical student laboratory[26] already uses experiments and open learning formats such as station learning to spark interest in science. As such, it should be easy to adapt this format for digital and complexity-differentiated learning.

Our research project wants to implement digital elements into central aspects of the regular student laboratory day with the goal of enhancing motivation and knowledge gain. Individualization and self-regulated learning in combination with digital media are supposed to have positive effects on motivation and learning outcomes.[27] Apart from the element of choice already prevalent in student laboratory courses as a major factor contributing to autonomy and therefore motivation,[28] we want to provide structure as a second factor supporting motivated learning.[5] Consequently, we offer tasks of different complexity in an ordered manner within a digital learning module, so that students can make informed choices about which tasks fit best to their interests and preknowledge. Moreover, we base the design of the learning module on the principles derived from Mayer's cognitive theory of multimedia learning[29] to optimally support memory processes during learning. Finally, we are developing a concept that will also be suitable for everyday school lessons. For that reason, the learning material used should be cheap, easy to create, and adaptable to the needs of teachers and their specific learning groups.

To realize such a concept, we combined two factors and created a digital and complexity-differentiated learning module. (1) A differentiation grid[30] is used for the formation of tasks of varying complexity. With the aim of making the subject challenging, relevant to everyday life, and involving multiple perspectives, tasks are constructed along two dimensions: horizontally (x-axis) the tasks increase in thematic complexity (from A to C), and vertically (y-axis) the tasks increase in cognitive complexity (from 1 to 4). The thematic complexity ranges from concrete (e.g., everyday aspects of the topic) to abstract (i.e., the chemical theory inherent in the topic). For the cognitive complexity we adapted Bloom's Revised Learning Taxonomy.[31] The tasks now become fields of the newly designed differentiation grid. (2) The differentiation grid and all the learning material needed to complete each task are embedded in an eBook[32] which is made available to students via in-house iPads. The arrangement in the form of an interactive eBook is intended to bundle learning material and make it available in a clearly arranged manner, providing structure. In addition, interactivity and the provision of multiple representations makes new types of enhanced tasks possible.[33] Students can then freely choose which tasks they want to complete by using their iPads. This way, they individually design their student lab day by using fields of varying complexity (see Figure 2).

After a short welcome and introduction to the technical (iPads) and methodological (differentiation grid) aspects of the day, the students have about three h to experiment and practice in the student lab. At this point, digital and complexity-differentiated learning modules will be used. This phase includes two types of tasks: (1) classical experiments to encounter scientific phenomena and (2) exercises that shed light on the underlying theory or cover everyday aspects of the topic. Both types of tasks are supported by digital media such as learning videos, interactive tasks (learningapps.org), quizzes, or interactive information and help buttons (thinglink.com). The fields of the grid can be chosen freely and in a free order. There is no

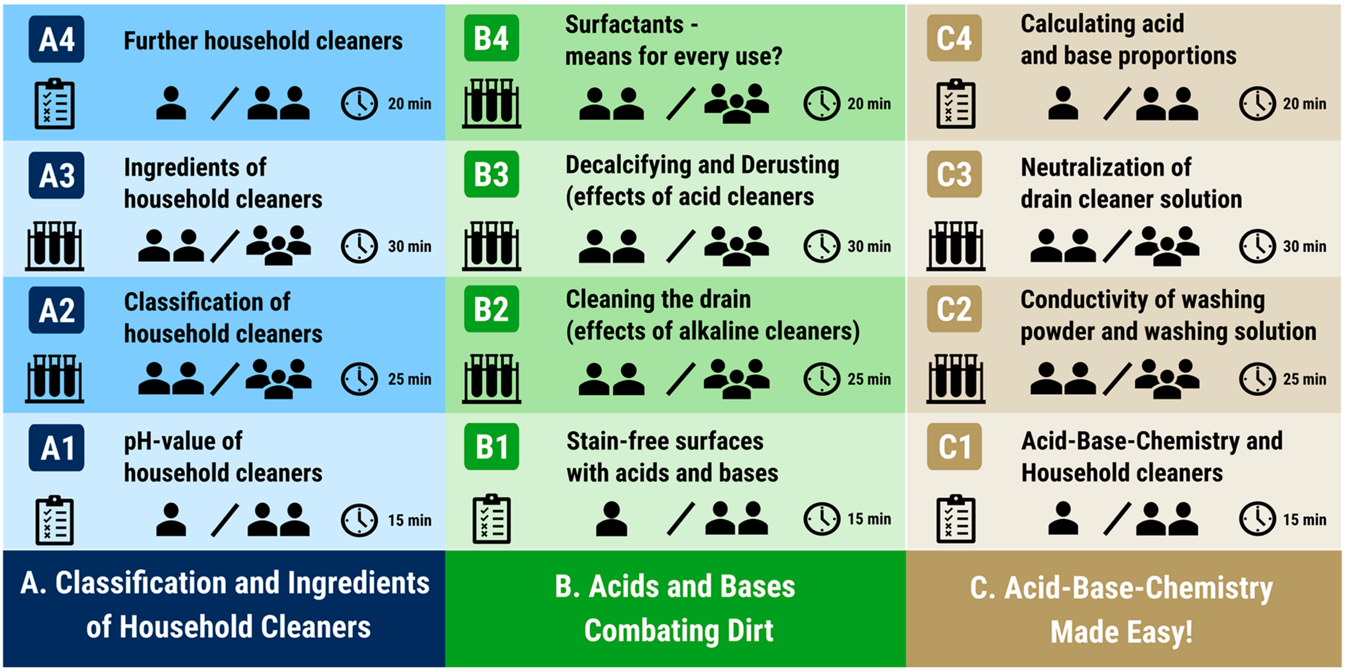

Figure 3. Digital and complexity-differentiated learning module "household cleaners".

preselection of compulsory fields, the students are only given the requirement that at least four fields must be completed. After completing a field, the students can compare their results with a solution to each task and document their learning progress. After a short discussion of open questions, there is room for feedback before the students leave the lab after about 4 h. To prove the practicability of this concept, a digital and complexity-differentiated learning module on the topic "household cleaners" was created (see Figure 3).

4. EMPIRICAL PILOT STUDY: EVALUATION OF A DIGITAL AND COMPLEXITY-DIFFERENTIATED LEARNING MODULE

The aim of the pilot study was a first summative and formative evaluation of the digital and complexity-differentiated learning module. We assessed students at three points of time: in the morning of their day in the student laboratory (pretest), on the same day directly after their visit (post-test), and 10−12 weeks after their visit (follow-up test). Questionnaires were also used after completion of each field during the day.

For the summative evaluation, we examined possible effects on learning:

(RQ1) How do students' knowledge, interest, and emotions change when students learn with the digital and complexity-differentiated learning module?[34]

First, we expected that students would gain knowledge on acid−based chemistry and household cleaners during the day in the student laboratory (i.e., from pre- to post-test). We further expected that these knowledge gains might be observed 12 weeks later at the follow-up-test, despite so far mixed evidence, when examining regular student laboratory courses.[35]

Second, based on self-determination theory[36] and control-value theory[37] we expected that the design of the learning module would benefit students' motivation and emotions. We assumed that the learning module gives students high levels of autonomy and control because they can choose the tasks they want to complete. Moreover, the structure of the differentiation grid should aid students in selecting tasks that fit their preknowledge and interest. We therefore expected increases in thematic interest and positive learning emotions (joy and curiosity) and decreases in negative learning emotions (frustration and boredom).

For the formative evaluation, we examined the opinions of the students toward the module and investigated students' perceived effort and difficulty of the created tasks in each field:

(RQ2) How do students evaluate the digital and complexity-differentiated learning module?

We asked students to rate the learning module, the use of the iPads, the differentiation grid, the duration, and the overall complexity of the module. We expected high ratings regarding the module, iPad/eBook use, and the differentiation grid. Duration and complexity were supposed to be rated as an average. Perceived effort and difficulty were expected to be the same as the intended levels of effort and difficulty inherent in the different fields of the differentiation grid.

Finally, we examined students' learning behavior:

(RQ 3) How do students use the digital and complexity-differentiated learning module (e.g., number and choice of fields)?

For this question, we did not apply any hypothesis.

4.1. Sample and Design

Prior to piloting the learning module with students, the learning module was tested within our work group and with student teachers of the eighth semester. Adjustments were made regarding the procedure and material. After a short revision phase, the learning module was piloted from May to July 2022 with three-eighth grade classes.

$N = 65$ students participated in the pilot study; a follow-up test was completed by $N = 54$ students. Approval for the study was given by their parents beforehand. A control group was omitted due to the small number of participants. Of the 65 participants, 46% were male and 54% female and between 13 and 15 years old. All groups attended upper secondary schools ("Gymnasium"), two schools were from Thuringia and one from Saxony.

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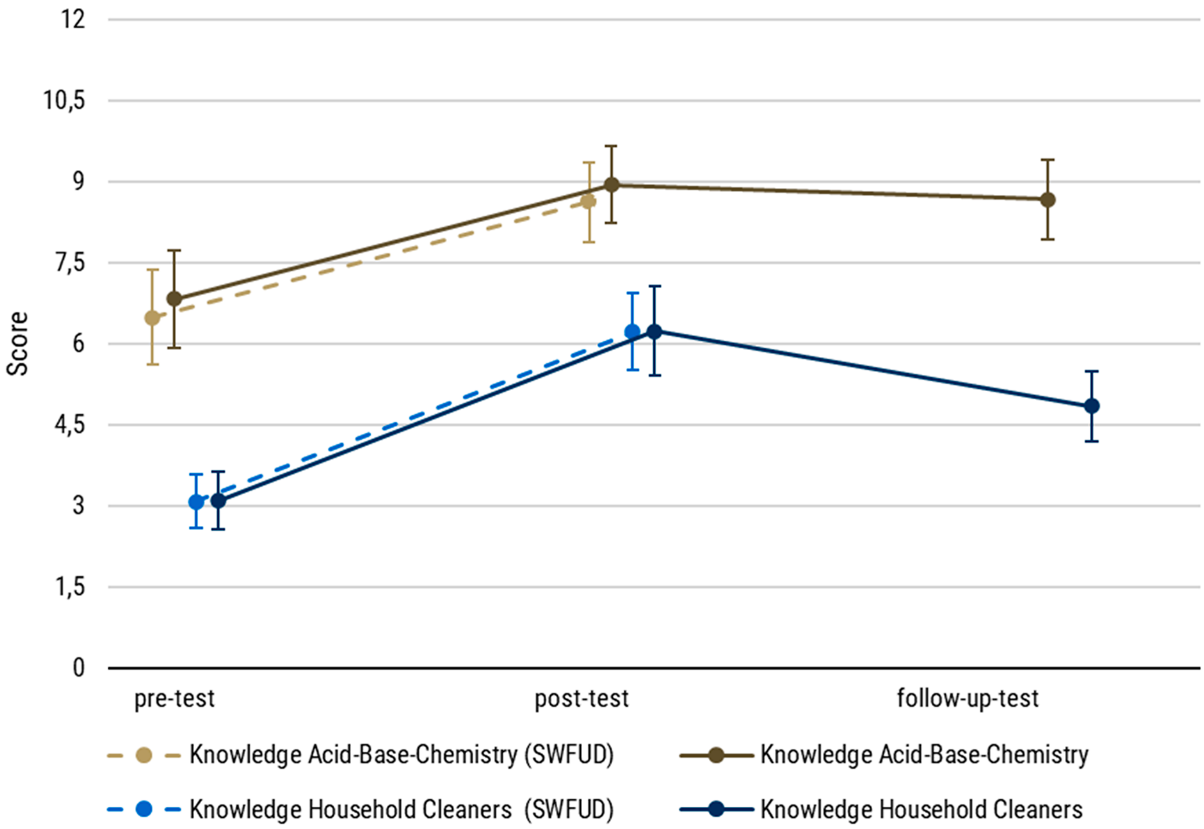

Figure 4. Changes in knowledge regarding acid−base chemistry and household cleaners (pre-, post-, follow-up-test). SWFUD stands for "Students Without Follow-Up Data" ($N = 65$) as opposed to students with follow-up data ($N = 54$; 53). High score is 12 for knowledge of acid−base chemistry; knowledge of household cleaners had an open scale, depending on the number of right answers. The figure shows mean values, and error bars represent the 95% confidence intervals.

4.2. Measures

The *knowledge of acid−base chemistry* was measured in the pre-, post-, and follow-up test with the same self-created, 12-item knowledge test. In this test, the students were asked to assign important terms relating to acid−base chemistry (e.g., pH value, neutralization) to the appropriate definitions. The definitions were lined oppositely to the terms in an unordered sequence. One point was awarded for each correct assignment, with a maximum score of 12. *Knowledge of household cleaners* was measured in the pre-, post-, and follow-up-test with a self-created knowledge test of five open items. Open items were used to better assess the quality of the prior knowledge of the subject. The students had to name types and ingredients of household cleaners, distinguish between soiling that can be removed with alkaline or acidic cleaners, and explain how surfactants work. One point was awarded for each correct answer. The items were rated by two individual researchers from our work group and mean values between them created. Both tests were created with experts from our work group. A within subjects ANOVA was used to determine the significance of changes over the three testing points (pre-, post-, follow-up).

Thematic Interest of household cleaners was measured in pre-, post-, and follow-up-test using four items from the Current Motivation Questionnaire (FAM)[38] that we adapted to the present context (Cronbach's alphas were $\alpha = 0.814$; 0.803; 0.861). Students made ratings on a five-point LIKERT scale (1 = not at all true, 5 = completely true). A within subjects ANOVA on the scale means was used to determine the significance of changes over the three measurement points (pre-, post-, follow-up).

Regarding *academic emotions*, the expectations before the visit (pretest) were compared with the emotions after the visit (post-test). For this purpose, adapted single items according to Pekrun[39] were used for the emotions joy, curiosity, frustration, and boredom. Participants were asked to make an assessment using a five-point LIKERT scale (1 = not at all true, 5 = completely true). *t* tests for dependent samples were conducted to test for significant changes.

Five closed and two open items were used in the post-test to formatively *evaluate* the various aspects of the learning module. On a five-point LIKERT scale (1 = very bad; 5 = very good), participants were asked to rate the learning module itself, the use of the iPads, and the differentiation grid. Duration and complexity were to be rated on a scale from 1 = too easy/too short to 5 = too difficult/too long (3 = just right). The two open items were as follows: (a) What did you like best about the learning module (and why)? (b) What could be improved in the learning module (and why)? The open items were coded by two individual researchers from our work group according to Kuckartz[40] by inductively reaching fitting categories and by coding consensually. Moreover, after the completion of each field students reported their perceived effort (How much effort did you just put in to work on these contents?)[41] and the perceived difficulty (How do you rate the difficulty of the content?) on a five-point LIKERT scale (effort: 1 = not at all, 5 = very strongly; difficulty: 1 = too easy, 5 = too difficult).

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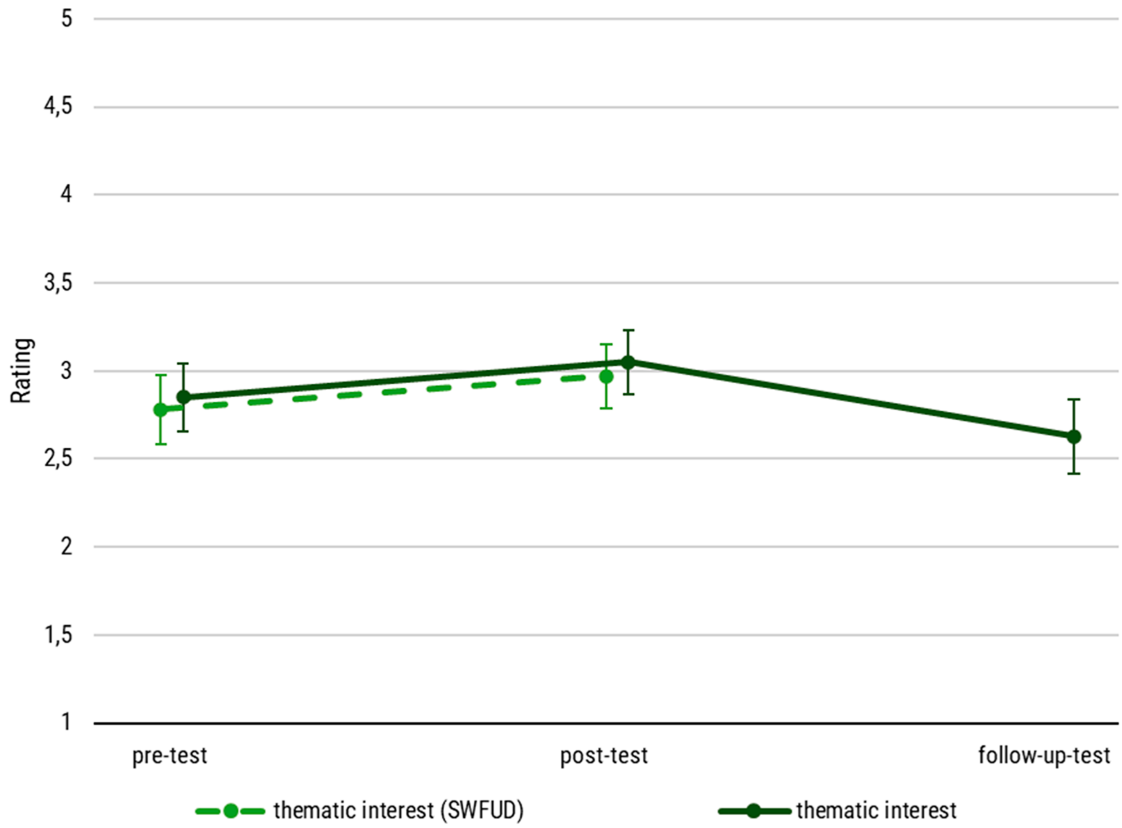

Figure 5. Changes in thematic interest (pre-, post-, follow-up-test). SWFUD stands for "Students Without Follow-Up Data" ($N = 65$) as opposed to students with follow-up data ($N = 54; 53$). The figure shows mean values, and error bars represent 95% confidence intervals.

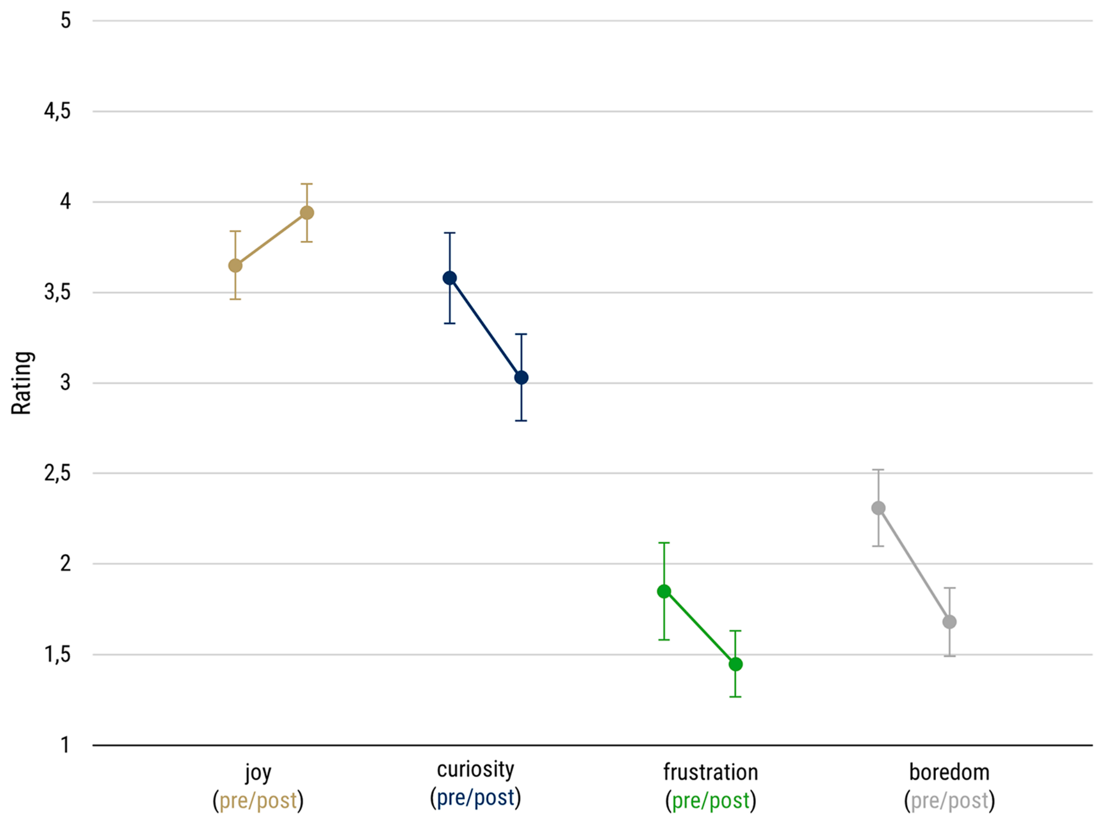

Figure 6. Changes in emotions: expectations toward the contents of the learning module (pretest) vs perceived emotions at the end of the student lab day (post-test). The figure shows mean values, and error bars represent 95% confidence intervals.

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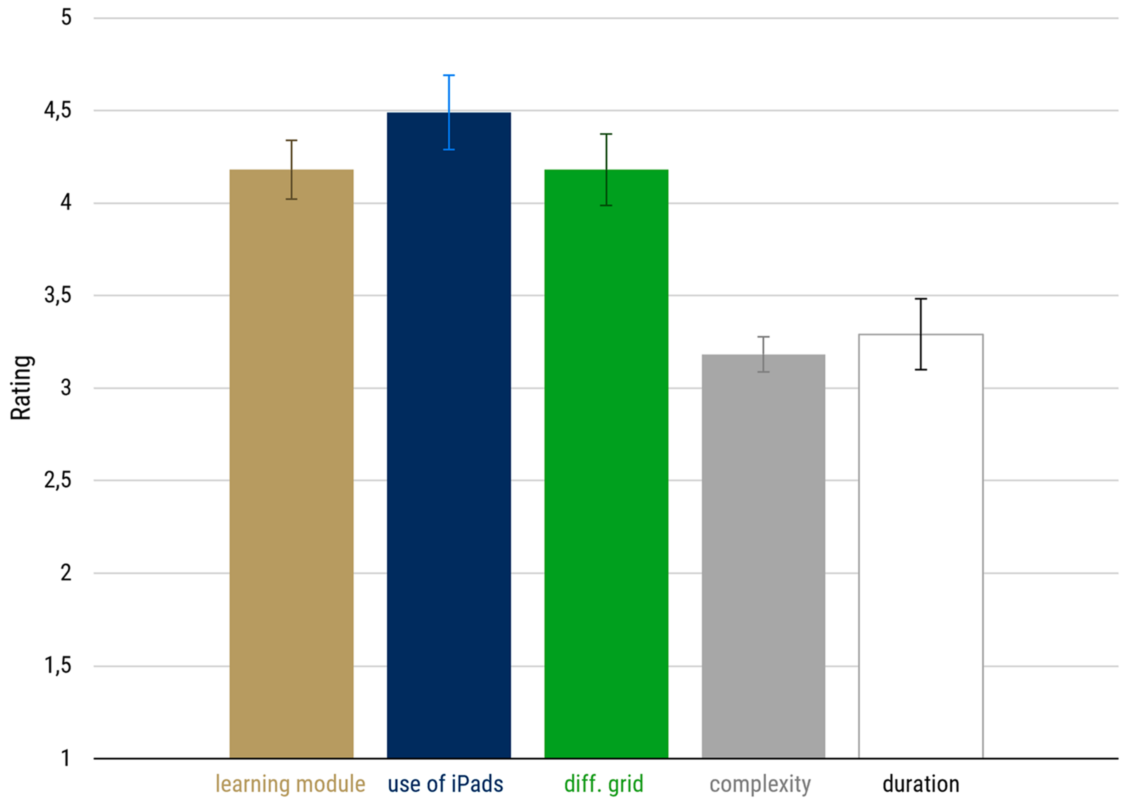

Figure 7. Evaluation of the learning module and the aspects usage of iPads, differentiation grid, complexity, duration (ratings at post-test).

To examine the *use of the module*, after the completion of each field, the duration and number (A1, C2, etc.) of the fields were recorded by entering them into an online tracking tool ("Please enter the field you just completed"). Duration was measured between completed fields. This user data was then used to calculate the number of completed fields per student.

4.3. Results and Discussion

Selected results of the pilot study are presented in the following. We note that results without a control group should be viewed with caution. However, they can provide initial indications of the quality of the learning module and, therefore, of the concept.

Changes in *knowledge* from pre- to post- and follow-up test can be seen in Figure 4. The effect for the knowledge of acid−base chemistry was significant at the 0.05 level, $F\ (1.8, 95.9) = 15.15$, $p < 0.001$, partial $\eta^2 = 0.22$. Posthoc pairwise comparisons with a Bonferroni adjustment indicated that there was no significant difference between the knowledge of acid−base chemistry at the post-test and the follow-up-test, ($p = 1.000$) and that it was significantly lower at pretest than at post-test, ($p < 0.001$) and at follow-up-test ($p < 0.001$). The effect for the knowledge of household cleaners was significant at the 0.05 level, $F\ (2, 104) = 26.29$, $p < 0.001$, partial $\eta^2 = 0.34$. Posthoc pairwise comparisons with a Bonferroni adjustment indicated that the knowledge of household cleaners was significantly lower at the pretest than at post-test, ($p < 0.001$) and at follow-up-test ($p < 0.001$). Knowledge was also significantly higher at the post-test than the follow-up-test ($p < 0.02$). Thus, both the knowledge about acid−base chemistry and the knowledge about household cleaners increased significantly after the lab day. While knowledge about acid−base chemistry remained almost the same after two months, the knowledge about household cleaners decreased again. However, the students' knowledge at follow-up was still higher than at pretest. The high knowledge retention on acid−base chemistry can possibly be explained by further treatment of the topic in class.

Results of the *thematic interest* survey at the pre-, post-, and follow-up test can be seen in Figure 5. We found significant differences over time, $F\ (1.84, 97.5) = 2.55$, $p < 0.001$, partial $\eta^2 = 0.14$. Post hoc pairwise comparisons with a Bonferroni adjustment indicated that there was no difference between the thematic interest at pretest and follow-up, ($p = 0.169$) and that thematic interest was significantly lower at pretest than at post-test ($p < 0.05$), and significantly higher at post-test than at the follow-up ($p < 0.001$). These results on thematic interest seem unsatisfactory, given that the increased interest returned to its initial level two months later. Given the present data, it is hard to speculate on reasons for this finding, since we cannot distinguish effects of the learning module from possible effects of chemistry classes at school.

Changes in *emotions* regarding the learning module are shown in Figure 6. The results indicate that joy increased significantly ($t(64) = -3.48$, $p < 0.001$), while the negative emotions of frustration ($t(64) = 3.59$, $p < 0.001$) and boredom ($t(64) = 3$, $p = 0.002$) were significantly decreased. Finally, also curiosity ($t(64) = 4.61$, $p < 0.001$) decreased, which may be due to the high informational content of the learning module. Perhaps also the duration of the learning module may have caused the students to lose curiosity over time. Nevertheless, these are positive results for the learning module.

The results of the *formative evaluation of the learning module* are shown in Figure 7. Students rated the learning module ($M = 4.19$), the differentiation grid ($M = 4.18$), and the use of iPads ($M = 4.49$) to be good or very good. Complexity ($M = 3.18$) and duration ($M = 3.29$) were very close to the hoped-for rating (3 = "just right"). This therefore shows a very positive response from the participants regarding the learning module.

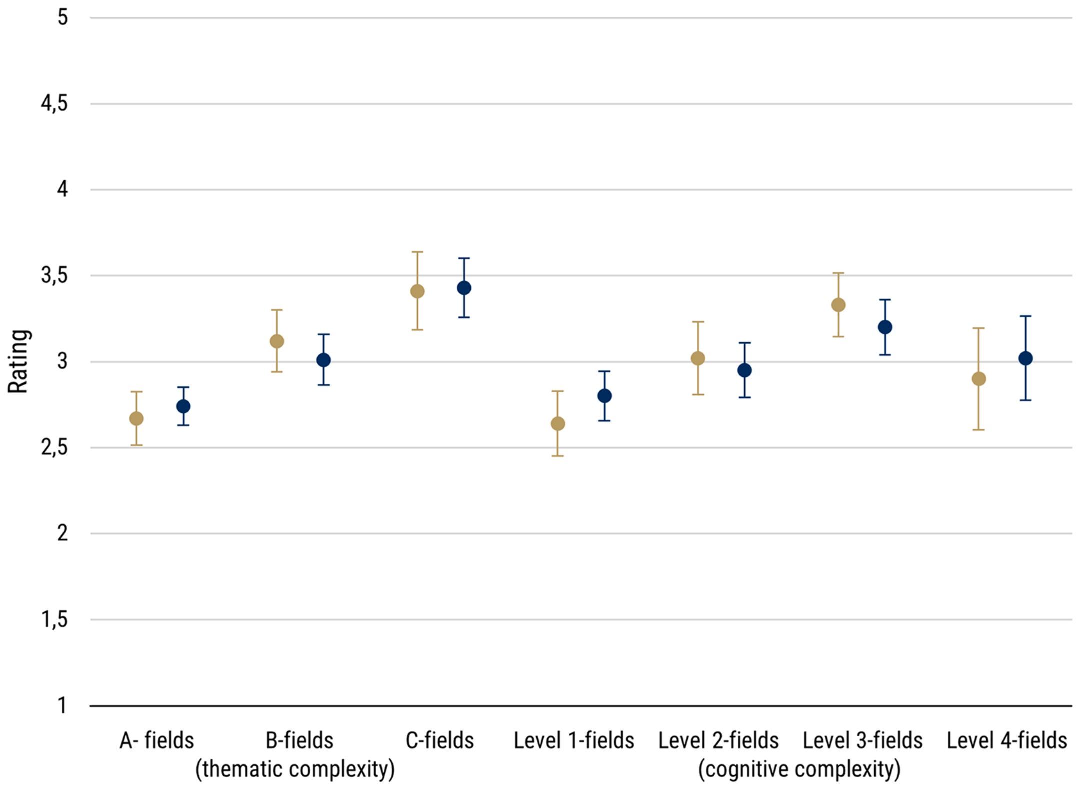

Figure 8. Perceived effort (gold) and difficulty (blue) of each type of field organized by increasing thematic (A→ C) and cognitive (Level 1 → Level 4) complexity.

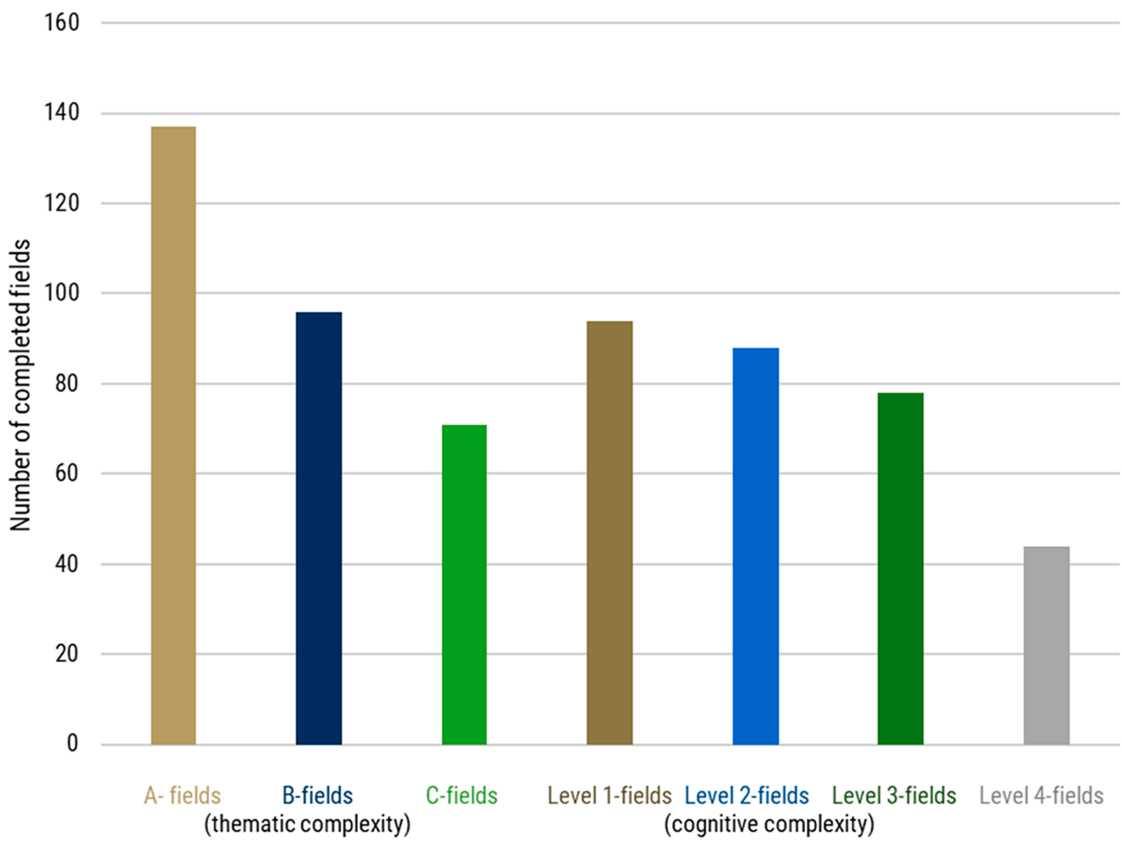

Figure 9. Number of completed fields organized by increasing thematic (A→ C) and cognitive (Level 1 → Level 4) complexity.

88% of the participants answered the open-ended question "What did you like best about the learning module?", most responding with "working with digital media" (39%) and "conducting experiments" (26%). Only 33% answered the

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question "What can be improved about the learning module?", with "technical aspects" (19%) and "content aspects" (12%) being the first options. Overall, the qualitative student data align with the conclusions from students' quantitative ratings, indicating the relevance of using digital media for the positive response to the learning module. This may be caused though by a novelty effect[42] or by the contrast to everyday school lessons where digital media and student led experiments may be used less frequently.

When the difficulty and effort levels (see Figure 8) of different tasks were compared, it became apparent that the students perceived the (thematically) most complex tasks also as the most complex ones. The same applied for the perceived effort. The supposedly cognitively most complex level-4 fields did, however, not follow this tendency. Their difficulty was rated similar to that of the level-2 fields, speaking against the quality of the level-4 fields. Selectivity effects, however, are also possible if we presume that mostly high achieving students chose to complete these fields: These students may have found the tasks to be less complex because of their already high knowledge level. Nevertheless, the overall tendencies are a good indicator that the perceived and intended levels of difficulty do match. The results thus generally confirm that students understood the structure of the learning module.

When looking at the *usage of the learning module*, we found that the number of completed fields decreased with increasing thematic and cognitive complexity (see Figure 9). On the one hand, this shows that the students tended to choose easier tasks when they had the opportunity to do so. On the other hand, it generally shows that the different difficulties of the fields, made visible to the students, had an influence on their task selection behavior. However, temporal (preference for short fields) and spatial conditions (choosing fields that are free) may also have played a role. It might make sense, though, to add incentives to the learning module for choosing more difficult fields. This way students might challenge themselves more, which, in turn, could have positive effects on learning and motivation. Most of the students were able to complete four to five fields (4.8 fields completed on average), so just slightly more than required of them. Students were asked to continue choosing and conducting fields even if they reached the required minimum. However, knowing that it takes "only" four fields for completion could have led the students to take more time than needed in each field. Despite this possibility, when looking at the intended duration of the fields, an average of five fields seems reasonable.

An overview of the test results and additional information about the study can be derived from the Supporting Information.

5. LIMITATIONS AND IMPLICATIONS OF THE RESULTS

From the available data, we initially conclude that the digital and complexity-differentiated learning module "household cleaners" represents a successful learning offer in several respects. First of all, results from our summative assessment concerning knowledge gain and changes in emotions are promising. The retention of knowledge and interest, which vary depending on the design of the student lab courses,[43,44] can be further improved. Investigating subject interest and students' ability self-concept in chemistry could provide further insight into the possible impact of using digital and complexity-differentiated learning modules. Beyond the emotions investigated so far, examining motivation constructs such as expectation of success and perceived usefulness seems fruitful based on Eccles expectancy-value theory.[45] Since the results for the thematic interest and the decrease in curiosity did not meet our expectations, further research is necessary. Evaluating the same concept with further offers of the same kind might also add further confirmation to the yielded results.

The formative evaluation of the module indicates that the use of digital media, especially the usage of iPads, is well received, and that the method of the differentiation grid is also accepted. It would be interesting to see to what extent results differ if the medium (iPads/eBooks) or method (differentiation grid) were changed. In addition, the complexity and duration of the learning module were rated close to the intended margins. Both aspects can be further adjusted, though, if necessary. When looking at the usage of the module, the matching of perceived and intended levels of effort and difficulty speaks to the quality of the complexity-differentiation. The fields of the highest cognitive complexity overall did not fit to these tendencies and could therefore be adapted or deleted. There also is a clear tendency for choosing easier tasks. The requirements for conducting the module could thus be adjusted, e.g., by requiring the students to complete a task of each thematic or cognitive complexity. Introducing obligatory fields might also help prevent the choice of too easy tasks even in higher achieving students.

There are some limitations to this pilot study.

(1) Limitations of the study design: Without a proper control or comparison group the results can only be seen as provisional. Moreover, the module was only tested with a small sample of upper-track German high schools ("Gymnasium").

(2) Limitations of the knowledge test: The knowledge test of acid–base chemistry already reached maxima for some students in the pretest, therefore their possibly positive development could not be measured. The scale needs to be adapted and more (difficult) items need to be included. The open items in the knowledge test in household cleaners proved difficult to be evaluated. A closed scale with defined maximum answers should prove to be more reliable.

(3) Limitations to the emotion items: For the comparison of emotions in pre- and post-test different items were used, one focusing on the emotional expectations toward the contents of the learning module (pretest), the other on the experienced emotions toward the conduction of the learning module (post-test). While also adding more items to determine reliability of the measure, this needs to be adjusted to improve the validity of the results.

(4) Sensitivity analysis might be required to check for influences of the different classes, gender or school grades on the results.

Further research is necessary to determine if digital and complexity-differentiated learning modules are a valuable method for science teaching in school student laboratories. This might show which part is important to which extent: the medium (iPads/eBooks), the method (differentiation grid), or both. Especially in the selection of fields, further questions arise: Which strategies do the students use to select their fields? Are there recurring learning paths in the selection of fields? Are there differences in the selection in subgroups, e.g., between students with better or worse grades in chemistry, and does the choice of fields influence the knowledge gain? What other influences on

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learning can be identified (e.g., subject interest, ability to self-concept of chemistry, prior knowledge, etc.)?

6. CONCLUSIONS AND OUTLOOK

The results of the pilot study show that digital and complexity-differentiated learning modules can be a viable alternative to the prominent classical student laboratory setting. Summative (knowledge gain, interest, emotions) as well as formative assessment (evaluation of individual aspects) yielded positive results, especially indicating advantages to using digital media. Moreover, the study underlined the quality of the exemplary learning module "household cleaners" concerning its overall complexity and duration but also its suitable positioning of the fields in the differentiation grid, thereby laying the groundwork for further learning modules to come. The usage of the learning module opens new questions about the students' decision process and individual or recurring learning paths that could help transform the difficulty and complexity-differentiated learning toward an adaptive learning environment.

In May and June 2023, a main study was conducted to answer, among other things, the outlined further questions from the conclusions and to substantiate the results of the pilot study. Thirteen classes with a total of 290 students were surveyed, who carried out the learning module "household cleaners" in the student laboratory. The research questions remained largely the same, with an additional focus on the students' choice of fields. Two-thirds of the groups conducted the digitally differentiated learning module as described above. The other third carried out a digital learning module without a differentiation grid; instead, the same fields were worked on as stations within the framework of station learning according to the classical student laboratory setting.

The results of both groups will be compared to see if the method of the differentiation grid really makes a difference when it comes to students' decisions and results of the learning module. By providing a broader database, the potential of this method for the student laboratory can be investigated and thus provide evidence for its use in regular chemistry classes. In order to investigate the effect of the medium, i.e., compared to an analogue differentiation grid or station learning setting, another study is planned for the summer of 2024. The digital and complexity-differentiated learning module "household cleaners" is available in German on our Web site (https://www.chemgeo.uni-jena.de/chemiedidaktik) under the Downloads tab. In addition, a second digital and complexity-differentiated learning module on the topic of "nanomedicine" has already been developed and is currently in the trial phase with teachers and students.[46]

In parallel, the platform *digitalchemlab* will also be further developed to progress digital media integration in all areas of chemistry education. First trainings for practicing teachers have already been developed and conducted, introducing them, for example, to the usage of iPads and presenting our tested digital and complexity-differentiated learning modules. First responses of the teachers were very positive, showing the increasing need for trainings in the usage of digital media and their applications for chemistry lessons. Since establishing equipment for a modern classroom (iPads, Smartboards, 3D-Printer) digital media have also become a bigger and more integral part of teaching at our university. Further projects are being planned combining aspects of different science education subjects to improve low-cost digital measurement systems. In doing so, we hope to set an example transferable to many working groups in the field of science education on how digital media can improve all aspects of their work and further enrich the studies of future and present teachers and hopefully thereby everyday school lessons.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01228.

Study Data and Remarks (PDF)

Impressions of the Digital Learning Module (PDF)

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Notes

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