Supporting learners' experiment design

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Abstract Inquiry learning is an educational approach in which learners actively construct knowledge and in which performing investigations and conducting experiments is central. To support learners in designing informative experiments we created a scaffold, the Experiment Design Tool (EDT), that provided learners with a step-by-step structure to select variables and to assign values to these variables, together with offering built-in heuristics for experiment design. To further structure the students' approach, the EDT was offered within a set of detailed research questions which again were grouped under a set of broader research questions. Learning results for learners who worked with the EDT were compared to results for learners in two control conditions. In the first control condition, learners received only the detailed research questions and not the EDT; in the second control condition, learners received only the limited set of general research questions. In all conditions, learners conducted their experiments in an online learning environment about the physics topic of Archimedes' principle. Conceptual knowledge was measured before and after the intervention using parallel forms of a knowledge test. Overall results showed significant learning gains in all three conditions, but no significant differences between conditions. However, learners who started with low prior knowledge showed a significantly higher learning gain in the EDT condition than in the two control conditions. This result indicates that the effect of providing learners with scaffolds does not follow a "one-

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size-fits-all" principle, but may depend on specific learner characteristics, such as prior knowledge.

Introduction

Inquiry learning, a constructivist approach, is now widely recognized as a valuable instructional approach in science education (e.g., Minner et al. 2010). Central to constructivist approaches is that learners actively construct knowledge (Fosnot and Perry 2005; Keselman 2003; Minner et al. 2010). Active thinking and working with new material adds to and (re)organizes existing cognitive structures and thereby fosters deeper understandings than passively receiving information (Cakir 2008; Fosnot and Perry 2005). Different levels of active cognitive engagement have been described in the ICAP-framework that provides a clear taxonomy of four different categories of learning engagement (Interactive, Constructive, Active, and Passive) that each elicits different knowledge gains or learning processes (Chi 2009; Chi and Wylie 2014). The main idea of the framework is that as learners become more cognitively engaged with the learning materials and show learning behaviors corresponding to the level of engagement, their learning will increase. The framework is supported by a large body of research (Chi and Wylie 2014). In inquiry learning, learners actively construct knowledge by engaging in multiple phases of inquiry and familiarizing themselves with the topic of interest, formulating research questions or hypotheses, planning and conducting experiments, drawing conclusions, reflecting upon these inquiry processes and results, and communicating their findings to others (de Jong 2006; Pedaste et al. 2015; White and Frederiksen 1998). The effectiveness of inquiry learning has been demonstrated in many studies, provided that learners are guided in their inquiry processes (e.g., Alfieri et al. 2011; Furtak et al. 2012; Lazonder and Harmsen 2016; Minner et al. 2010).

One of the core elements in the multifaceted task of inquiry learning is the actual investigation during which learners design and conduct experiments (Osborne et al. 2003). Designing experiments involves a number of distinct elements. Learners first need to identify the variables associated with answering their research question or testing their hypothesis. More specifically, they need to specify the dependent, independent and control variables; they need to determine what variable(s) to measure or observe, what variable to manipulate, and what variable(s) to control (Arnold et al. 2014). The second step in designing experiments is to determine values for the independent and control variables. Different values are assigned to the independent variable across experimental trials, allowing the learners to investigate the effects on the dependent variable. Variables that are not manipulated, control variables, have the same value across experimental trials, creating similar background conditions that allow the learners to compare results (Schunn and Anderson 1999; Tschirgi 1980). Well-designed experiments serve as a bridge between the research question or hypothesis and the data analysis (Arnold et al. 2014), and provide the learner with adequate information to answer research questions or test hypotheses (de Jong and van Joolingen 1998).

However, learners find it difficult to set up well-designed experiments. They often design experiments that do not align with their research question or test their hypothesis by manipulating variables that have no relation with the research question or hypothesis, or

they fail to identify the manipulatable and observable variables within their research question or hypothesis (de Jong and van Joolingen 1998; Lawson 2002). If the research question or hypothesis does not include a directly manipulatable variable, learners are often unable to convert abstract or theoretical variables into variables they can measure or observe (Lawson 2002). Another difficulty is that learners sometimes vary too many variables, making it challenging to draw conclusions. When too many variables are varied, one cannot tell which variable is responsible for an observed effect (Glaser et al. 1992).

To overcome these difficulties and help learners with the processes of inquiry learning, learners should be guided (Hmelo-Silver et al. 2007). Effective forms of guidance for designing fruitful experiments include providing learners with heuristics and giving them scaffolds. Heuristics are rules of thumb in the form of hints and suggestions about how to carry out certain actions (Zacharia et al. 2015). Examples of heuristics for designing experiments are 'vary one thing at a time', 'assign simple values to the independent variable', and 'keep records of what you are doing' (Klahr and Dunbar 1988; Veermans et al. 2006). In the 'vary one thing at a time' heuristic, also known as the control of variables strategy (CVS), learners vary only the variable of interest and keep all other variables constant (Klahr and Nigam 2004). CVS allows the learner to conclude that any effect on the dependent variable can be attributed to the one variable that was varied. In their overview of inquiry support, Zacharia et al. (2015) show that CVS is the most popular heuristic used to support experimentation.

Scaffolds support learners in performing a task that they cannot perform on their own. Scaffolds support a learning process by providing structure and/or taking over part of the task from the learners (de Jong and Lazonder 2014; Reiser 2004; Simons and Klein 2007). In the current study, we designed such a scaffold to support learners in the process of designing experiments. This scaffold, the Experiment Design Tool (EDT), gave learners a structure for experiment design, provided them with concrete variables to manipulate and measure, prompted them to assign values to variables across experimental trials, and included specific experimentation heuristics. The final design of the EDT was primarily based on the Scaffolding Design Framework (Quintana et al. 2004), as further explained in the Method section. The EDT was integrated into an online learning environment containing a virtual laboratory. Virtual laboratories are software simulation programs in which learners carry out experiments using a computer (de Jong et al. 2014). These laboratories have the advantage that variables can be assigned many values; they are also accurate, time- and cost-effective, and experiments can be repeated easily (Balamuralithara and Woods 2009; de Jong et al. 2013; Gomes and Bogosyan 2009; Schiffhauer et al. 2012, April). The virtual laboratory used in the current study covered the physics topics of buoyancy and Archimedes' principle.

There are indications that the type of guidance that is effective for learning differs between learners with different levels of prior knowledge (Raes et al. 2012). Research has shown that unguided learners with low prior knowledge apply less sophisticated strategies and demonstrate more undirected behavior in inquiry learning than more knowledgeable learners, who are using better strategies and require fewer trials to reach conclusions (Alexander and Judy 1988; Klahr and Dunbar 1988). There is general agreement that learners with low prior knowledge benefit from higher levels of guidance (e.g., Alexander and Judy 1988; Hmelo et al. 2000; Tuovinen and Sweller 1999). More knowledgeable learners are less likely to need additional guidance because they already possess enough knowledge to support the construction of mental representations. For these learners, guidance can become redundant and even have a negative effect on learning, which is referred to as the "expertise reversal effect" (Kalyuga 2007).

The objective of this study was to evaluate the effectiveness of a specific scaffold for experiment design and to investigate whether this scaffold had a positive effect on learners' gain of conceptual knowledge. In doing so, we were specifically interested in whether it was indeed the lower prior knowledge students who would profit most from working with the EDT.

Method

In the current study, we compared learners' gain in domain knowledge between a condition in which students worked with the EDT, and two control conditions. Learners in all conditions worked in an online learning environment where they received research questions and then had to design and conduct experiments in a virtual laboratory, called "Splash", on buoyancy and Archimedes' principle. In the EDT condition, learners received a set of thirteen specific research questions that were organized under a series of five broader research questions that matched the sub-laboratories in Splash. For each of the thirteen detailed research questions, learners could design an experiment by using the EDT. These thirteen research questions were provided to give all students the same starting points for designing their experiments, and the five main categories were used to organize the work for the learners. To evaluate the effect of the EDT, two control conditions were developed. In the 'control specific' (CS) condition, learners worked with the same learning environment as the learners in the EDT condition, but without the EDT itself, which means they received the thirteen specific questions grouped under the five broader questions. In the 'control main' (CM) condition, learners again worked with the same learning environment, but received only the five main research questions. In this way, we could single out the effect of the EDT per se from a possible effect of the related research questions. We expected that learners who worked with the EDT would show higher conceptual knowledge gains than learners who did not work with the EDT. Moreover, we expected that low prior knowledge learners in particular would be more likely to benefit from the EDT than learners with high prior knowledge.

Participants

A total of 120 third-year students (14–15 years old) from four pre-university track classes at two secondary schools in the Netherlands participated in this study. In the Netherlands, there are several levels of education. Students in the pre-university track receive the highest level of secondary education in order to prepare them for university studies. We chose to include pre-university track students because the complexity and "properties" of the learning task fit well with this educational level. Within their own class, learners were randomly assigned to one of the three conditions.

After eliminating learners who missed a session or who conducted fewer than four experimental trials about Archimedes' principle (as indicating too little learning activity), the data from a total of 86 learners were taken into account in the analyses.

Domain: Archimedes' principle

The domain involved in the present study was Archimedes' principle, which states that "an object fully or partially immersed in a fluid is buoyed up by a force equal to the weight of

the fluid that the object displaces" (Halliday et al. 1997, as cited in Hughes 2005). This principle therefore entails that the mass of fluid displaced by a floating or suspended object is equal to the mass of the object, and the volume of fluid displaced by a sunken or suspended object is equal to the volume of the object (Hughes 2005).

Understanding of buoyancy is a prerequisite for learning about Archimedes' principle, and Heron et al. (2003) found that it was helpful to provide learners with laboratory experience in buoyancy prior to introducing Archimedes' principle, in order to address intuitive ideas and misconceptions. The learners who participated in our study had already been taught about buoyancy by their teacher in regular classes before they participated in our study, but to ensure that all of them understood buoyancy and to familiarize them with the structure of the learning environment, including the laboratory and the EDT, we chose to present a set of inquiries about buoyancy prior to introducing Archimedes' principle. Post-test scores revealed very high scores on buoyancy, indicating that they indeed possessed the required prior knowledge about buoyancy.

In the Netherlands, Archimedes' principle is not part of the official examination program, but it is sometimes taught as additional material. However, none of the schools that participated in our study had taught students about Archimedes' principle, which made it a suitable topic for them to learn about in the learning environments.

Materials

Virtual laboratory: Splash

Splash is a virtual laboratory (Fig. 1) on the domains of buoyancy and Archimedes' principle. The laboratory that was used in the current study covered five topics. The first three topics fell within the domain of buoyancy; in this study they served to activate learners' knowledge about buoyancy and to familiarize them with the learning environment. The final two topics were about Archimedes' principle.

The laboratory displays water-filled containers in which learners can place balls. Learners can choose the properties of the balls (mass, volume and density). The designed balls can be dropped in the containers and learners can observe whether the balls sink fully, are suspended, or float in water. Moreover, for Archimedes' principle, the displaced water
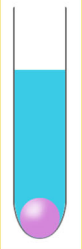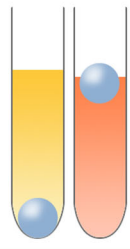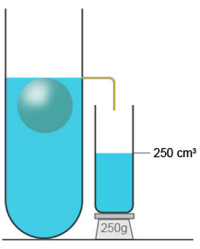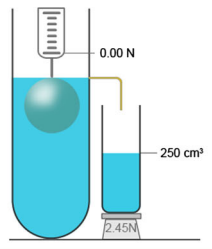

Fig. 1 Examples of topics in the Splash laboratory

will flow into empty containers that display the mass and volume of the displaced water, or forces.

Learning environment

Learners in all conditions worked in an online learning environment, which had a similar structure in each condition. Learners first received instructions stating that they had to answer a set of research questions, which meant that they had to plan experiments and conduct these experiments in the Splash laboratory. The learning environment incorporated three main elements: a research question (Fig. 2a), the laboratory in which experiments could be conducted (Fig. 2b), and a text field in which conclusions from the experiments could be entered (Fig. 2c). After learners entered their conclusion for the research question, they received a new research question to investigate.

Learners in the EDT condition had to use the EDT (Fig. 2d) to plan experiments and note down the results they obtained for thirteen more specific research questions in order to answer the five main research questions. An example of a more specific question is: "Conduct a series of experiments with objects that all have the same mass, but differ in volume. What is the volume and mass of the displaced water? First, do this for objects that sink, then objects that suspend, and then objects that float". An example of a main question is: "How do properties of objects placed in water influence the amount of water displacement caused by these objects?". Learners in the CS condition worked in essentially the same learning environment, but without the EDT. Learners in the CM condition worked with the same learning environment as the CS group, but they were provided with just the five main research questions, one for each of the five topics in Splash. A more detailed description of the EDT is given in the next section.

The Experiment Design Tool

The EDT (Fig. 3) provides learners with structure by breaking down the process of designing and conducting an experiment into several steps: (1) choosing the variables and assigning the chosen variables as independent, control, and dependent variables; (2) assigning values to the variables; (3) conducting the experiment; and (4) analyzing the results. It also helps learners to design experiments that follow the CVS, to work with simple values (e.g., 100, 150, etc.), and it helps them to keep records of what they are doing.

Step 1   First, learners are given a list of predefined variables. For each variable, they decide whether they want to vary it across experimental trials (independent variable), keep it the same (control variable) or measure/observe it (dependent variable) by dragging the variable to the chosen category. They receive feedback on their actions by means of a pop-up screen. For example, if they indicate that they want to vary a variable, they receive feedback that this means that they want to study the effect of the chosen variable on the variable they want to measure or observe.

Step 2   Second, learners specify the number of experimental trials that together will make up one experiment and they choose the values of the control and independent variables. They assign one value per experimental trial to the selected independent variable (e.g., in the first trial they experiment with a mass of 300 g and in the second trial they use a mass of 400 g), and a value to each

Fig. 2 The learning environments. On the left is the interface for the CS condition, and on the right the interface for the EDT condition is depicted. In the EDT interface the conclusion box only becomes visible when learners have reached the analysis tab in the EDT
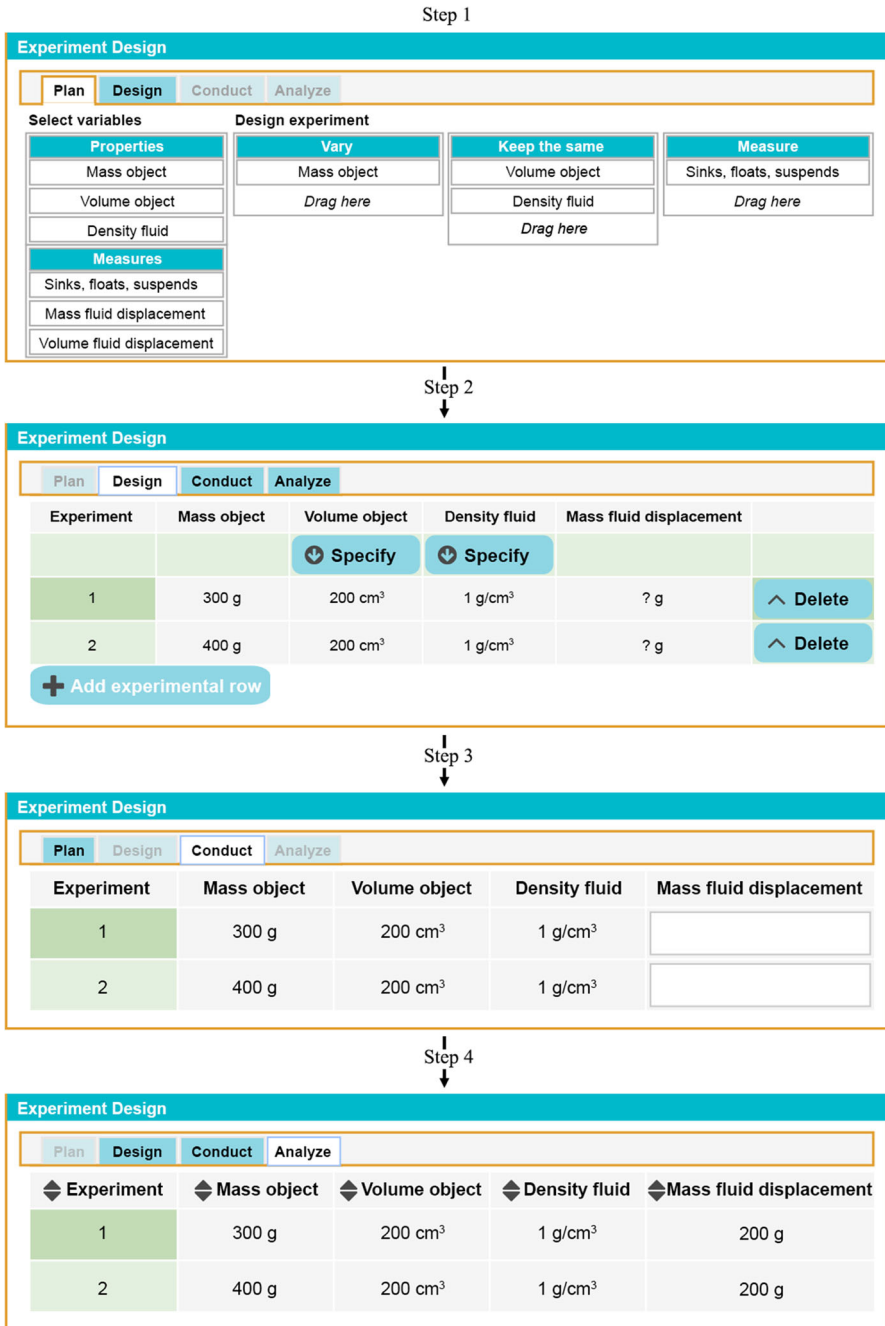
Fig. 3 The Experiment Design Tool

control variable that remains the same over all experimental trials within an experiment (e.g., volume $= 200$ cm^3 in every trial for that experiment).

Step 3   Third, learners run their experiment. The trials they design in the EDT are automatically transferred to Splash. After observing the results in Splash, they document their observation or measurement of the dependent variable in the tool.

Step 4   Fourth, learners analyze their results. They can sort their data in ascending or descending order per variable. This makes it easier to compare results and to decide if they can draw conclusions based on their data, or if they need to plan and conduct more trials or even more experiments.

The main framework that was used for the design of the EDT is the Scaffolding Design Framework by Quintana et al. (2004) that gives guidelines for the design of scaffolds:

Guideline 1   "Use representations and language that bridge learners' understanding". Pre-university track learners have begun learning how to design experiments, but they are not familiar with scientific terms such as independent, control, and dependent variables. In the EDT, these terms are replaced by language that is used in the classroom. For example, "independent" is replaced by "vary" and "dependent" is replaced by "measure".

Guideline 2   "Organize tools and artefacts around the semantics of the discipline". In experiment design, learners have to be aware that different types of variables exist, each with their own functionality. The EDT distinguishes between independent or control variables that can be varied or kept the same within an experiment and dependent variables that can be measured.

Guideline 3   "Use representations that learners can inspect in different ways to reveal important properties of underlying data". The EDT offers learners the possibility of recording their experimental design, observations, and/or measures. The recorded design and measures are presented in the form of a table. Each variable can be sorted in ascending or descending order, which helps to reveal important properties of the underlying data.

Guideline 4   "Provide structure for complex tasks and functionality". In experiment design, learners have to decide which variables to use, specify their roles within the experiment, and decide which values they want to assign to the variables. The EDT offers structure in several ways. The EDT consists of four tabs that break down the process of experiment design into smaller steps as explained previously. Additional structure is provided within the distinct tabs. The first tab contains a table with three columns to explicitly distinguish between the different types of variables. Moreover, learners are given a set of (relevant) variables they can include in the design of their experiment by dragging these variables to one of the columns and thereby specifying the roles of these variables. In the second tab, learners can specify the values of the control and independent variables. The EDT offers a range of possible values they can choose from in order to restrict their choices. They can design a maximum of six experimental trials at once. In the third tab learners can record their observation or measure, and the fourth tab contains a table that allows learners to sort variables in ascending or descending order.

Guideline 5	"Embed expert guidance about scientific practices". Expert guidance is incorporated in the EDT in several ways. First, several heuristics regarding experiment design that are often applied by successful scientists are implicitly present in the EDT. For example, 'vary one thing at a time' is built in by restricting the number of varied variables to just one, and 'assign simple values to the independent variable' is implemented by means of sliders that only allow learners to select simple values. Second, the EDT provides learners with feedback on their actions by means of a pop-up screen.
Guideline 6	"Automatically handle non-salient, routine tasks". All control variables only have to be assigned a value once. The EDT automatically assigns the chosen value to all trials within the experiment.
Guideline 7	"Facilitate ongoing articulation and reflection during the investigation". The EDT provides learners with feedback about their actions. Learners are encouraged to think about their experimental design: the EDT explains what learners' actions entail and asks them if they intended to perform those actions or if they want to reconsider.

Assessment

Learners' conceptual knowledge was assessed both before and after the intervention with parallel forms of a pencil-and-paper knowledge test that was designed specifically for this study. The pre- and post-test included the same questions, but the values within questions, as well as the order of questions, were different. The tests each consisted of two parts that addressed what learners encountered in a session with the learning environment in the current study—buoyancy and Archimedes' principle—and used open-ended questions for which learners could obtain a maximum of 35 points. The first part of each test (25 points) concerned buoyancy. The second part of each test (10 points) concerned Archimedes' principle. After learners' tests were scored, one item related to Archimedes' principle was removed from the analysis because learners interpreted that question very differently than was intended, which left a total of nine possible points for the second part of the test.

In the test, learners were asked to write down definitions of the key concepts, and they had to apply this knowledge by providing the masses, volumes, and densities of balls in different situations, the amount of displaced water, and/or forces that act upon the ball or the displaced water. Learners received one point for each correct answer. An example of an Archimedes' principle question was: "A ball is being placed in a tube filled with water. This causes the water to be displaced. The displaced water is caught in a measuring cup. Below you can see the set-up before the ball is released. Provide the amount of displaced water and the values displayed on the spring balance and the scale after the ball was released in the tube". The set-up that was shown to them was a figure taken from Splash. In the figure, a ball is hanging on a spring balance placed above a water-filled tube, with a measuring cup on a scale next to it to catch the displaced water. In this example, learners could receive one point for the correct amount of displaced water, one point for the correct value displayed on the spring balance, and one point for the correct value displayed on the scale.

Because the test consisted of open questions that were scored using a coding scheme, a second researcher used the coding scheme to score the post-tests from one of the four classes ($n = 30$). Agreement between the two researchers reached Kappa = 0.943.

To determine the reliability of the tests, separate Cronbach's alpha's for both parts of the pre-test and the post-test were determined, based on the participants whose data were taken into account for this study ($n = 86$). The first part of the pre-test (about buoyancy) had a Cronbach's alpha of .92 and the second part of the pre-test (about Archimedes' principle) a Cronbach's alpha of .84. The post-test had a Cronbach's alpha of .91 for the buoyancy part and a Cronbach's alpha of .88 for the Archimedes' principle part.

Procedure

The study took place in the classroom during four sessions of 50–60 min each, over a period of two and a half weeks. During the first session, learners' prior conceptual knowledge was measured using the pre-test. Learners could use the entire session to complete the test, but all learners finished within half an hour. The intervention began in the second session, where learners worked with the learning environment that matched their condition. The topic of investigation in this session was buoyancy, in order to familiarize them with the learning environment and to activate their knowledge. Learners were told that they were to do experiments about floating, sinking and suspended objects, and density by individually designing and conducting experiments on the computer to answer the provided research questions. All the information learners needed to be able to successfully complete the tasks were presented to them in the learning environment, there was no teacher intervention. Learners in all conditions also received a booklet consisting of lined paper and all the research questions so that they could take notes whenever they wanted. Learners in the control conditions were encouraged to write down their experiments, including the results, in the booklet. They could use the entire second session to learn about buoyancy by means of inquiry learning. In the third session learners worked in the same learning environment as in the second session, but now they learned about Archimedes' principle, more specifically about water displacement and forces, instead of buoyancy. During the fourth session, learners' conceptual knowledge was measured with the post-test, for which they could again use the entire session.

Results

In the current study, the EDT condition was compared with two control conditions to study the effect of the EDT on learners' gain of conceptual knowledge about Archimedes' principle. Because the data were not normally distributed, an independent samples Kruskal–Wallis test was conducted to check for a priori differences between conditions. No significant differences were found between the conditions regarding physics grade, $H(2) = 1.97$, $p = .374$; math grade, $H(2) = 2.24$, $p = .327$; and pre-test scores for both buoyancy, $H(2) = 1.26$, $p = .534$ and Archimedes' principle, $H(2) = 1.70$, $p = .428$, indicating that the groups were comparable. Moreover, there was no significant difference on learners' post-test scores for buoyancy; in all conditions learners, on average, answered 88% of the questions on buoyancy correctly.

Our first analysis concerned learners' knowledge gains about Archimedes' principle and whether learners who worked with the EDT gained more knowledge than learners who did not work with the EDT. First, we explored whether learners gained knowledge about Archimedes' principle independent of their condition. A Wilcoxon signed-rank test

showed a significant increase in score from pre- to post-test ($Z = 6.126$, $p < .001$, $d_{Co-hen} = 0.99$), demonstrating a significant learning effect.

Separate analyses per condition were also performed to explore learners' learning gain per condition. Learners' scores significantly increased from pre- to post-test in all conditions (EDT condition: $Z = 4.133$, $p < .001$, $d_{Cohen} = 1.33$; CS condition: $Z = 3.576$, $p < .001$, $d_{Cohen} = 0.83$; CM condition: $Z = 3.044$, $p = .002$, $d_{Cohen} = 0.92$), showing a large learning effect in all conditions. Table 1 shows the means and SDs of the pre- and post-test scores for all conditions, as well as the difference scores between pre- and post-test.

To determine whether learners who worked with the EDT gained more conceptual knowledge than learners in the control conditions, an independent samples Kruskal–Wallis test was performed. No significant differences were found between the conditions, $H(2) = 2.96$, $p = .228$.

Secondly, we were specifically interested in differences in the effects of guidance on low prior knowledge learners and high prior knowledge learners. Learners were classified as low prior knowledge learners if they had a maximum of two out of nine correct answers (the lower quartile of the maximum score) on the part of the pre-test that covered the Archimedes' principle. Based on this criterion, 63 out of 86 learners were classified as low prior knowledge learners. Since a solid majority of our learners had low prior knowledge about Archimedes' principle, leaving very few high prior knowledge learners, we only analyzed the results for low prior knowledge learners. An independent samples Kruskal–Wallis test showed a significant difference between the conditions, $H(2) = 6.54$, $p = .038$. Follow-up Mann–Whitney analyses showed significantly higher learning gains for low prior knowledge learners in the EDT condition compared to low prior knowledge learners in the CS condition, $U = 115.50$, $z = 2.438$, $p = .015$, $r = .16$. Table 2 presents the means and SDs of the pre- and post-test scores of low prior knowledge learners, per condition. These findings demonstrate that low prior knowledge learners benefited from additional support in the form of the Experiment Design Tool.

Table 1 Test scores for Archimedes' principle (max score = 9)

	EDT ($n = 26$)		CS ($n = 32$)		CM ($n = 28$)		Total ($n = 86$)	
	M	SD	M	SD	M	SD	M	SD
Pre-test	2.31	2.72	1.59	1.78	1.43	2.06	1.76	2.20
Post-test	5.66	2.30	3.72	3.12	3.89	3.18	4.36	3.01
Difference score	3.35	2.58	2.13	2.66	2.46	3.61	2.60	2.99

Table 2 Test scores of lower prior knowledge learners for Archimedes' principle (max score = 9)

	EDT ($n = 18$)		CS ($n = 23$)		CM ($n = 22$)		Total ($n = 63$)	
	M	SD	M	SD	M	SD	M	SD
Pre-test	0.72	0.89	0.70	0.93	0.50	0.86	0.63	0.89
Post-test	5.17	2.33	2.74	3.08	3.64	3.20	3.75	3.05
Difference score	4.44	2.23	2.04	2.99	3.14	3.27	3.11	3.02

Conclusion and discussion

For the current study, we designed an EDT based on the Scaffolding Design Framework by Quintana et al. (2004), and studied its effect on conceptual learning results for secondary school students. The EDT was specifically created to allow learners to design informative experiments and gain conceptual knowledge. The effectiveness of the EDT was studied by comparing an experimental condition, in which learners designed and conducted experiments using the EDT, with two control conditions, in which learners worked in a similar learning environment but without the EDT. We were interested in the effects of the EDT on learners' conceptual knowledge gains, specifically for low prior knowledge learners. Our results showed that low prior knowledge learners who were guided by the EDT gained significantly more conceptual knowledge than those in the CS condition, and descriptive statistics showed—not significant—higher learning gains for learners in the EDT condition than those in the CM condition. This effect was not found when learners with all levels of prior knowledge were taken into account, which is in conjunction with previous findings that low prior knowledge learners benefit more from guidance than their more knowledgeable peers (Alexander and Judy 1988). An important difference between different levels of learners is seen in the strategies they apply to work towards a solution of a problem (Hmelo et al. 2000; Schauble et al. 1991). Low prior knowledge learners lack internal information about concepts and meaningful relationships between concepts, and they show less sophisticated strategies than high prior knowledge learners (Alexander and Judy 1988; Schauble et al. 1991). As a result, in inquiry learning low prior knowledge learners often conduct unsystematic experiments in which learners fail to vary the appropriate variable and in which there is a mismatch between the research question and the conducted experimental trials, whereas high prior knowledge learners show goal-oriented inquiry behavior and conduct well-structured experiments (Hmelo et al. 2000; McElhaney and Linn 2011). In other words, high prior knowledge learners are better equipped to structure a task themselves than low prior knowledge learners, which could explain why we found significantly higher learning gains in favour of the EDT for low prior knowledge learners only. One of the main features of the EDT is that it provides learners with structure and heuristics to help them design systematic experiments, and it provides them with a useful strategy for gaining domain knowledge; learners automatically apply the Control of Variables Strategy, allowing them to discover the effect of one independent variable on the dependent variable at a time.

Another difference between learners with different levels of prior knowledge and experience is that novices have the tendency to immediately start working towards a solution to the problem without thinking it through, whereas experts first try to understand the problem (Getzels and Csikszentmihalyi 1976; Paige and Simon 1966). This tendency may be especially problematic when learners try to make inferences about research questions within domains in which experimental results are influenced by interacting variables, as in Archimedes' principle, rather than by a single variable. Dealing with interacting variables has been found to be especially difficult for learners when they must design and conduct experiments in computer-supported learning environments, and it is greatly affected by learners' inadequate application of the Control of Variables Strategy (Beishuizen et al. 2004). Grasping the concept of Archimedes' principle requires learners to understand that the density (mass divided by volume) of the object compared to the density of the fluid determines if the object floats, suspends, or sinks in the fluid. Additionally, learners must understand that different relationships exist between the object's

properties and the amount of displaced fluid for objects that float and objects that sink (i.e., for floating objects the mass of the object equals the mass of the displaced fluid, and the volume of the object is greater than the volume of the displaced fluid, whereas for sinking objects the volume of the object equals the volume of the displaced fluid, and the mass of the object is greater than the mass of the displaced fluid). If learners immediately start working towards answering research questions regarding Archimedes' principle by conducting random experiments, and thereby fail to consider relative density and interactions between floatability, object properties and fluid displacement, they will end up with experimentation outcomes from which it is extremely difficult to extract relationships between the independent and dependent variables. The EDT prevents learners from immediately working towards a solution, but instead encourages them to think about their experimental designs and it provides them with feedback that prompt them to reflect upon their experimental designs.

Another result that deserves some attention is that low prior knowledge learners who worked with the EDT only outperformed those in the CS condition significantly and not those in the CM condition. The thirteen specific questions that were provided to learners in the EDT and the CS condition organized the main research questions and were meant to aid the students, but descriptive statistics showed higher learning gains for learners in the CM condition than for learners in the CS condition, who in fact had very little learning gain. This may be explained by the added task demands of additional research questions that was posed on learners in the CS condition who were not equipped with sufficient prior knowledge, capability and/or tools—either cognitive through prior knowledge and experiences or external by means of scaffolding tools such as the EDT. Even though the additional questions aimed to provide a sense of direction for designing experiments, they also take time to answer and add to the task, which may have caused learners who were not provided with additional inquiry support in the form of the EDT to struggle with successfully completing the task within the given time. The additional questions and the time they took to answer may have been beyond learners' zone of proximal development, and in order for learning to occur the activities and guidance should match their zone of proximal development. In a recent study by Perez et al. (2017) in which they identified productive inquiry in virtual labs by means of sequence mining, they also found that novice learners who conducted simpler experiments matching their level of expertise achieved higher learning outcomes than novices who focused more on complex circuit configurations.

Most studies in which the effectiveness of tools and scaffolds have been tested present results that do not take conditions related to the functioning of scaffolds into account (Zacharia et al. 2015). Our results show that there's no one-size-fits-all approach that applies to learners' guidance regarding experiment design, and that prior knowledge should be evaluated when introducing scaffolds. The effect of scaffolding is very much influenced by the context and can be different per situation. The Scaffolding Design Framework should be adapted to stress the importance of context, and show that the relationship between learner characteristics, domain characteristics, and the place in the curriculum are of high importance to take into account in the design of scaffolds.

Future studies should also include qualitative data regarding learner decisions to understand their rationales behind their experiment designs and qualitative data about learner actions in designing experiments to provide us with richer insights in the processes underlying the results. Furthermore, it should be investigated whether we are generally in need of more sensitive and sophisticated models of scaffolding in order for scaffolds to remain one step ahead of the learner and thereby be able to support the advancing learner.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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