

## Article

# Digital Sequential Scaffolding during Experimentation in Chemistry Education—Scrutinizing Influences and Effects on Learning

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**Abstract:** Sequential scaffolding during experimentation can support students in acquiring knowledge and experimentation skills. This study aims to explore students' understanding and perception of digital sequential scaffolds in chemistry education, investigate predictors of this understanding and perception, and examine the effects on learning outcomes and processes. A total of 183 secondary school students conducted hands-on experiments on redox reactions using digital sequential scaffolds. This study collects data through questionnaires and analyzes prior knowledge, self-perceived experimentation competence, chemistry-related self-concept, and interest as predictors. This research also examines the influence of students' understanding and perception on cognitive and motivational learning outcomes. The findings show that learners experienced digital sequential scaffolds as helpful and were motivated by them to conduct hands-on experiments. Results also reveal that only students' prior experience with sequential scaffolds and prior self-perceived experimentation competence significantly predict their understanding of the concept and usage of the digital sequential scaffolds. Regarding motivation, outcomes show that perceived benefit and motivation regarding experimentation predict the motivational outcomes. Overall, our findings contribute to understanding sequential scaffolding in chemistry education and inform instructional design practices.

**Keywords:** digital sequential scaffolding; chemistry education; learning support



**Citation:** Fleischer, T.; Moser, S.; Deibl, I.; Strahl, A.; Maier, S.; Zumbach, J. Digital Sequential Scaffolding during Experimentation in Chemistry Education—Scrutinizing Influences and Effects on Learning. *Educ. Sci.* **2023**, *13*, 811. <https://doi.org/10.3390/educsci13080811>

Academic Editors: Shirly Avargil, Jenna Koenen and Maggie Gregson

Received: 15 June 2023

Revised: 2 August 2023

Accepted: 4 August 2023

Published: 7 August 2023



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## 1. Introduction

Scientific problem-solving activities such as student hands-on experiments in chemistry learning provide learners with authentic and motivating learning experiences. These approaches aim, among other things, at imparting conceptual knowledge and improving scientific research skills. However, learning success is not guaranteed when conducting experiments, especially for inexperienced learners who can quickly become overstrained by the demands of the inquiry-based experimentation process [1,2]. Guided inquiry learning can be helpful in this regard [3]. Guidance during inquiry learning significantly and positively affects inquiry learning activities, performance success, and learning outcomes [3]. One beneficial support strategy is the provision of individually retrievable sequential scaffolds that incrementally provide consecutive hints up to the complete solution on learner demand and mediate between guidance [4–7]. Sequential scaffolds can be analog or digital. Affeldt et al. [4] worked with sequential scaffolds in the form of analog cue cards (text and graphic combination), which are intended to assist students, for example, in conducting experiments (solubility of solids in water). The first scaffold shows the required materials

and chemicals, the second scaffold shows the steps for conducting the experiment in the wrong order, and the third scaffold shows the steps for conducting the experiment correctly. Digital sequential scaffolds, as in this paper (see Section 2, Table 1), are based on digital content such as augmented reality, images, and videos, which can be accessed via QR codes using a digital device (e.g., tablet). For example, in our study, the first digital scaffold for the conduction (electrolysis of water) is an image showing the correct initial position of the three-way valve. The second scaffold is a short video showing correctly drawing the water to the zero mark. The third scaffold is a picture showing how to properly connect the metal spikes to the battery (all other digital sequential scaffolds are described in Section 2). By sequential scaffolds, we here refer to hints, in the manner of worked examples, in different stages ranging from the first primary (partial) hints to worked examples providing the complete solution (max. three hints). Results of Instructional Design Research show, e.g., that learning from worked examples requires less effort for novice learners [8,9]. Further, digital media have proven to be an appropriate means for presenting worked examples (e.g., as text or video) tailored to the task at hand and the needs of the learners [10]. However, we assume there is a lack of information about the learners' understanding of the concept of digital sequential scaffolds and learners' related perceptions.

**Table 1.** Digital sequential scaffolds of the experiments.

Experiment	Scaffolds Set-Up	Scaffolds Conduction	Scaffolds Observation
Electrolysis of a zinc iodide solution	(1) Partial set-up of the experiment as an augmented reality 3D model.	(1) Short video showing how to apply zinc iodide solution to an object carrier.	(1) Image showing the two reaction products
	(2) Complete set-up of the experiment as an augmented reality 3D model.		
Electrolysis of water	(1) Partial set-up of the experiment as an augmented reality 3D model.	(1) Image showing the correct initial position of the three-way valve	(1) Image showing the gases at 1 and 2 mL
	(2) Complete set-up of the experiment as an augmented reality 3D model.	(2) Short video showing how to correctly draw the water to the zero mark (3) Image showing how to connect the metal spikes to the battery	(2) Image showing the gases at 2 and 4 mL

The effect of learners' understanding and perception of digital sequential scaffolds has not been adequately investigated. First, it remains unclear to what extent students understand the underlying rationale of the concept of digital sequential scaffolds and what they think about using digital sequential scaffolds. Second, what factors influence learners' understanding and perception of digital sequential scaffolds seems interesting. To determine all of those open questions, it seems necessary to analyze learners' understanding and perception of the digital sequential scaffolds, as well as, on the one hand, to explore possible predictors of students' understanding and perception of digital sequential scaffolds and, on the other hand, to scrutinize the effects of students' understanding and perception about digital sequential scaffolds on learning outcomes and processes.

This pre-post intervention study aims to thoroughly examine learners' self-reported understanding and perception of digital sequential scaffolds during experimentation in school-based chemistry learning. A total of 183 secondary-school students self-directedly conducted hands-on experiments on redox reactions. The students were provided with digital sequential scaffolds in an adapted manner of worked examples that could be individually retrieved via tablets (see Section 2). They incrementally supported the set-

up, conduction, and observation of the experiments with videos, images, or augmented reality content.

### *1.1. Sequential Scaffolding during Experimentation*

Research, particularly on cognitive load, has shown that knowledge is not acquired efficiently when students are asked to solve practice problems [8]. Since experiments within inquiry-based learning frameworks can quickly overstrain learners, students can and should be supported during learning [2,11]. Providing sequential scaffolding (also called guided aids or incremental scaffolds) can be a supportive strategy here [4,5]. Consistent with Vygotsky's [12] notion of the zone of proximal development, inexperienced students particularly benefit from studying examples of fully and/or partially worked-out solution procedures and then solving conventional practice problems independently. Related research confirms that learning from worked examples is less demanding for novice learners [8,9,13].

Großmann and Wilde [14] investigated the effects of incremental scaffolding on students' knowledge acquisition during inquiry-based experimentation. They compared the effects of incremental scaffolding (successively provided hints up to the sample solution) to worked-out examples (fully worked out example as a guide). They revealed that sequential scaffolds (incremental scaffolds) were more effective for knowledge acquisition for learners with lower prior knowledge than studying worked examples. Sequential scaffolds, described in the current paper, refer to hints that are worked examples at different levels, ranging from first basic (partial) hints to fully worked-out examples. For example, we created two digital sequential scaffolds that display an augmented reality 3D model of the experimental set-up of the electrolysis of a zinc iodide solution (described in more detail in Section 2). The first scaffold shows a partial set-up of the experiment so that the students can finish the set-up on their own with this scaffold (first basic (partial) hint). The second scaffold shows the complete set-up of the experiment so that all students can set up the experiment successfully and continue with the conduction of the experiment (worked-out example as sample solution). It has already been demonstrated (e.g., [4,6]) that such sequential scaffolding strategies have positive effects. The provision of sample solutions (fully worked-out examples) is intended to enable the complete processing of tasks; in the present case, two hands-on experiments on redox reactions and, in particular, the experiment phases set-up, conduction, and observation. It is important to note that the sequential scaffolds nevertheless trigger thinking impulses and are thus not a mere reception of the sample solution. Therefore, the hints enable step-by-step independent processing of the mentioned experimental phases and should therefore ensure that all students can produce and compare partial solutions independently [15–17]. Such hints can be used to allow students to progress in their experiments, if necessary, but also as validation after an experiment or its setup has been completed. How many scaffolds are provided and how learners use them needs to be considered. The difficulty of the task usually determines the amount of help offered. Therefore, to a certain extent, the task's difficulty level can be determined independently by the learners and adapted to their level of performance [9,18].

Positive effects on engagement and self-regulation with regard to learning with sequential scaffolding have already been described [18]. Studies regarding learning success in processing scientific problems in chemistry lessons also showed positive effects using sequential scaffolds [17]. Mustafa et al. [19] found, in their quasi-experimental study of sequential scaffolds during experimentation in lower secondary school chemistry classes, that students who used sequential scaffolds outperformed those without sequential scaffolds in terms of conceptual knowledge acquisition. This was verified using a pre-post comparison of learner-generated concept maps. Authors conclude that sequential scaffolds are a suitable method to support students where this support is needed [19]. Other results were found for biology classes in lower secondary schools [20]. The effect of sequential scaffolds in experimentation on procedural and conceptual knowledge growth was investigated in a

control group comparison. It was found that procedural knowledge increased significantly in the group using sequential scaffolds. However, there was no significant increase in conceptual knowledge. Prior procedural and conceptual knowledge of the students was identified as a predictor of knowledge gain. In addition, the treatment did not significantly interact with prior knowledge, leading the authors to conclude that students benefit from the sequential scaffolds regardless of previous knowledge [20]. In upper secondary school biology classes, sequential scaffolding was effective in promoting scientific reasoning. In contrast, no benefit of sequential scaffolds related to method and subject knowledge to the sub-processes of experimentation was found. However, the cognitive load of students could be lowered [21]. Kleinert et al. [22] investigated the use of sequential scaffolds in the evaluation of experiments in biology and mathematics classes (secondary school) with regard to students' perceived competence and intrinsic motivation. Perceived competence was significantly increased among students working with sequential scaffolds. Positive tendencies were also found for intrinsic motivation during experimentation, but not in mathematics classes [22]. In Schmidt-Borcheding et al.'s [23] study, grade eight students solved a physics laboratory task in dyads. The authors also reported evidence for positive motivational effects in favor of incremental scaffolds over an explicit worked examples laboratory guide through the steps of the solution.

As just described, studies on the use and benefits of sequential scaffolds are still quite heterogeneous regarding the research designs used and the variables examined. Therefore, further research is needed, especially for chemistry education. Thus, this study aims to contribute to the research field of sequential scaffolding in experimentation in chemistry education by analyzing the understanding and perception of digital sequential scaffolds by learners in lower secondary chemistry classes.

### 1.2. Research Questions

This study presents a learning environment for school-based chemistry education called "EXBOX-Digital" that offers hands-on experiments and additional support using digital sequential scaffolds. The overarching research aim of this study is to explore learners' understanding and perception of the digital sequential scaffolds presented during digitally supported hands-on experiments in chemistry education. Since the scaffolds support the different steps of haptic experimentation (set-up/conduction/observation), the scaffolds aim to support the students in the process of haptic experimentation. Given the relatively low number of studies that investigated learners' understanding and perception of digital sequential scaffolds in detail, this study set out (1) to explore possible predictors of students' understanding and perception of digital sequential scaffolds and (2) to scrutinize the effects of students' understanding and perception of digital sequential scaffolds on learning outcomes and processes. The research objectives guiding this study are as follows:

First, we want to obtain insights into students' understanding and perception of digital sequential scaffolds. Therefore, we conducted an exploratory factor analysis to clarify the underlying structure of the adapted questionnaire (according to Affeldt et al. [4]) about the understanding and perception of digital sequential scaffolds. The factors obtained in this way (factors 1, 2, and 3) are the basis for further analyses.

The next step is to investigate possible predictors of students' understanding of the concept and usage of digital sequential scaffolds (factor 1), the perceived benefit of the scaffolds (factor 2), and learners' motivation regarding the experiment (factor 3). Predictors include cognitive variables (prior knowledge, self-perceived experimentation competence, and chemistry-related self-concept) and interest as motivational prerequisite. Prior experience with sequential scaffolds in experimentation is included as a control variable: It is important to consider possible control variables. Otherwise, the results may be biased. Assuming that the influence of the control variables is significant but not considered, it could be the case that the influence of the predictors on the criteria would be distorted.

Taken together, our first research question (RQ1) is: To what extent do prior knowledge, self-perceived experimentation competence, and chemistry-related self-concept as well as chemistry-related interest influence students' understanding of the concept and usage of digital sequential scaffolds (factor 1), perceived benefit of the scaffolds (factor 2), and learners' motivation regarding the experiment (factor 3)?

In a further step, we investigate how students' understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds, and learners' motivation regarding the experiment (factors 1, 2, and 3) in turn influence cognitive learning outcomes (post knowledge, self-perceived experimentation competence after the experiment) and motivational learning outcomes (situational interest (catch/hold) after the experiments, perception of fulfillment of basic needs).

Thus, our second research question (RQ2) is:

To what extent does students' understanding of the concept and usage of digital sequential scaffolds, their perceived benefit, and learners' motivation regarding the experiment (factors 1, 2, and 3) influence cognitive and motivational learning outcomes? To answer this question, we have used the instruments from the post-test (post knowledge, self-perceived experimentation competence after the experiments, situational interest after the experiments, and perception of the fulfillment of basic needs).

## 2. Materials and Methods

In the current study, learners learned about redox reactions using the "EXBOX-Digital"-approach. In the first step of the intervention, the students worked with an interactive, adaptive online learning program (browser-based on a tablet, individual work), which provided them with basic knowledge about redox reactions. The learning program contains both spoken and written texts, pictures, and animations, as well as short videos, exercises, and sample solutions with explanatory information, which comprehensively convey the basic content of redox reactions. At the beginning, the students' knowledge about this domain is determined based on knowledge tasks. To this end, they were initially asked five knowledge questions in single-choice format, for example, on the different definitions of oxidation as a reaction with oxygen or an electron release. Based on this, only the content that the students were initially unable to solve correctly is presented. If knowledge questions were answered correctly, it was assumed that the content is already understood, and therefore the corresponding learning module was not offered additionally. This adaptive design of the learning program allows the students to deal with the learning content at their own learning pace and according to their individual knowledge. After completing the learning program, all students should have had a basic knowledge of redox reactions.

Following the instructions of the learning environment (second step of the intervention), students conducted two hands-on experiments on redox reactions (electrolysis of a zinc iodide solution and electrolysis of water). Each student had their own experiment box in which they could find all the necessary materials and chemicals. In these experiments, the content learned in the learning program could be applied directly to the experimental situation. Here, the chemical reactions and phenomena can be observed and experienced independently. The learning goal of the experiments was to show that the chemical reactions in the experiments were redox reactions. Students should have recognized that oxidation and reduction (partial reactions) take place simultaneously. In relation to electrons, they should have recognized that the electrons are donated during oxidation and accepted during reduction. The students received a worksheet with a short work assignment for the experiments and the digital sequential scaffolds. The idea here is not to work off given "recipes" but to encourage self-directed experimentation in the spirit of inquiry-based learning. To support the experimentation process, the worksheet contains triggers for digital sequential scaffolds (QR codes, AR Trigger) that learners can access independently using a tablet, depending on their needs. The sequential scaffolds were assigned to the typical phases of (haptic) experimentation: set-up, conduction, and observation. They allow for step-by-step independent processing of the mentioned experimental phases and

should have thus ensured that all students were able to produce and compare (partial) solutions independently; in this case, this is to allow students to progress in their experiments independently, but also for independent control (possible by the respective last sequential scaffold) after the set-up, the conduction, and the observation. The difficulty of the task/experiment usually determines the amount of help provided.

Electrolysis of a zinc iodide solution: Two pencil leads must be connected to an object carrier with adhesive tape and to a battery with two cables. The zinc iodide solution should be dripped onto the object carrier (3 drops) so that it is in contact with both pencil leads. After a short time, the resulting iodine and zinc can be observed.

Here, the work assignment is “Make zinc and iodine using the battery”. We designed the number of scaffolds according to the difficulty of the experiment. Since the electrolysis of a zinc iodide solution is a simple experiment, there were two scaffolds for the set-up, one for the conduction and one for the observation (see Table 1). For the set-up of this experiment, the students had two sequential scaffolds that displayed an augmented reality 3D model of the experimental set-up. The first scaffold showed a partial set-up of the experiment so that the students could finish the setup on their own with this scaffold. The second scaffold shows the complete set-up of the experiment so that all students could set up the experiment successfully and continue with the conduction of the experiment. The scaffold for the conduction was a short video showing how to apply the zinc iodide solution to the object carrier so that it is in contact with both electrodes. The scaffold for the observation was an image showing the two reaction products (see Table 1). The students thus had the opportunity to check whether they were able to complete the experiment successfully or if they needed clarification on this.

Electrolysis of water: Here, two 10-milliliter syringes (syringes without needles), which were open at the bottom and to which a metal spike (electrode) and a three-way valve were attached, must be fixed in a small box (clicked in) so that the three-way valve is at the top. After the water (washing soda as electrolyte) had been filled into the box, it must be drawn up to the zero mark with another syringe (without needle). However, this only works if the three-way valve was in the correct position. The three-way valve must then be adjusted again so that the liquid remains in the syringe at zero and does not flow back into the box. The metal spikes were connected to a 9 V block battery with the cables. After a short time, hydrogen and oxygen are produced in a ratio of 2:1.

The work assignment is “Produce hydrogen and oxygen using the battery”. There was also a tip to fill the water into the box and fill up to the zero mark (not how the fill-up works). We designed the number of scaffolds according to the difficulty of the experiment. Since the electrolysis of a zinc iodide solution is a moderately difficult experiment, there were two scaffolds for the set-up, three for the conduction, and two for the observation (see Table 1). Again, the students had two sequential scaffolds which displayed an augmented reality 3D model of the experimental set-up. The first scaffold showed a partial set-up of the experiment so that the students could finish the set-up on their own with this scaffold. The second scaffold showed the complete set-up of the experiment, so that all students could set up the experiment successfully and continue with the conduction of the experiment. The first scaffold for the conduction was an image showing the correct initial position of the three-way valve. The second scaffold was a short video showing how to correctly draw the water to the zero mark. The third scaffold was a picture showing how to connect the metal spikes to the battery properly. The first scaffold for the observation was an image showing the gases at 1 and 2 mL. The second scaffold was an image that shows the gases at 2 and 4 mL (see Table 1). The students thus had the opportunity to check whether they were able to complete the experiment successfully, if they were not sure about this.

In general, these sequential scaffolds were intended to ensure that each student can successfully complete at least one experiment. The students could thus proceed at their own learning pace and individual competence when experimenting.

### 2.1. Sample

A total of 183 students (8th grade) from three Austrian secondary schools participated in this study. The study took place within the framework of a cooperative project with the participating schools. Students had little prior knowledge (up to two lessons) of redox reactions. After completing the learning program, which was part of the intervention (see Section 2), all students should have had a basic knowledge of redox reactions (oxidation/reduction as oxygen uptake or release, oxidation/reduction always take place together, oxidation/reduction as electron release or uptake). Participation was voluntary and anonymous, i.e., all data were collected and analyzed anonymously from winter 2020 to summer 2022. Students could withdraw from the study at any time without negative consequences. All study participants were informed about the scientific purpose of the study. Due to missing data, 141 participants were included in the following analyses. Of those participants, 56 were female, 69 were male, and four were non-binary persons (12 values were missing). Participants had a mean age of  $M = 13.66$  years ( $SD = 0.55$ ).

### 2.2. Data Collection

The data collection took place in the chemistry rooms of the respective schools in the framework of a double lesson. The pre-test was already carried out two weeks earlier, and the post-test was at the end of the double lesson. The procedure of the study and the functionality of the self-developed app for scanning the sequential scaffolds were described at the beginning. It was explained that all sequential scaffolds (hints) could be used independently in case help was needed. On the part of the schools, there was a time limit of 100 min (double lesson) for the whole session. We set no time limit to finish the experiments. All participants completed at least one of the two experiments within the double lesson.

### 2.3. Measures

In the pretest questionnaire, students answered questions related to their prior knowledge regarding redox reactions, self-perceived experimentation competence, chemistry-related self-concept, and chemistry-related interest. In the post-test, we asked students about their understanding and perception of digital sequential scaffolds, conceptual knowledge acquisition, self-perceived experimental competence after the intervention, situational interest (catch/hold), and satisfaction of basic needs (autonomy/competence).

Students' understanding and perception of digital sequential scaffolds: To analyze students' understanding and perception of digital sequential scaffolds, we adapted the sequential scaffold questionnaire (19 items, e.g., "I think it's good that you should first take one sequential scaffold and then the next one"; four-point Likert-scale "1 = strongly disagree" to "4 = strongly agree") of Affeldt et al. [4] and analyzed its structure using exploratory factor analysis. Both Bartlett's test ( $\text{Chi-Square}(171) = 709.82, p < 0.001$ ) and Kaiser–Meyer–Olkin Measure of Sampling Adequacy ( $KMO = 0.79$ ) indicate that the variables are suitable for factor analysis ( $n = 141$ ). A principal component analysis with varimax rotation indicates the presence of six factors, explaining 64.5% of the variance. Subsequent reliability analyses show adequate reliability for three factors: "learners' understanding of the concept and usage of digital sequential scaffolding" ( $\alpha = 0.77$ ; six items), "learners' perceived benefit of digital sequential scaffolding" ( $\alpha = 0.80$ ; five items), and "learners' motivation regarding experimentation" ( $\alpha = 0.62$ ; three items). The first factor, "learners' understanding of the concept and usage of digital sequential scaffolding", relates to learners' understanding of the chances that sequential scaffolds provide for individually conducting hands-on experiments without a prescribed procedure. The second factor, "learners' perceived benefit of digital sequential scaffolding," covers learners' perception regarding the possible advantages of using sequential scaffolds for autonomous experimentation. The third factor, "learners' motivation in relation to experimentation", addresses learners' motivation resulting from using scaffolds to conduct hands-on experiments. A more detailed explanation and further insight into the items of these three factors provided

in the Section 3, where three sample items of each factor are evaluated descriptively (see Table 2). The remaining three factors showed reliability values below  $\alpha = 0.50$  and were therefore not included in the following analyses.

**Table 2.** Descriptive analysis of sample items for the three factors.

Factor	Factor Loadings	Item	M	SD
(1)		Learners' understanding of the concept and usage of digital sequential scaffolding		
	0.71	(1) I think it's good that you should first take one sequential scaffold and then the next one	3.32	0.88
	0.69	(2) I find it easy to use the sequential scaffolds	3.39	0.85
	0.68	(3) I like that the first sequential scaffold is not immediately the complete solution	3.36	0.88
(2)		Learners' perceived benefit of digital sequential scaffolding		
	0.77	(4) I was able to conduct the experiment better because of the sequential scaffolds	3.38	0.89
	0.72	(5) I could observe the experiment better because of the sequential scaffolds	2.99	0.96
	0.57	(6) I was able to set up the experiment better because of the sequential scaffolds	3.26	0.98
(3)		Learners' motivation regarding experimentation		
	0.77	(7) The sequential scaffolds have made me even more curious about the experiment	2.73	0.96
	0.71	(8) I had more desire to understand the background of the experiment because of the sequential scaffolds	2.78	0.91
	0.68	(9) The sequential scaffolds have motivated me to carry out the whole experiment without using sequential scaffolds	2.80	0.91

Sorted by factors and factor loadings. (Four-point Likert-scale "1 = strongly disagree" to "4 = strongly agree").

**Knowledge regarding redox reactions:** Before and after the intervention, we assessed expertise in redox reactions using a self-developed knowledge test consisting of 15 closed (single choice or multiple choice) items (e.g., "An oxidation is a chemical reaction . . ."). The items were rated as correct or incorrect. The knowledge items were matched to the learning program's content and the experiments.

**Self-perceived experimentation competence:** Instructional scaffolds like sequential scaffolding can support the students' perception of competence [22]. Perceived competence, similar to perceived self-efficacy, refers to beliefs in one's competence to act in a specific way. In this study, the self-perceived experimentation competence of the students in chemistry was surveyed in the pre-test (prior self-perceived experimentation competence) and the post-test (self-perceived experimentation competence post). For this purpose, a scale with 15 items ( $\alpha = 0.88$ ) was developed based on Busker et al. [24] and Meinhardt et al. [25], assessing students' self-perceived competence in setting up, conducting, and observation of experiments before and after the intervention (e.g., "I have manual skills to set up experiments independently"). All items could be answered on a five-point Likert-scale ("1 = strongly disagree" to "5 = strongly agree"). A mean value was calculated across all domains, once for pre- and once for post-test scores.

**Chemistry-related self-concept:** In general, self-concept encompasses the totality of cognitive representations of one's abilities and relates to a mental model, which contains ideas, estimations, abilities, and evaluations of oneself [26]. Before the intervention, students' subject-specific ability self-concept regarding academic performance in the field of chemistry was assessed using the scales for measuring the school self-concept from Schöne et al. [26] (4 items;  $\alpha = 0.89$ ; e.g., "I am talented in chemistry"; a five-point Likert scale was used to agree).

**Interest in chemistry education:** We measured learners' overall interest in learning during chemistry education in the pre-test via an adapted version of the interest subscale from Rheinberg et al.'s [27] questionnaire of current motivation to learn (5 items; e.g., "The

tasks in chemistry education seem very interesting to me.”;  $\alpha = 0.78$ ). Each item could be answered on a seven-point Likert-scale (“1 = disagree” to “7 = agree”).

**Situational interest:** In contrast to an enduring interest in a topic, situational interest describes an interest that arises in a current learning situation and is based primarily on the situational characteristics of the learning environment, the individually perceived interestingness of the content, and the emotional experience during engagement with that content [28]. We assessed learners’ situational interest in learning with the “EXBOX-Digital” in the posttest with an adapted version of the twelve-item scale by Knogler et al. [28]). The scale consists of two subscales: the situational interest catch scale, which refers to the initial occurrence of situational interest, where a person’s attention is drawn to a particular topic for the first time, and their curiosity about that content or subject area is aroused, and a positive emotional experience is generated (6 items; e.g., “I found the learning with the “EXBOX-Digital” exciting”;  $\alpha = 0.91$ ) and the situational interest hold scale, that characterizes a stabilized, relatively durable, content-related motivational quality during a learning situation (6 items; e.g., “I would like to learn more about parts of the “EXBOX-Digital””;  $\alpha = 0.86$ ). Participants could indicate their answers on a five-point Likert scale ranging from 1 = completely disagree to 5 = agree entirely.

**Perceived competence and autonomy support:** Satisfying basic needs is essential for self-determined learning, and promotes intrinsic motivation and well-being [29]. In the post-test, the fulfillment of learners’ basic needs was assessed in the sense of learners’ perception of motivation-supportive teaching features of the “EXBOX-Digital” utilizing adapted scales from Rakoczy et al. [30]. We used two subscales: Perceived autonomy support (five items; e.g., “During the “EXBOX-Digital” lessons, I had the opportunity to explore new topics”;  $\alpha = 0.76$ ). and perceived competence support (four items; e.g., “In the lessons with the “EXBOX-Digital” I was told, how I could improve.”;  $\alpha = 0.59$ ).

**Prior experience with sequential scaffolds in experimentation:** As a possible influencing factor, we assessed via one question if students had already conducted an experiment with sequential scaffolds in chemistry education. Students could answer with “yes” or “no”.

### 3. Results

#### 3.1. Factor Analysis-Descriptives

Table 2 shows the descriptive analysis of three sample items for each factor. The items are ordered by factors and factor loadings. Mean values ( $M$ ) and standard deviations ( $SD$ ) of the items are shown (see Table 2).

For the items of the first factor, learners’ understanding of the concept and usage of digital sequential scaffolding, the reported mean values are over  $M = 3.00$  (on a 4-point Likert scale), corresponding to a relatively high, positive level of agreement (see Table 2). Specifically, for item (1), the values show that the students appreciate the principle of sequential scaffolding while experimenting, as 84.9% of the students tend to agree/strongly agree (53.2% strongly agree) that it is good to use the first sequential scaffold and then the next one (only 6.5% strongly disagreed). The results for item (2) are similar; 84.4% of the students tend to agree/strongly agree (58.9% strongly agree) that it was easy to use the sequential scaffolds (only 4.3% strongly disagreed). Item (3) asked whether students like that the first scaffold does not directly show the complete solution. Here, 84.3% of the students tend to agree/strongly agree (57.9% strongly agree) that they like this structure of sequential scaffolds (only 5.7% strongly disagreed) (see Table 2).

For the items of the second factor, the perceived benefit of digital sequential scaffolding, mean values again are at or above a level of  $M = 2.99$ , corresponding to a high level of agreement (see Table 2). Results for item (4) reveal that more than half of all students strongly agree (58.6%) that the sequential scaffolds made it easier for them to carry out the experiment (27.1% tend to agree). Only 6.4% of the students strongly disagreed here. Item (5) asked whether students could observe the experiment better due to the sequential scaffolds. Here, 71.3% of the students tend to agree/strongly agree, and only 8.6% strongly disagree. The results for item (6) are similar; 80.0% of the students tend to

agree/strongly agree (55.0% strongly agree) that they could set up the experiment better using the sequential scaffolds (only 9.3% strongly disagree) (see Table 2).

For the items of the third factor, learners' motivation regarding the experiment, mean values are close to  $M = 3.00$ , which corresponds to a high level of agreement (see Table 2). For item (7), this means that more than half of all students (61.7% tend to agree/strongly agree) are more curious about the experiment because of the sequential scaffolds (12.1% strongly disagreed here). Similar results are revealed for item (8); 62.4% of the students tend to agree/strongly agree that they had more desire to understand the experiment's background because of the sequential scaffolds (only 8.5% strongly disagreed). Item (9) asked whether the sequential scaffolds motivated the students to carry out the whole experiment without using sequential scaffolds. Here, 64.5% of the students tend to agree/strongly agree, and nearly one-quarter of all strongly agreed, whereas only 8.7% strongly disagreed (see Table 2).

### 3.2. Results Relating to Research Question 1

First, to determine the strength and direction of possible linear relationships between the three factors and the learners' prerequisites, we conducted correlation analyses with Pearson's correlation coefficient for all variables except for prior experience with sequential scaffolds (here we used point-biserial correlations as this variable is dichotomous).

Table 3 shows that students' understanding of the concept and usage of digital sequential scaffolds significantly correlated with self-perceived experimentation competence ( $r = 0.29$ ,  $p < 0.001$ ) and with prior experience with sequential scaffolds ( $r = 0.19$ ,  $p < 0.05$ ). Further, also the perceived benefit of the scaffolds significantly correlated with self-perceived experimentation competence ( $r = 0.18$ ;  $p < 0.05$ ) and with prior experience with sequential scaffolds ( $r = 0.28$ ;  $p < 0.001$ ). Prior knowledge, self-concept, and prior interest show no relationship with students' understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds, and motivation regarding experimentation.

**Table 3.** Means, standard derivations, and correlations.

	M	SD	1	2	3	4	5	6	7
1. Understanding of concept and usage	3.26	0.66							
2. Perceived benefit	3.19	0.70	0.63 ***						
3. Motivation regarding experimentation	2.77	0.70	0.24 **	0.30 ***					
4. Prior self-perceived experimentation competence	3.67	0.70	<b>0.29 ***</b>	<b>0.18 *</b>	0.15				
5. Prior knowledge	3.80	3.23	−0.16	−0.06	0.06	0.15			
6. Chemistry-related self-concept	2.59	0.96	−0.06	−0.07	−0.03	0.46 ***	0.33 ***		
7. Interest in chemistry education	3.66	1.50	0.05	0.07	0.13	0.44 ***	0.27 ***	0.68 ***	
8. Prior experience with sequential scaffolds	-	-	<b>0.19 *</b>	<b>0.28 ***</b>	0.11	0.05	−0.06	0.03	0.16

Note: M and SD represent mean and standard deviation, respectively. \* indicates  $p < 0.05$ . \*\* indicates  $p < 0.01$ . \*\*\* indicates  $p < 0.001$ .

To identify the impact of self-perceived experimentation competence on students' understanding of the concept and usage of digital sequential scaffolds and the perceived benefit of the scaffolds, we run regression analysis. To test the influence of the control variable (prior experience with sequential scaffolds), the control variable is first included as the first block in a hierarchical regression analysis. In this way, it can be checked whether the control variable provides an additional variance explanation and are thus suitable for predicting the AV. Multicollinearity is not present in both regressions, but residuals are not normally distributed; hence, BCa bootstrapping was used.

It was found that prior experience with sequential scaffolds and self-perceived experimentation competence explain significantly the variance in the value of students'

understanding of the concept and usage of the digital sequential scaffolds ( $F(2, 121) = 7.52$ ,  $p < 0.001$ ,  $R^2 = 0.11$ ,  $R^2_{Adjusted} = 0.10$ ; see Table 4).

**Table 4.** Regression results using factor 1 “leaners’ understanding of the concept and usage of digital sequential scaffolds” as criterion.

Predictor	b	SE <sub>b</sub> <sup>a</sup>	beta	T	p	Fit	Difference
<i>Model 1</i>							
(Intercept)	3.07 [2.90, 3.23]	0.81		36.43	<0.001		
Prior experience with sequential scaffolds	0.27 [0.03, 0.50]	0.12	0.20	2.27	0.025	$R^2 = 0.04$ *	
<i>Model 2</i>							
(Intercept)	2.15 [1.59, 2.68]	0.28		6.99	<0.001		
Prior experience with sequential scaffolds	0.24 [0.00, 0.46]	0.12	0.18	2.04	0.044		
Prior self-perceived experimentation competence	0.26 [0.11, 0.41]	0.07	0.27	3.09	0.002	$R^2 = 0.11$ ***	$\Delta R^2 = 0.07$ **

Note: <sup>a</sup> Confidence intervals and standard error per BCa-bootstrapping based on 1000 bootstrap samples; \* indicates  $p < 0.05$ . \*\* indicates  $p < 0.01$ . \*\*\* indicates  $p < 0.001$ .

Table 4 shows that the control variable prior experience with sequential scaffolds explains only 4% of the variance. Including self-perceived experimentation competence, the variance explanation increases by 7% to a total of 11%. Thus, the control variable in model 1 can contribute significantly to the variance explanation and model 2 also shows a significant variance clarification. The model improvement is also statistically significant ( $\Delta R^2 = 0.07$  \*\*). Both variables are identified as significant predictors in model 2. This means that the control variable of prior experience with sequential scaffolds significantly affects the research question of how self-perceived experimentation competence affects students’ understanding of the concept and usage of the digital sequential scaffolds.

Further, regarding the perceived benefit of the scaffolds, it was found that prior experience with sequential scaffolds and self-perceived experimentation competence explain a significant amount of the variance in the value of the perceived benefit of the scaffolds ( $F(2, 121) = 7.27$ ,  $p = 0.001$ ,  $R^2 = 0.11$ ,  $R^2_{Adjusted} = 0.09$ ; see Table 4).

Table 5 shows that the control variable of prior experience with sequential scaffolds explains 9% of the variance. Including self-perceived experimentation competence, the variance explanation increases by 2% to a total of 11%. The control variable in model 1 again contributes significantly to the variance explanation and model 2 also shows a significant variance clarification. However, the model improvement is not significant ( $\Delta R^2 = 0.02$ ). Only the control variable was identified as a significant predictor, whereas self-perceived experimentation competence did not contribute significantly to variance explanation.

Taken together, after controlling for prior experience with sequential scaffolds, correlation and regression analysis confirmed students’ self-perceived experimentation competence as a significant predictor of students’ understanding of the concept and usage of the digital sequential scaffolds (factor 1), but not for perceived benefit of the scaffolds (factor 2), and no relationship with learners’ motivation towards experimentation (factor 3) was shown. Prior experience with graded aids in experimentation was confirmed as a significant control variable for students’ understanding of the concept and usage of the digital sequential scaffolds and for the perceived benefit of the scaffolds.

**Table 5.** Regression results using factor 2 “perceived benefit” as criterion.

Predictor	b	SE <sub>b</sub> <sup>a</sup>	beta	T	p	Fit	Difference
<i>Model 1</i>							
(Intercept)	2.96 [2.77, 3.12]	0.09		33.77	<0.001		
Prior experience with sequential scaffolds	0.42 [0.19, 0.67]	0.12	0.30	3.43	<0.001	R <sup>2</sup> = 0.09 ***	
<i>Model 2</i>							
(Intercept)	2.44 [1.67, 3.15]	0.47		7.43	<0.001		
Prior experience with sequential scaffolds	0.41 [0.16, 0.66]	0.12	0.28	3.28	0.001		
Prior self-perceived experimentation competence	0.14 [-0.06, 0.35]	0.10	0.14	1.61	0.108	R <sup>2</sup> = 0.11 ***	ΔR <sup>2</sup> = 0.02

Note: <sup>a</sup> Confidence intervals and standard error per BCa-bootstrapping based on 1000 bootstrap samples; \*\*\* indicates  $p < 0.001$ .

### 3.3. Results Relating to Research Question 2

Another aim was to scrutinize the possible effects of learners’ understanding and perception of digital sequential scaffolds on learning (e.g., post-test knowledge, situational interest catch and hold, self-perceived experimental competence after the intervention, and perceived competence and autonomy support).

Again, we conducted correlation analysis with Pearson’s correlation coefficient to determine the strength and direction of possible linear relationships between the variables.

Table 6 shows that students’ understanding of the concept and usage of the digital sequential scaffolds significantly correlated with self-perceived experimentation competence ( $r = 0.22$ ;  $p < 0.05$ ) and with perceived competence support ( $r = 0.20$ ;  $p < 0.05$ ) and autonomy support ( $r = 0.24$ ;  $p < 0.01$ ). Students’ perceived benefit of the scaffolds significantly correlated with situational interest catch ( $r = 0.33$ ;  $p < 0.001$ ), situational interest hold ( $r = 0.17$ ;  $p < 0.05$ ) and with perceived competence support ( $r = 0.27$ ;  $p < 0.01$ ) and autonomy support ( $r = 0.31$ ;  $p < 0.001$ ). Finally, students’ motivation regarding experimentation significantly correlated with situational interest catch ( $r = 0.44$ ;  $p < 0.001$ ), situational interest hold ( $r = 0.53$ ;  $p < 0.001$ ), and with perceived competence support ( $r = 0.33$ ;  $p < 0.001$ ) and autonomy support ( $r = 0.20$ ;  $p < 0.05$ ). There was no relationship between post-knowledge and students’ understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds, and motivation regarding experimentation.

**Table 6.** Means, standard derivations, and correlations.

	M	SD	1	2	3	4	5	6	7	8
1. Understanding of concept and usage	3.26	0.66								
2. Perceived benefit	3.19	0.70	0.63 ***							
3. Motivation regarding experimentation	2.77	0.70	0.24 **	0.30 ***						
4. Post-test knowledge	6.51	3.21	0.04	-0.09	0.04					
5. Situational interest Catch	3.86	0.85	0.16	0.33 ***	0.44 ***	0.12				
6. Situational interest Hold	3.02	0.96	-0.01	0.17 *	0.53 ***	0.05	0.68 ***			
7. Self-perceived experimentation competence (post)	3.86	0.71	0.22 *	0.16	0.12	0.33 ***	0.41 ***	0.22 **		
8. Perceived competence support	2.77	0.64	0.20 *	0.27 **	0.33 ***	0.23 **	0.41 ***	0.44 ***	0.225 **	
9. Perceived autonomy support	3.12	0.55	0.24 **	0.31 ***	0.20 *	0.34 ***	0.50 ***	0.40 ***	0.48 ***	0.49 ***

Note: M and SD represent mean and standard deviation, respectively. \* indicates  $p < 0.05$ . \*\* indicates  $p < 0.01$ . \*\*\* indicates  $p < 0.001$ .

To identify the impact of students' understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds and motivation regarding experimentation on self-perceived experimentation competence after the experiment, situational interest (catch and hold), and perceived autonomy and competence support, we ran regression analysis, depending on the correlation between the variables. Multicollinearity is not present, and residuals are normally distributed for all regressions.

### 3.3.1. Influence on Situational Interest (Catch)

Multiple linear regression identifies perceived benefit of the scaffolds as a predictor of situational interest (catch) ( $b = 0.24$ ;  $\beta = 0.21$ ;  $t(134) = 2.56$ ;  $p < 0.012$ ), as well as motivation regarding experimentation ( $b = 0.46$ ;  $\beta = 0.38$ ;  $t(134) = 4.73$ ;  $p < 0.001$ ). Both variables, perceived benefit of the scaffolds and motivation regarding experimentation, explained a significant proportion of the variance in situational interest (catch) ( $R^2 = 0.23$ ;  $R^2_{adjusted} = 0.22$ ;  $F(2, 135) = 20.60$ ,  $p < 0.001$ ).

### 3.3.2. Influence on Situational Interest (Hold)

Perceived benefit of the scaffolds and motivation regarding experimentation explained a significant proportion of the variance in situational interest (hold) ( $R^2 = 0.28$ ;  $R^2_{adjusted} = 0.27$ ;  $F(2, 135) = 26.13$ ,  $p < 0.001$ ). Here, however, motivation regarding experimentation was identified as a significant predictor ( $b = 0.73$ ;  $\beta = 0.53$ ;  $t(134) = 6.86$ ;  $p < 0.001$ ), whereas the perceived benefit of the scaffolds did not contribute significantly to variance explanation ( $b = -0.005$ ;  $\beta = -0.005$ ;  $t(134) = -0.060$ ;  $p = 0.952$ ).

### 3.3.3. Influence on Self-Perceived Experimentation Competence after the Experiment

A simple linear regression with self-perceived experimentation competence after the experiment as the dependent variable and students' understanding of the concept and usage of digital sequential scaffolds as the explanatory variable is significant,  $F(1, 134) = 6.56$ ,  $p < 0.012$ . 5% of the variance of self-perceived experimentation competence after the experiment ( $R^2 = 0.05$ ;  $R^2_{adjusted} = 0.04$ ) can be explained by the students' understanding of the concept and usage of digital sequential scaffolds. The regression coefficient of the students' understanding of the concept and usage of digital sequential scaffolds variable is  $B = 0.23$  ( $\beta = 0.22$ ) and is significant ( $t(134) = 2.56$ ;  $p < 0.012$ ).

### 3.3.4. Influence on Perceived Competence Support

Students' understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds, and motivation regarding experimentation explained a significant proportion of the variance in perceived competence support ( $R^2 = 0.14$ ;  $R^2_{adjusted} = 0.12$ ;  $F(3, 134) = 6.86$ ,  $p < 0.001$ ). Here, however, again only motivation regarding experimentation was identified as a significant predictor ( $b = 0.24$ ;  $\beta = 0.26$ ;  $t(133) = 3.07$ ;  $p = 0.003$ ), whereas students' understanding of the concept and usage of digital sequential scaffolds did not contribute significantly to variance explanation ( $b = 0.03$ ;  $\beta = 0.03$ ;  $t(133) = 0.28$ ;  $p = 0.782$ ), nor did perceived benefit of the scaffolds ( $b = 0.15$ ;  $\beta = 0.16$ ;  $t(133) = 1.50$ ;  $p = 0.136$ ).

### 3.3.5. Influence on Perceived Autonomy Support

Students' understanding of the concept and usage of digital sequential scaffolds, perceived benefit of the scaffolds, and motivation regarding experimentation explained a significant portion of the variance in perceived autonomy support ( $R^2 = 0.10$ ;  $R^2_{adjusted} = 0.09$ ;  $F(3, 134) = 5.20$ ,  $p = 0.002$ ). Here, however, only the perceived benefit of the scaffolds was identified as a significant predictor ( $b = 0.17$ ;  $\beta = 0.23$ ;  $t(133) = 2.04$ ;  $p = 0.043$ ), whereas students' understanding of the concept and usage of digital sequential scaffolds did not contribute significantly to variance explanation ( $b = 0.06$ ;  $\beta = 0.07$ ;  $t(133) = 0.66$ ;  $p = 0.511$ ), nor did motivation regarding experimentation ( $b = 0.08$ ;  $\beta = 0.10$ ;  $t(133) = 1.20$ ;  $p = 0.236$ ).

Taken together, regression analyses here show that the perceived benefit of the scaffolds (factor 2) and learners' motivation towards experimentation (factor 3) predict motivational variables (situational interest catch and hold as well as perceived autonomy and competence support). In contrast, understanding the concept (factor 1) predicts the rather cognitive aspect of self-assessed post-experiment experimentation competence.

#### 4. Discussion

Sequential scaffolds are instructional methods that contribute to effective and independent solutions to complex tasks [18], such as experimentation in school-based chemistry learning [17,19]. There is little research on digital sequential scaffolds [31,32] or a detailed understanding of the students' perspective [4]. To fill this gap, this study investigated learners' understanding and perception of digital sequential scaffolds presented to support self-directed experimentation in chemistry education. These learning aids are provided to the learners in stages during the work process with the "EXBOX-Digital". The main objectives of the current study were to explore possible predictors of students' understanding and perception of digital sequential scaffolds (RQ1) and to scrutinize their effects on cognitive and motivational learning outcomes and processes (RQ2).

To comprehend learners' understanding and perception of digital sequential scaffolds, we first used exploratory factor analysis to reduce the large number of items in the adapted questionnaire (according to Affeldt et al. [4]) into fewer numbers of factors and to find an underlying structure. Three relevant factors were extracted, covering three significant aspects of the understanding and perception of digital sequential scaffolds. The first factor relates to cognitive aspects when learning with digital sequential scaffolds and can be described as: "learners' understanding of the concept and usage of digital sequential scaffolding". It reveals to what extent the learners did understand the chances that sequential scaffolds provided for individually conducting the hands-on experiments without a prescribed procedure. By analyzing the descriptive values of the factors, the results of the first factor show that the students reported a relatively high understanding of the concept and usage of the digital sequential scaffolds. The second and third factors dealt with motivational aspects: The second factor, "learners' perceived benefit of digital sequential scaffolding," covered to what extent learners saw advantages in using the sequential scaffolds for autonomous experimentation. The results reveal that students saw benefits in the digital sequential scaffolds, as the sequential scaffolds helped them to set up, conduct and observe the experiment. The third factor, "learners' motivation regarding experimentation," described the resulting motivation from using the scaffolds to deal with the hands-on experiments. Again, the descriptive results show that learners were motivated by the scaffolds to conduct the hands-on experiments. These results add to prior research findings, stating that sequential scaffolds can promote independent learning [4,6,7,22].

Based on the detected three-factor structure, we analyzed how person-related characteristics influence the different aspects of working with digital sequential scaffolds. For example, Stiller and Wilde [20] already reported that the beneficial effect of sequential scaffolds occurs regardless of prior knowledge. Thus, our next goal was to investigate further possible predictors of students' understanding and perception of digital sequential scaffolds (factors 1, 2, and 3). Based on regression analysis, we found that only students' prior experience with sequential scaffolds and students' prior self-perceived experimentation competence significantly predicted students' understanding of the concept and usage of the digital sequential scaffolds (factor 1) and to a smaller extent learners' perceived benefit of the scaffolds (factor 2). Considering the amount of explainable variation, we mainly found an interrelation between the cognitive aspects: The higher the self-reported prior experimentation competence, the higher the understanding of the concept and usage of digital sequential scaffolds. This relationship is significant, regardless of previous experiences with sequential scaffolds (which only explained a small amount of variance in factor 1). Regarding learners' perceived benefit of the scaffolds (factor 2), results show that students' prior experience with digital scaffolds mainly predicts their view about the

benefit of sequential scaffolds. In contrast, students' self-reported prior experimentation competence does not add much more to the variance explained. Interestingly, there is no relationship between prior person-related characteristics and learners' motivation regarding experimentation (factor 3). This indicates that most of our investigated pre-existing person-related characteristics, except for students' self-reported prior experimentation competence, did not predict the motivation-related aspects. Consequently, it seems reasonable to assume that digital sequential scaffolds can be implemented for heterogeneous groups of students. Our control variable, prior experience with sequential scaffolds, mainly played a role in judging the scaffolds' benefits.

Finally, we investigated how students' understanding and perception of the digital sequential scaffolds (factors 1, 2, and 3) influence cognitive and motivational outcomes after the experiments. Here, we found a clear pattern: the motivation-related factors, "perceived benefit of the scaffolds" and "learners' motivation regarding experimentation," predict the investigated motivational outcomes (situational interest catch/hold and perceived autonomy/competence support). Kleinert et al. [22] found that intrinsic motivation was higher among students working with sequential scaffolds. Also, Schmidt-Borcherding [23] found positive effects of sequential scaffolds on motivation. Our results complement these findings and show that the more the students saw a benefit in the scaffolds and a relation between the scaffolds and the hands-on experiments, the higher their situational interest (in particular on the catch scale); the perceived benefit of the scaffolds and motivation regarding experimentation significantly predicted the situational interest in this specific learning situation (catch). In contrast, a more sustainable interest (hold) was predicted by motivation regarding experimentation alone. Further, the more students saw a benefit in the scaffolds and the more they were motivated to work with the experiments, the higher their perceived fulfillment of basic needs was: the students had a greater sense of autonomy and competence, i.e., they were more likely to feel that they had control of their learning. They understood or were able to cope with the requirements and that the task was easy to complete. Here, the two motivation-related factors had different effects: An increase in perception of the benefits led to a rise in students' feeling of autonomy support. In contrast, an increase in motivation regarding the experimentation led to higher feelings of competence support. Additionally, the cognitive factor, "understanding of the concept and usage of digital sequential scaffolding," predicts the rather cognitive aspect of learners' self-reported post-experiment experimentation competence. This also contributes to prior research showing that using sequential scaffolds significantly increased learners' perceived competence [22]. Complementary to previous studies, e.g., [14,22,23], which follow a classical pre-post intervention, we do not have a repeated measures design in this study. Using the three factors derived from factor analysis, we investigated which variables influence students' understanding and perception of digital sequential scaffolds (RQ 1 with pre-test scores) and what influence students' understanding and perception of digital sequential scaffolds have on motivational and cognitive learning outcomes (RQ 2 with post-test scores). This is an innovative approach that supplements previous sequential scaffolding studies, showing that learners experienced digital sequential scaffolds as helpful and were motivated by them to conduct the hands-on experiments. While this study builds upon previous research on sequential scaffolds, it contributes to the field by providing empirical evidence and insights into the parameters that shape learners' understanding, perception, and outcomes in the context of digital sequential scaffolds (factor analysis to identify three significant factors related to cognitive and motivational aspects; students' prior experience with scaffolds and their self-perceived experimentation competence as significant predictors; learners' perceived benefit of scaffolds and motivation regarding experimentation predict motivational outcomes). By linking these parameters together, the study offers a more comprehensive understanding of how scaffolds can support independent learning and enhance motivation during experimentation in chemistry education.

Several limitations of this study need to be acknowledged. First, these findings are limited by the use of a cross-sectional design, measuring no long-time effects of digital

sequential scaffolds. Second, we conducted an exploratory factor analysis to clarify the underlying structure of the adapted questionnaire from Affeldt et al. [4]. We only obtained three reliable scales from factor analysis. It would be advantageous to reformulate items for the other three scales and possibly for the third factor ( $\alpha = 0.64$ ) and test the factor structure again; Nevertheless, all three used factors are suitable and show reliable values. The results of the descriptive analysis show that the students report that the sequential scaffolds help them to set up, conduct and observe the experiment. Since the study was conducted in the context of a double lesson (time restrictions), it was not possible to conduct additional interviews in which students could have described in more detail why they found the sequential scaffolds helpful. Further, the present study was undertaken with secondary students. To obtain further insight, it would be valuable to repeat it with a different sample (senior high school) and adapted content. Additionally, the students' intermediate knowledge directly after the learning program was not surveyed, as it was not possible due to practical limitations (time restrictions). In this regard, our knowledge test assessed knowledge, not the activities the students performed during the inquiry; a direct assessment of whether guidance promotes the inquiry processes as expected could give additional information [3]. Finally, motivation is a construct that can be affected by gender and context. For this reason, gender effects could also be investigated in further studies, and analyses of motivation could be carried out for other topics, such as acid–base reactions.

## 5. Conclusions

Taken together, the study delivers new insights into the use of digital sequential scaffolds during experimentation in chemistry education. Students conducted hands-on experiments on redox reactions using digital sequential scaffolds, which supported them during the set-up, conduction, and observation of the experiment. We took a detailed look at students' understanding and perception of digital sequential scaffolds and analyzed the prerequisites, and the consequences of those aspects. The findings show that learners experienced digital sequential scaffolds as helpful and were motivated by them to conduct the hands-on experiments. Results also reveal that only students' prior experience with sequential scaffolds and prior self-perceived experimentation competence significantly predict understanding of the concept and usage of the digital sequential scaffolds. Regarding motivation, outcomes show that perceived benefit and motivation regarding experimentation predict the motivational outcomes. Our results justify the decision to use sequential scaffolds for a heterogeneous group of learners in terms of thematic interest, chemistry-related self-concept, or prior domain knowledge; and lead to the assumption that self-perceived experimentation competence is relevant for students' understanding of the concept and usage of the digital sequential scaffolds, while learners' perceived benefit of the scaffolds depends on whether learners have previous experiences with this form of instructional help. Further, raising students' understanding of the concept and usage of the digital sequential scaffolds might lead to a higher self-perceived experimentation competence while increasing the perception of the benefits of sequential scaffolds and the motivation for experimentation through the scaffolds, leading to higher motivational outcomes. Overall, our findings contribute to understanding sequential scaffolding in chemistry education and inform instructional design practices.

**Author Contributions:** Conceptualization, all authors; methodology, all authors; validation, T.F. and S.M. (Stephanie Moser); investigation, T.F., S.M. (Stephanie Moser), I.D. and A.S.; data curation, all authors.; writing—original draft preparation, all authors.; writing—review and editing, all authors; visualization, T.F. and S.M. (Stephanie Moser); project administration, T.F., I.D., S.M. (Stephanie Moser), A.S. and J.Z.; funding acquisition, T.F., I.D., S.M. (Stephanie Moser), A.S. and J.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Robert Bosch Stiftung, Stuttgart, Germany. Grant number: 00906424-003.

**Institutional Review Board Statement:** All participants were students from Austrian secondary schools. Participation was anonymous, i.e., all data were collected and analyzed anonymously, on a voluntary basis. All study participants were informed about the scientific purpose of the study. Due to all these measures in the implementation of this study an audit by an ethics committee was waived.

**Informed Consent Statement:** Informed consent was obtained from all participants involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not public due to the ongoing research.

**Conflicts of Interest:** The authors declare no conflict of interest.

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