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The influence of prior knowledge on experiment design guidance in a science inquiry context

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ABSTRACT

Designing and conducting sound and informative experiments is an important aspect of inquiry learning. Students, however, often design experiments that do not allow them to reach conclusions. Considering the difficulties students experience with the process of designing experiments, additional guidance in the form of an Experiment Design Tool (EDT) was developed, together with reflection questions. In this study, 147 pre-university students worked in an online inquiry learning environment on buoyancy and Archimedes' principle. Students were randomly assigned to one of three conditions, each of which contained a different version of the EDT. Since students' prior knowledge has been found to influence the amount and type of guidance they need, the versions of the tool differed with respect to the level of guidance provided. A pre- and post-test were administered to assess students' conceptual knowledge. No overall differences between conditions were found. In a subsequent analysis, students were classified as either low, low-intermediate-, high-intermediate, or high prior knowledge students. For Archimedes' principle we found that low-intermediate prior knowledge students gained significantly more conceptual knowledge than low prior knowledge students in the fully guided condition. It is hypothesised that students need at least some prior knowledge in order to fully benefit from the guidance offered.

Introduction

Educators prepare learners for the world, and must use teaching methods that allow students to gain knowledge and acquire useful skills. In science education, teaching methods in which students have an active role increase students' performance on assessments compared to traditional lecturing (Freeman et al., 2014). According to Freeman et al., actively building one's own knowledge results in deeper and more meaningful learning, and students perform better on examinations when they learn actively than when they merely attend lectures. One effective active learning method is guided inquiry learning, during which students get acquainted with and practice inquiry skills and processes in order to gain knowledge about a domain by engaging in scientific investigations (Lazonder & Harmsen, 2016; Minner, Levy, & Century, 2010; Pedaste et al., 2015).

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In inquiry learning, students commonly work through an inquiry cycle that is comprised of several inquiry phases. Different versions of these inquiry cycles have been specified by scholars, many of whom have created their own inquiry cycle (e.g. de Jong, 2006a; Kuhn & Pease, 2008; Lim, 2004; National Research Council, 1996; White & Frederiksen, 1998). Pedaste et al. (2015) summarised these different approaches in a review study on inquiry cycles; on the basis of the phases they found, they distilled a set of core inquiry phases: orientation, conceptualisation, investigation, conclusion, and discussion. In the *orientation phase* the topic of investigation is explored by the student. For learning through conducting inquiry to occur, it is crucial for the student to have a basic understanding of the topic of investigation. If the student does not have at least basic knowledge about the topic, it is very difficult or even impossible to formulate meaningful research questions and to design useful experiments (e.g. Quintana et al., 2004). In the *conceptualisation phase* students formulate research questions or hypotheses to investigate. During the *investigation phase*, which can be seen as a pivotal phase, students design and conduct experiments. Based on those experiments, they then draw conclusions in the *conclusion phase*. The *discussion phase* can take place, as described by Pedaste et al. (2015), at the end of each previously described phase, or at the end of the entire inquiry cycle. In this phase students reflect upon their inquiries and communicate their findings. In the current study, students participated in an online inquiry learning environment that contained information about the topic of investigation, provided them with research questions, contained an online lab in which they could conduct their designed experimental trials, and that had a conclusion input box for them to formulate their conclusions to the experiments in. We specifically focussed on the effect of different forms of guidance to aid learners in applying useful strategies for selecting variables and assigning values to them in the investigation phase. The investigation phase is at the heart of the inquiry model of Pedaste et al. (2015), and serves as a bridge between the hypothesis or research question and the conclusion (Arnold, Kremer, & Mayer, 2014).

An important aspect of designing experiments is the selection and manipulation of variables that are expected to have an effect on the dependent variable. Students can apply various strategies that allow them to connect experimental results to the influential variable or to explore the boundaries of a domain. First of all, when students choose the dependent, independent and control variables, they can apply the Control of Variables Strategy (CVS), which entails that all variables, except for the manipulated variable, should be controlled for (Chinn & Malhotra, 2002; Klahr & Dunbar, 1988). It is important for students to understand that any variable that is not controlled for can influence the outcome of an experiment, resulting in the inability to ascribe an observed effect to a specific variable. Second, it is useful for students to be familiar with strategies for choosing values for variables within an experiment design. Two of those strategies that are often applied by scientists are (1) the use of extreme values and (2) equal increments between trials (Veermans, van Joolingen, & de Jong, 2006). Using extremely low or high values allows exploration of the boundaries of a domain, whereas using equal increments between trials provides information about if and when an effect occurs, and about the strength of an effect, if present.

To design informative experiments, students need to have prior knowledge about the domain of investigation. Prior knowledge has been found to be the most important factor for learning and performance in general (e.g. Ausubel, 1968; Kalyuga, 2007), and

there is a positive correlation between students' prior knowledge and their ability to apply higher-order cognitive skills, as in designing experiments (Hailikari, Katajavuori, & Lindblom-Ylanne, 2008). Students with little prior domain knowledge who participate in inquiry learning use less sophisticated strategies and need more experiments to reach conclusions than their more knowledgeable peers, who employ more well-structured goal-oriented inquiry strategies (Alexander & Judy, 1988; Hmelo, Nagarajan, & Day, 2000; Schauble, Glaser, Raghavan, & Reiner, 1991). These findings were confirmed by Hattie and Donoghue (2016), who, in a recent paper, based on a meta-synthesis of a large set of meta-analyses, stated that active forms of learning, such as inquiry learning, that promote the acquisition of deep knowledge have a profound effect, but only when they are offered to learners after they have acquired the necessary prerequisite knowledge. Moreover, they highlight the importance of active learning methods such as inquiry learning in order to gain deep-level understandings in science education, because future learning in science education usually builds upon this knowledge.

Taken together, a lack of prior knowledge and/or little command over experiment design makes designing informative experiments difficult for many students. They often tend to design experiments that have nothing to do with their research question or that have design flaws that interfere with their ability to draw conclusions. Common mistakes include using irrelevant variables that have no relationship with the research question, leaving out relevant variables, varying too many variables at the same time, and not considering control variables (de Jong, 2006b). Considering the difficulties students experience, it is not surprising that inquiry learning has been found to be ineffective when students are minimally prepared and guided; however, inquiry approaches are effective and even superior to other instructional methods when proper guidance is given (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; d'Angelo et al., 2014; Hmelo-Silver, Duncan, & Chinn, 2007). Guidance allows students to achieve tasks they could not have accomplished on their own (Zacharia et al., 2015). In computer-supported learning environments, tools and scaffolds are among the best-documented forms of guidance (de Jong & Lazonder, 2014; Zacharia et al., 2015). They simplify or take over part of the task, allowing students to gain higher-order skills (de Jong, 2006b; Reiser, 2004; Simons & Klein, 2007).

Students' prior knowledge not only influences the quality of their spontaneous experimental designs, it also influences the type and amount of guidance that is beneficial. Many studies have demonstrated that students with diverse levels of prior knowledge benefit from different types of guidance (Kalyuga, 2007; Lambiotte & Dansereau, 1992; Tuovinen & Sweller, 1999). For example, Tuovinen and Sweller (1999) found that guidance in the form of worked examples was superior to exploration for low prior knowledge students who were learning to use a database programme; however, no differences in learning were found for high prior knowledge students, because they already possessed well-developed domain schemas. Lambiotte and Dansereau (1992) provided students with different forms of guidance during lectures (i.e. knowledge maps, outlines, and lists with key terms), and compared their recall of the material. They found that the most effective type of guidance for low prior knowledge learners was the least effective type for high prior knowledge students. Low prior knowledge students performed significantly better when they received knowledge maps then when they received an outline or a list with key terms, whereas the opposite was true for high prior knowledge students who performed best

with the list containing key terms. Kalyuga (2007) found that some forms of guidance that are beneficial for students with low prior knowledge can be redundant or even have negative effects for high prior knowledge students, which is referred to as the 'expertise reversal effect'. There seems to be a general consensus that low prior knowledge students benefit from higher levels of guidance than high prior knowledge students (Lazonder, Wilhelm, & Hagemans, 2008), but guidance can also add to the difficulty of a task when the guidance itself is hard to understand (Roll, Briseno, Yee, & Welsh, 2014; van Joolingen & de Jong, 1991). In some situations, low prior knowledge students perform better when they first enact trial-and-error types of behaviours, after which they can make better sense of the provided guidance and use it to their benefit (Roll, Briseno, et al., 2014; Roll, de Baker, Aleven, & Koedinger, 2014).

To guide students in designing experiments when performing an inquiry task with online labs, we designed a tool, the Experiment Design Tool (EDT), which was demonstrated to have a positive effect on conceptual learning gains for low and low-intermediate prior knowledge students in two previous studies (van Riesen et al., 2018; van Riesen et al., in review). The EDT guides students in designing their experiments by providing them with a predefined list of domain-related variables that are relevant for the experiments students are expected to design. The tool guides students in the process of specifying the independent, dependent and control variables, and in assigning values to the independent and control variables. It supports students in following a CVS approach, in that for each independent variable, students specify one value per experimental trial, and for each control variable they select one value that is automatically assigned to all trials within an experiment (for a detailed description of the EDT, see the Method section).

In the current study we further investigated the value of the EDT for inquiry learning, and we varied the level of guidance by providing not only a full version of the EDT in which variables had to be assigned to the categories of independent, dependent, and controlled, but also a minimalist version in which this distinction was not included. We wanted to explore whether this version was more beneficial for students with a high level of prior knowledge. In addition, we introduced a new component in the EDT, namely, a structured reflection about the experiment design.

Designing experiments (often as a series of trials) should be performed as a thoughtful and planned activity. This experiment design process can be facilitated by reflection about the process and the strategies used. A large body of research has demonstrated the importance and advantages of reflection for successful learning. Reflection can lead to deeper learning, help students integrate new and existing knowledge, allow them to gain more complex knowledge, and assist them to produce better experiments (Davis, 2000; Kori, Mäeots, & Pedaste, 2014). In inquiry learning, the goal of designing and conducting experiments is to gain knowledge and/or skills, which requires students to differentiate, integrate, and restructure ideas. Reflecting on original ideas, obtained experiment results, and relationships between ideas and results can help students to successfully process all the information and build a coherent understanding (Linn, Eylon, Rafferty, & Vitale, 2015), on the basis of which they can revise their experimentation strategies and develop more effective strategies for designing experiments (Davis, 2000; Linn et al., 2015; Pedaste et al., 2015). In order to increase the quality of students' reflections, students can be prompted to evaluate their experimental designs based on a set of carefully chosen criteria (Kori et al., 2014; White & Frederiksen, 1998). In the current study, we evaluated a

Reflection Tool that prompted students to carefully screen their experiments and consider lessons learned for future experiment design.

In two previous studies (van Riesen et al., 2018; van Riesen et al., (in review), different versions of the EDT were found to have a positive effect on conceptual learning gain for low and low-intermediate prior knowledge students. In the current study, we aim to acquire a better understanding of how the EDT can be adapted and used to benefit students with all levels of prior knowledge. For this purpose, in the current study we compared three versions of the EDT: a minimalist version of the EDT, a regular version of the EDT, and a regular version of the EDT with incorporated reflection questions.

Method

The current study focused on the effect of different types of guidance for designing and conducting experiments on students' gain in knowledge about the physics topics of buoyancy and Archimedes' principle. Three conditions were compared, each of which involved third-year pre-university students who worked in an online inquiry learning environment incorporating a virtual lab, but with a different version of the Experiment Design Tool in each case.

Participants

A total of 167 third-year pre-university students, approximately 15 years of age, participated in the current study. Twenty students were excluded from the analyses: eighteen because they missed a session, one because this student's difference score on the test about Archimedes' principle deviated more than 2 SDs from the overall mean, and one because this student's difference score on the test about Archimedes' principle deviated more than 2 SDs from the mean of the low-intermediate prior knowledge group to which the student belonged. This left a total of 147 students whose data were taken into account for analyses. All students had already learned about buoyancy within their regular science classes, but the topic of Archimedes' principle was new to them. Buoyancy was included in the learning environment so that the students could familiarise themselves with the learning environment and to activate their prior knowledge about buoyancy, which is a prerequisite to learn about Archimedes' principle. The students participated in the experiment during their regular science classes and participation was obligatory.

Domain and learning environment

Students in all conditions worked in an online inquiry learning environment created with the Go-Lab software (Gillet, Rodríguez-Triana, de Jong, Bollen, & Dikke, 2017) revolving around buoyancy and Archimedes' principle. Three versions of the same online inquiry learning environment were created. All environments were organised with three types of tabs: the method tab, two orientation tabs (one for buoyancy and one for Archimedes' principle), and a set of experiment tabs (see Figure 1). In the method tab, information was provided about navigating through the inquiry learning environment, about the type and purpose of the inquiry learning, and about actions students could perform and how they could do that. The orientation tabs contained
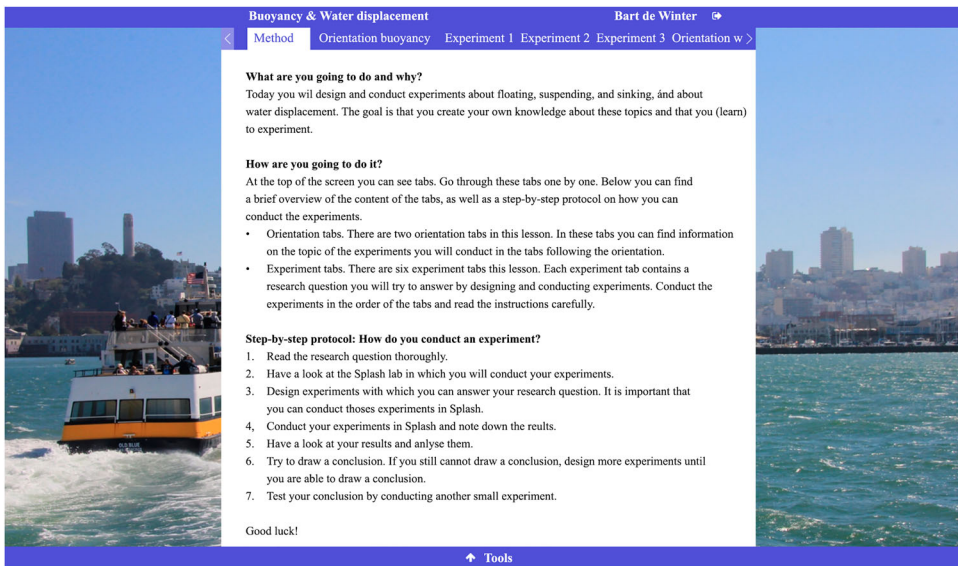
Figure 1. The learning environment.

materials such as texts, images, and videos, and was intended to activate (prior) knowledge about buoyancy and Archimedes' principle. Each experiment tab contained a research question (e.g. 'How do the mass, the volume, and the density of a floating ball influence the amount of water that is displaced in terms of mass and volume?') together with a version of the EDT that enabled students to design their own experiments, an online laboratory called Splash, and a conclusion text box.

The three inquiry learning environments that were developed for use in this study were identical, and differed only with respect to the type of guidance provided for designing experiments and the texts related to that. The guidance students received in the different conditions is described in detail in the section on Experiment Design.

Online virtual lab: Splash

Splash is a virtual laboratory about buoyancy and Archimedes' principle (see Figure 2). In Splash, several fluid-filled tubes are shown, in which balls can be dropped. The density of the fluids in the tubes, as well as the mass and volume (and therefore the density) of the balls can be manipulated. Mass divided by volume equals density; therefore, mass and volume of the balls could be specified by the user. Density of the balls was automatically calculated by Splash, based on the values students had chosen for mass and volume.

After specifying the mass and volume variables for the balls and the density of the fluid, students could drop the balls in the tubes and observe whether the balls sank, suspended, or floated in the fluids. The labs about buoyancy allowed students to refresh their knowledge about the relationships between mass, volume and density, and between the density of an object, the density of the fluid, and floatability. The labs about Archimedes' principle (see Figure 2) allowed students to additionally inspect the mass and volume of the displaced fluid, as well as the forces involved.
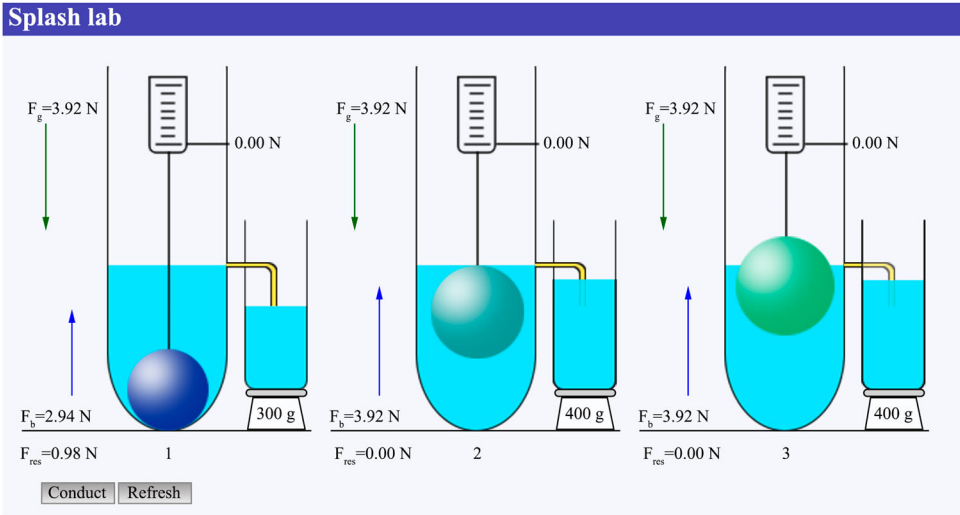
Figure 2. Online virtual lab 'Splash': Archimedes' principle lab.

Experiment design

The three conditions differed with respect to the tool (EDT) that guided students in the design of their experiments: (1) in the EDT condition students used the full version of the EDT, (2) in the EDT+ condition, students worked with the Reflection Tool in addition to the full version of the EDT, and (3) students in the EDT− condition worked with a minimalist version of the EDT.

Experiment design tool

The Experiment Design Tool (Figure 3) in its full version presented students with a pre-defined list of domain-related variables that were relevant for the experiments students had to design in order to be able to answer research questions.
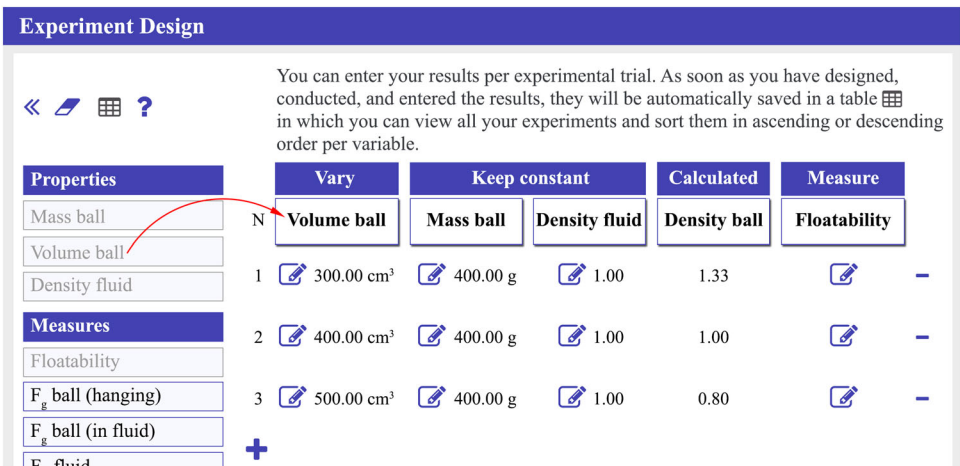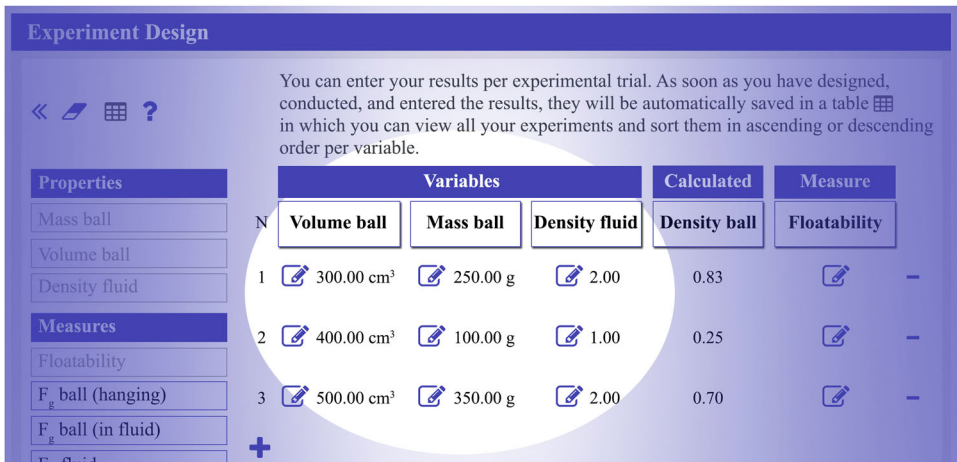

Figure 3. Regular experiment design tool.

For each variable, students could drag and drop the variable into one of three boxes (see Figure 3). This indicated whether they wanted to vary it (independent variable), keep it constant (control variable), or measure it (dependent variable). For each independent variable students specified one value per experimental trial, and for each control variable they selected one value that was automatically assigned to all trials within an experiment. Students could only choose values within a given range in order to restrict their choices. The trials that students designed in any EDT were automatically transferred to the lab, so that students could run an experiment without having to retype the values they had chosen for the independent and control variables. After the students had conducted their experimental trials based on the values they assigned to the variables, they could observe the resulting effects, and enter their results in the tool. The designed experiments were automatically transferred to the Splash lab so that students did not need to enter the values for the independent and control variables again; however, to force the students to take good notice of the experimental outcomes, the obtained values for the dependent variable were not automatically filled in, but had to be entered by the students themselves. Students were encouraged to design and conduct as many experiments as necessary to be able to draw a conclusion.

At any time, students could view all their previously designed and conducted experimental trials by pressing the table icon (Figure 3, top left). In the table, they could sort their data per variable in ascending or descending order, making it easier to compare trials.

Minimalist experiment design tool

In the EDT− condition students had to design their experiments using a minimalist version of the Experiment Design Tool (Figure 4). The only difference from the full version of the EDT is that the minimalist EDT did not distinguish between independent and control variables. Instead, students could simply drag variables into the table and assign a value to each variable in each trial. The minimalist EDT provided students with the same variables as the full EDT, as well as an identical range of values to assign to the variables.

Figure 4. Minimalist experiment design tool.

Experiment design tool with integrated reflection tool

In the EDT+ condition a reflection component was integrated in the EDT. After students designed an experiment and conducted at least three trials, they had to answer reflection questions that were based on the design of their experiment. For example, students were asked whether they had designed relevant trials and enough trials to be able to answer the research question completely. If they indicated that they did, the Reflection Tool extracted information about the number of varied variables from the student log files to ask specific questions about why students varied one or more variables in their experiment. Subsequent reflection questions were again based on students' designed experiment and concerned strategies that students had used for assigning values to the variables. For example, students who changed one variable were asked why they had chosen to assign (1) extreme values, (2) values with the same increment between trials, (3) values within a small range, or (4) another strategy. They could enter their conclusions on the research question only after they had entered their response to the reflection questions. The reflection procedure is visualised in Figure 5. Please note that students had to continue designing, conducting and reflecting on their experiments until they reached the conclusion input box in which they could type their conclusion.

Knowledge test

A paper-based test measured students' knowledge about buoyancy and Archimedes' principle. The parallel pre- and post-test version of the test each allowed students to gain a total of 25 points for open questions concerning buoyancy and 33 points for open questions concerning Archimedes' principle. An example of a question is:

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
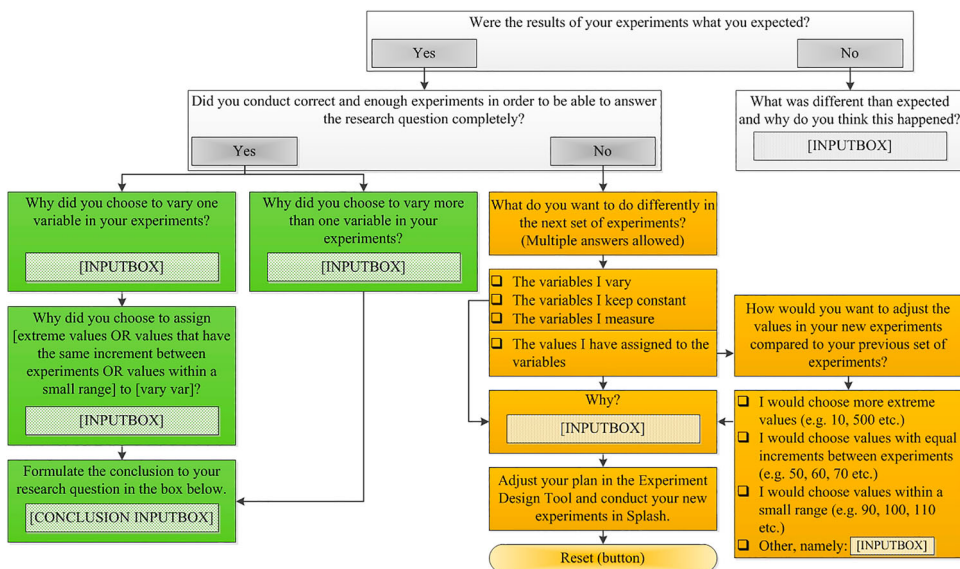

Figure 5. Flowchart reflection questions.

released. Provide the amount of displaced water and the values displayed on the spring balance and the scale after the ball has been released in the tube.

Students could receive one point for each correct value they provided, meaning that they could obtain four points for the entire question in the example. Students could obtain a total of 58 points. Cronbach's Alpha was .933 for the pre-test about buoyancy and .893 for the pre-test on Archimedes' principle, .898 for the post-test on buoyancy and .910 for the post-test on Archimedes' principle, meaning that the reliabilities of the tests are very high.

Procedure

The study involved four sessions of 45–50 min each, which all took place inside the classroom within a timeframe of two and a half weeks. We chose to conduct our study inside the classroom, because this provides us with valuable insights into students' learning within their natural environment where the tool will ultimately be used. Students' prior knowledge about buoyancy and Archimedes' principle was measured during the first session. They were given thirty minutes to complete the pre-test; all of them finished within this time limit. After the test, students were assigned to their conditions; they were ranked based on their previous physics grade and then assigned to a condition to create three comparable participant pools for each condition. The remaining time was used to instruct students within their condition on how to work with the learning environment. Each group of students was shown the learning environment they were going to work with. The experimenter first showed the method tab and discussed all the information in this tab (i.e. what they were going to do and why, how they would do it, and a step-by-step procedure for conducting an experiment). It is important for students to understand the purpose of the activity and how to perform the activity, which is why everything was discussed thoroughly and they were encouraged to ask any questions they had. Then the orientation tab was shown and students were told that they could find any information they might need to successfully conduct their experiment there. Third, the research tab was shown, which included the research question, the EDT, a conclusion text box, and in the EDT+ condition the reflection tool. A demonstration of the EDT was given, in which all the options were used and explained. In the EDT+ condition, the reflection tool was also demonstrated and they were told that the questions were meant so that they would carefully think about their experiments. Students could get clarifications if they did not understand a question. For example, one reflection question asked them if they had conducted correct and enough experiments in order to be able to answer the research question; students were informed that correct and enough experiments meant that their conclusions to the research questions were based on the results they obtained from their experiments and that they should conduct as many trials as necessary to eliminate chance. During the second session, students worked with the learning environment on the topics of buoyancy and water displacement. At the start of the session, they were encouraged to read the research questions in the experiment tabs very carefully, in order to design useful experiments so that they could draw conclusions. All necessary prior domain information could be found in the learning environment, as well as instructions they had already received orally in the first session. Then, students started to work on experiments related to the domains of buoyancy and part of

Archimedes' principle (water displacement). During the third session, students worked with the learning environment on experiments related to the domain of Archimedes' principle. In the fourth session, students again had thirty minutes to complete the post-test about buoyancy and Archimedes' principle.

Results

Our first analysis addressed whether students had learned from working with the learning environments, and if there was a difference in learning gains between conditions. A one-way repeated measures ANOVA with the pre- and post-test as time factors showed a significant learning gain for buoyancy, $F(1, 144) = 65.62$, $p < .0005$; Wilk's $\Lambda = 0.687$, partial $\eta^2 = .31$, and for Archimedes' principle, $F(1, 144) = 119.82$, $p < .0005$; Wilk's $\Lambda = 0.546$, partial $\eta^2 = .45$. No significant differences were found between conditions for buoyancy, $F(2, 144) = 0.20$, $p = .822$; Wilk's $\Lambda = 0.997$, partial $\eta^2 = .003$ or Archimedes' principle, $F(2, 144) = 0.33$, $p = .718$; Wilk's $\Lambda = 0.995$, partial $\eta^2 = .005$. The mean scores and the standard deviations on the pre- and post-test, as well as the difference scores between pre- and post-test, are shown in Table 1. These scores seem to indicate that students had greater prior knowledge of buoyancy than of Archimedes' principle and also that they ended up with greater knowledge of buoyancy than of Archimedes' principle.

Our second main interest was the effect of prior knowledge on students' gain of conceptual knowledge when receiving different levels and types of guidance for designing experiments. Based on their pre-test scores, students were classified as low prior knowledge (L) students, low-intermediate prior knowledge students (LI), high-intermediate prior knowledge students (HI), or high prior knowledge students (H). Table 2 shows the classification of students based on their prior knowledge. Students were classified as to their knowledge level for buoyancy and Archimedes' principle separately, meaning that a student could, for example, be a high prior knowledge student for buoyancy, but a low prior knowledge student for Archimedes' principle.

For buoyancy, the number of students in the categories were 21, 32, 29 and 65 (from low to high, respectively). Because the data were not normally distributed, independent samples Kruskal–Wallis tests were performed for each category, and no significant differences were found between conditions for gain in conceptual knowledge, see Table 3.

For Archimedes' principle, student numbers were not evenly divided over the different categories, with 92 and 46 students in the two low prior knowledge categories and only 7 and 2 students in the two high prior knowledge categories (from low to high, respectively).

Table 1. Test scores by condition.

Test	EDT (N = 52)		EDT+ (N = 48)		EDT− (N = 47)		Total (N = 147)	
	M	SD	M	SD	M	SD	M	SD
Buoyancy (max = 25)								
Pre-test	16.04	7.31	15.40	7.78	17.28	6.93	16.22	7.34
Post-test	20.69	4.16	19.54	6.27	21.15	4.79	20.46	5.14
Difference score	4.65	6.92	4.15	5.66	3.87	6.24	4.24	6.28
Archimedes' principle (max = 33)								
Pre-test	7.33	6.66	7.15	5.36	7.45	5.56	7.31	5.88
Post-test	13.71	8.59	12.77	6.92	12.83	6.88	13.12	7.50
Difference score	6.38	6.25	5.63	7.24	5.38	5.65	5.82	6.39

Table 2. Classification of students based on their prior knowledge.

Type of student	Pre-test buoyancy	Pre-test Archimedes' principle
Low prior knowledge	0–6 correct	0–8 correct
Low-intermediate prior knowledge	7–12 correct	9–16 correct
High-intermediate prior knowledge	13–18 correct	17–24 correct
High prior knowledge	19–25 correct	25–33 correct

Consequently, no analysis could be performed or conclusions drawn for the two highest categories for Archimedes' principle. Independent samples Kruskal–Wallis tests for Archimedes' principle showed a significant difference between conditions in gain of conceptual knowledge for low-intermediate prior knowledge students, $H(2) = 6.20$, $p = .045$, but not for the low prior knowledge students, $H(2) = 0.54$, $p = .765$. Follow-up Mann–Whitney analyses for the low-intermediate prior knowledge students showed significant differences between the EDT condition and the EDT− condition, ($U = 153.00$, $p = .037$), as well as between the EDT condition and the EDT+ reflection condition, ($U = 69.50$, $p = .027$), both in favour of the EDT condition. Table 4 shows the means and standard deviations of the pre- and post-test scores, as well as difference scores, for Archimedes' principle for the low and the low-intermediate groups.

Conclusion and discussion

In the current study, third-year secondary students designed and conducted experiments in an online inquiry environment to learn about buoyancy and Archimedes' principle. Three types of guidance were compared in terms of students' gain of conceptual knowledge. Overall, no differences were found between conditions. However, when we took prior knowledge level into account, we found a significant difference between conditions for low-intermediate prior knowledge students (who had 26–50% correct on the pre-test about Archimedes' principle) for Archimedes' principle. Low-intermediate prior knowledge students who worked with the regular Experiment Design Tool had an increase in score from pre- to post-test that was almost double the increase of students in both of the other conditions.

Among scholars, there is a general consensus that low prior knowledge students benefit from additional guidance (Kalyuga & Renkl, 2010). Guidance can act as a substitute for the knowledge and skills that are required to accomplish a task (Tuovinen & Sweller, 1999). Results of the current study partly support this view, but also add a few nuances to this overall conclusion. For the buoyancy domain, we did not find differences between conditions for any of the prior knowledge level categories. This may have been caused by the fact that buoyancy was a topic that students had studied before and that overall did not give them too many problems, as became clear from the average scores on the pre- and post-test for buoyancy. All of the learning environments may have refreshed students' memories about the subject matter, given the relatively high knowledge gains in all groups. So, if a domain is relatively simple for students they can succeed without too much guidance. For Archimedes' principle, the situation was different. Here, students scored much lower on the pre-test, to the extent that we did not have enough students in the two high prior knowledge level categories to do analyses. Still, interesting patterns emerged from the analyses for the low prior knowledge and low-intermediate prior

Table 3. Statistics of students within their prior knowledge group.

PK	Test values			Condition											
				EDT−			EDT			EDT+			Total		
	H		*p*	*N*	*M*	SD	*N*	*M*	SD	*N*	*M*	SD	*N*	*M*	SD
Buoyancy knowledge gain															
L	5.404	2	.067	5	11.20	5.26	7	16.00	4.97	9	8.33	6.02	21	11.57	6.25
L-I	0.358	2	.836	9	8.22	6.12	11	8.18	5.29	12	7.08	5.87	32	7.78	5.59
H-I	2.555	2	.279	8	6.50	4.72	13	3.46	4.91	8	5.00	4.72	29	4.72	4.81
H	0.111	2	.946	25	0.00	3.86	21	−0.24	2.90	19	−0.53	2.12	65	−0.92	3.08
Archimedes' principle knowledge gain															
L	0.536	2	.765	31	6.16	5.70	32	6.00	6.56	29	6.90	8.03	92	6.34	6.74
L-I	6.204	2	.045	14	3.86	5.76	15	8.67	4.98	17	4.41	5.26	46	5.63	5.63
H-I	–	–	–	2	4.00	2.83	3	−0.33	6.66	2	−2.50	3.54	7	0.29	5.06
H	–	–	–	–	–	–	2	5.50	0.71	–	–	–	2	5.50	0.71

Table 4. Test scores of students with low and low-intermediate prior knowledge about Archimedes' principle.

	EDT (n = 32)		EDT+ (n = 29)		EDT− (n = 31)		Total (n = 92)	
Test	M	SD	M	SD	M	SD	M	SD
Low prior knowledge students								
Pre-test	3.13	3.12	3.62	3.28	4.35	3.37	3.70	3.26
Post-test	9.13	6.46	10.52	7.02	10.52	6.21	10.03	6.52
Difference score	6.00	6.56	6.90	8.03	6.16	5.70	6.34	6.74
Test	EDT (n = 15)		EDT+ (n = 17)		EDT− (n = 14)		Total (n = 46)	
	M	SD	M	SD	M	SD	M	SD
Low-intermediate prior knowledge students								
Pre-test	11.60	1.99	11.94	2.30	12.57	3.11	12.02	2.46
Post-test	20.27	5.75	16.35	5.45	16.42	5.75	17.82	5.81
Difference score	8.67	4.98	4.41	5.26	3.86	5.76	5.63	5.63

knowledge students only. Low-intermediate prior knowledge students using the full version of the Experiment Design Tool that distinguished independent and control variables performed better than low-intermediate prior knowledge students in the EDT− condition who used the minimalist version of the Experiment Design Tool, which did not provide students with that distinction. In the full version of the EDT, a clear distinction is made between independent and control variables, encouraging students who worked with this tool to consider control variables and design more structured experiments. In contrast, students in the EDT− condition had to think about controlling variables on their own, and thus had to be aware of the advantages of designing more structured experiments. Arnold et al. (2014) analysed difficulties students (aged 16–19) encountered in designing experiments, and found that 75% of the students failed to consider control variables. They suggested guiding students in this by showing them how they can control variables, which is what the full version of the Experiment Design Tool does.

Low-intermediate prior knowledge students who worked with the Experiment Design Tool but who also were required to reflect upon their experiments also showed lower increases in scores from pre- to post-test than students who used the full version of the Experiment Design Tool, comparable to students in the EDT− condition. This may be explained by the difficulties students often experience when they have to reflect upon their learning; reflection can be considered to be a task by itself (Kori et al., 2014). In the current study, students who had to reflect upon their experiment designs, were instructed on how to use the reflection tool but they did not receive extensive training about reflection. Considering the already difficult processes involved in designing experiments and the students' limited prior knowledge about the subject matter, the additional task of reflection may have made it too difficult without extensive reflection training, resulting in limited conceptual knowledge gains.

Another outcome we want to highlight is that we found a significant difference between conditions for the topic of Archimedes' principle only for low-intermediate prior knowledge students, and not for low prior knowledge students. A fair share of scholars have found that students with low prior knowledge benefit from higher levels of guidance (e.g. Lazonder et al., 2008), based on which we expected that low prior knowledge students would benefit the most, and high prior knowledge students the least, from additional guidance for designing experiments in terms of knowledge gain, but this was not supported by our data. We hypothesise that students need to possess at least some prior knowledge,

or time to gain this knowledge, in order for them to benefit from guiding tools in online learning environments. In the current study, students were provided with orientation materials on the topic being investigated, but familiarising themselves with the topic meant that they could spend less time on their experiments. Low prior knowledge students had to acquire the required prior domain knowledge, and in addition had to apply this knowledge by designing and conducting informative experiments from which they could extract knowledge. Alternatively, they could skip the step of getting familiar with the subject matter, and start designing and conducting experiments immediately, which is rather difficult or even impossible without the necessary prior knowledge. In both scenarios, low prior knowledge students would need more time to learn about the subject matter than their more knowledgeable peers. In addition to this, low prior knowledge students often apply less sophisticated strategies and require more trials to reach conclusions than students with more prior knowledge (Alexander & Judy, 1988; Klahr & Dunbar, 1988). All of this may have prevented them from utilising the offered additional guidance to their benefit.

Our study demonstrates that the type of guidance that is expected to be effective for students with different levels of prior knowledge needs to be considered very carefully, because the boundary between what works and what does not work can be very narrow. This also calls for a flexible and adaptive design of guidance. Software developers should develop guidance that is configurable by the teacher or that automatically adapts to students' levels of learning. In our study we used an EDT that we adapted to create three versions simply by changing the configurations which can easily be done by teachers themselves. This allows them to use the same tool in the classroom for learners with distinct levels of prior knowledge and to adapt the tool when necessary. Ideally, students' knowledge and skills should be monitored regularly in order to make a good fit between guidance and students' needs. Our results suggest that for guidance to have an effect, prior knowledge needs to be at a level such that the guidance can build upon the students' initial knowledge and skills but it should stay within the students' capabilities of handling the guidance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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