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Siswa A. N. van Riesen, Hannie Gijlers, Ton de Jong, Anjo Anjewierden

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Supporting Planning and Conducting Experiments

Siswa A. N. van Riesen, Hannie Gijlers, Anjo Anjewierden, and Ton de Jong,
s.a.n.vanriesen@utwente.nl, a.h.gijlers@utwente.nl, a.a.anjewierden@utwente.nl, a.j.m.dejong@utwente.nl
University of Twente

Abstract: In inquiry learning learners design and conduct experiments. Learners experience difficulties with the involved processes and need guidance to design useful experiments. To guide students in this we created a configurable experiment design tool that is usable in multiple domains. The tool was tested with two configurations; one with a CVS structure in which learners had to design at least three experimental trials before conducting their experiment, and one in which this was not required. In the current study secondary students designed and conducted experiments in an online lab about buoyancy and Archimedes' principle. Three conditions were compared in terms of students' conceptual knowledge gain. Students worked with one configuration of the tool, or with no tool. Results showed significant differences between conditions for lower prior knowledge students' learning gain about buoyancy.

Introduction

Inquiry learning stimulates learners to actively construct their own knowledge by means of doing investigations, allowing them to gain higher-order understandings, instead of passively absorbing information presented to them. Learners follow (part of an) inquiry cycle that comprises orienting on the topic of interest, formulating hypotheses and/or research questions, setting up and conducting experiments, drawing conclusions, and reflecting upon their inquiry (Pedaste et al., 2015). Moreover, inquiry learning promotes learners' autonomous working attitudes and inquiry skills, both of which are important educational objectives in current curricula worldwide; it also promotes a positive attitude towards learning, and it motivates them to acquire, integrate, and apply new knowledge (Edelson, Gordin, & Pea, 1999).

An important phase of inquiry learning is the investigation phase during which learners design and conduct experiments to test a hypothesis or answer a research question. Based on results from their experiments they analyse their data and draw conclusions accordingly. The experimentation phase thus builds a bridge between the hypothesis or research question and the analysis of the data.

However, learners find it difficult to design valuable experiments (de Jong & van Joolingen, 1998). It involves several processes and requires understanding of inquiry. They need to understand that they have to design experiments with which they can test their hypothesis or answer their research question. Often learners design experiments that do not comply with their hypothesis or research question, for instance by including variables that have nothing to do with it (de Jong & van Joolingen, 1998).

After selecting relevant variables, learners need to determine what to measure (dependent variable), vary (independent variable) and control for (controlled variable). Then they have to assign values to the independent and controlled variables. Learners often vary too many variables, which makes it difficult to draw correct conclusions because any effect that occurs may be due to a variety of influences. An effective strategy often applied by professional researchers is the Control of Variable Strategy (CVS) in which only one variable of interest is varied and all other variables are kept constant (Klahr & Nigam, 2004). CVS allows learners to draw conclusions from unconfounded experiments.

In order to successfully learn from experimentation learners must plan and apply systematic ways of designing experiments (de Jong & Njoo, 1992). However, research indicates that learners tend not to analyse a task or problem they have to solve, but to act immediately, without planning (Manlove, Lazonder, & de Jong, 2006). If learners do engage in planning, they often use unsystematic ways, which may cause them to struggle with the task (de Jong & van Joolingen, 1998).

Guiding learners in planning and conducting experiments helps them to design useful and systematic experiments from which they can derive knowledge (Zacharia et al., 2015). In computer supported inquiry learning environments some of the most often used forms of guidance are heuristics and tools. Heuristics are hints or suggestions about how to carry out assignments, actions, or learning processes. Examples of heuristics to direct learners to apply the CVS strategy are 'vary one thing at a time (VOTAT)', and 'control all other variables by using the same value across experimental trials' (Veermans, van Joolingen, & de Jong, 2006). Tools can transform or take over part of a task and thereby help learners accomplish tasks they would be unable to do on their own (de Jong, 2006). An example is a monitoring tool in which experiments are stored (Veermans, de Jong, & van Joolingen, 2000). Learners can replay conducted trials, and rearrange them in ascending or descending order to be better able to compare results. It eliminates the difficulty of remembering conducted experimental trials, interpreting results, and simultaneously thinking of appropriate follow-up trials.

Based on heuristics and scaffolding elements that have shown to be effective for learning, an Experiment Design Tool (EDT) was developed that can be applied in different domains and configured so that it fits teachers' intentions with the inquiry learning activity. In the current study two configurations of the EDT were compared in terms of effectiveness regarding students' learning gain about buoyancy and Archimedes' principle. One configuration incorporated the CVS-strategy and required planning; learners were obliged to apply CVS and to plan multiple trials before conducting their experiment. The other configuration had a more exploratory character; learners were free to conduct their designed trials when they wanted to and were not obliged to apply CVS.

Method

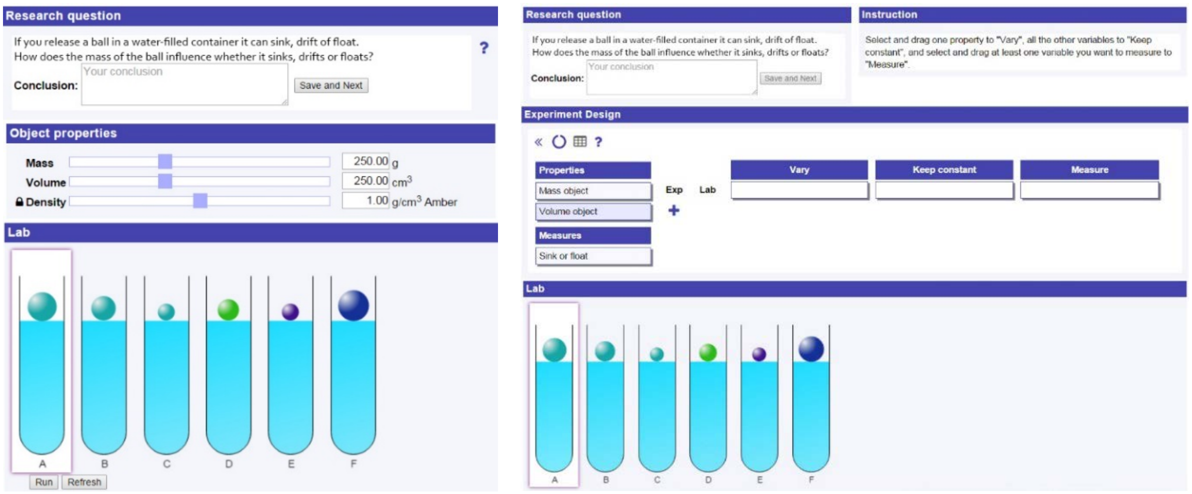
In the current study students planned and conducted experiments in an online learning environment about buoyancy and Archimedes' Principle. Three learning environments were compared with different levels of support for planning and conducting experiments, but that were the same in all other aspects. In two learning environments students received additional support for planning and conducting experiments by means of one of the two configurations of the EDT. In the third learning environment students were not guided by an additional tool.

Participants

A total of 159 third grade pre-university students (aged 15) from three secondary schools in the Netherlands were randomly assigned to one of the conditions. After eliminating outliers and students that missed a session -e.g. one class missed a session because of an overlooked field trip- 104 students remained for analyses.

Learning environments

The three learning environments in which students worked were all structured in similar ways. They all consisted of instructions, research questions, a virtual lab, a mechanism to prepare experiments, a help button to retrieve domain information, and a conclusion text box. Upon entering the environment, instructions appeared explaining that the student had to design experiments and conduct those in a virtual lab in order to answer research questions. The environment contained a total of fourteen questions presented one by one. For each research question students had to design and conduct an experiment, and draw a conclusion accordingly. Once students had submitted a conclusion, a new research question appeared for which they again had to design and conduct an experiment.



(a) (b)

Figure 1. The learning environments for the (a) control group, and (b) EDT conditions.

The learning environments only differed in the support offered to students (Figure 1). The environment of the control condition did not contain a tool to help plan experiments. Experiments were prepared and conducted directly in the lab by means of sliders to adjust the values of the variables in the experiment.

The environments of the EDT conditions each contained one configuration of the EDT to guide the preparation and conduction of experiments. It provided students with structure in the form of a table that incorporated and emphasised three types of variables (independent, controlled and dependent). Students could select variables from a box and decide per variable if they wanted to vary it across experimental trials, keep it constant, or measure it. After they specified the variables, they assigned values -within a restricted range- to the independent and controlled variables. For each independent variable they specified a different value per trial. For each controlled variable they assigned one value; the EDT automatically assigned that same value to all trials within the experiment. Results for the dependent variable could only be entered after the trials were conducted. In addition to preparing the experiments, the EDT offered a second table in which all the previously conducted trials were presented. In this table, variables could be sorted in ascending or descending order, making it easier to reach conclusions or decide if more trials or even experiments were required to answer the research question. At all times, students could see instructions about how to operate the EDT. The instructions were just-in-time and were based on students' actions. For example, when students started planning an experiment, they were instructed to drag and drop all properties to the boxes vary or keep constant, and to drag at least one variable to measure. The two configurations of the EDT differed in three aspects. In one configuration students were obliged to 1) apply CVS, 2) plan at least three trials before conducting experiments, and they 3) received different instructions that were congruent with these two aspects. In the other configuration students were able to, but not obliged to, do the same and they received instructions congruent with the configuration.

Assessment

Students' conceptual knowledge of buoyancy and Archimedes' principle was assessed both before and after the intervention with a parallel pre- and post-test. The test consisted of 58 open questions that measured students' understanding of the key concepts and principles of the topics in the virtual lab.

Procedure

The study was performed during four sessions of 50 to 60 minutes each, over a period of two and a half weeks. In the first session the students received instructions about what they were going to do. Thereafter they had half an hour to complete the pre-test, which was sufficient for all students to finish. Finally, they were randomly assigned to a condition, received instructions about the upcoming tasks, the learning environment was shown, and they could ask any question. During the second session students first received a booklet matching the condition they were assigned to and then individually worked with the learning environment behind a computer to learn about buoyancy. The booklet contained instructions about the tasks, and all the research questions they had to answer during the session. The third session was similar to the second session; students also worked with the learning environment but the topic of investigation was Archimedes' principle instead of buoyancy. During the fourth session students took the post-test and were informed about the purpose of the study.

Results

A significant conceptual knowledge learning gain was found in all conditions for buoyancy (control condition: n = 34, $Z = 3.226$, $p = .001$; exploratory EDT condition: n = 33, $Z = 3.302$, $p = .001$; more structured EDT condition: n = 37, $Z = 3.015$, $p = .003$) and for Archimedes' principle (control condition: n = 34, $Z = 3.554$, $p < .001$; exploratory EDT condition: n = 33, $Z = 2.943$, $p = .003$; more structured EDT condition: n = 37, $Z = 2.757$, $p = .006$) using Wilcoxon signed-rank tests. Independent-Samples Kruskal-Wallis Tests showed no significant differences between the conditions for both parts of the test (buoyancy: $H(2) = .253$, $p = .881$; Archimedes' principle: $H(2) = .651$, $p = .722$).

However, research shows that tools can be especially effective for low prior knowledge students. We divided students in two groups based on pre-test scores; one group included students with the 50% lowest scores and the other group included students with the 50% highest scores. Independent-Samples Kruskal-Wallis Tests demonstrated a significant difference in learning gain between conditions for lower prior knowledge students on buoyancy, $H(2) = 6.17$, $p = .046$, in favour of the exploratory EDT condition (control: $M = 7.17$, $SD = 5.68$; exploratory EDT: $M = 10.93$, $SD = 5.28$; more structured EDT: $M = 5.75$, $SD = 6.58$), but not for Archimedes' principle. Also, no significant difference was found for higher prior knowledge students.

Conclusions and implications

The current study showed a different effect of guidance for lower prior knowledge students, who performed better with guidance in the form of an exploratory EDT on the first domain, than for higher prior knowledge students, who did equally well with and without guidance, which is in line with other research. Higher prior knowledge students often demonstrate more well-structured, goal-oriented inquiry behaviour; they use more sophisticated strategies to induce knowledge and encounter less problems than lower prior knowledge students (Hmelo, Nagarajan, & Roger, 2000). Additional support for higher prior knowledge students has found to be redundant, because they already have sufficient knowledge to construct mental representations (Kalyuga, 2007).

Research about the level of support for lower prior knowledge students shows that they find it difficult to interpret support, and perform better when they first have the opportunity to explore the domain of interest by themselves rather than immediately starting with systematic ways of designing experiments. However, research also suggests that these learners benefit from more support because additional guidance helps overcome missing schemas and reduces working memory load (Roll, Briseno, Yee, & Welsh, 2014). Interestingly, the current study showed that lower prior knowledge learners performed best when they were guided by a tool, bút this effect was only found in the first domain and the tool had to be configured so that students could still explore the domain without too many restrictions. The different effect of guidance for buoyancy and Archimedes' principle might be explained by the level of difficulty of the two domains. Buoyancy -the first domain of experimentation- is generally regarded as easier than Archimedes' principle by students. We hypothesise that students received enough support to let them perform better on the tasks within buoyancy, whereas they may have needed additional support for the more difficult topic of Archimedes' principle. Future studies should focus on students' inquiry processes and the level and form of support they need in distinct domains with different levels of difficulty.

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