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EXAMINING THE ADDED VALUE OF THE USE OF AN EXPERIMENT DESIGN TOOL AMONG SECONDARY STUDENTS WHEN EXPERIMENTING WITH A VIRTUAL LAB

Nikoletta Xenofontos[1], Anna Fiakkou[1], Tasos Hovardas[1], Zacharias C. Zacharia[1], Anjo Anjewierden[2], Lars Bollen[2], Margus Pedaste[3]

[1] University of Cyprus (CYPRUS)
[2] University of Twente (THE NETHERLANDS)
[2] University of Tartu (ESTONIA)

Abstract

The purpose of this study was to evaluate the effect of a newly developed software tool, namely the Experiment Design Tool (EDT), on student's learning and inquiry skills. To do so, two conditions were compared; the experimental condition (use of the EDT) and the control condition (no use of the EDT). In each condition, an Inquiry Learning Space (ILS; an online learning environment) and a virtual lab were selected from the Go-Lab learning platform (http://www.golabz.eu/). The data collection involved pre- and post-tests on students' content knowledge and inquiry skills. Results revealed that the integration of the EDT in a computer supported inquiry learning environment facilitated the advancement of content knowledge, whereas the development of inquiry skills requires longer experience with such EDT tools or learning environments. Further research should be pursued, with students of different ages and in different subject domains, in order to investigate the effect of the EDT on students' learning and inquiry skills.

Keywords: Experiment, inquiry based learning environments, virtual lab.

1 INTRODUCTION

Experimentation is a crucial aspect of inquiry. It is at the center of the investigation phase of the inquiry cycle [1] and it influences preceding and subsequent inquiry phases or processes, such as the data collection and the data interpretation processes [2]. Therefore, any failures during experimentation might lead to an inability to address the research questions and/or hypotheses at hand [1]. For instance, any mistakes during the conduction of an experiment could lead to the collection of wrong data and unavoidably to reaching to invalid and misleading conclusions [3].

Despite the fact that the execution of valid experiments is highly important in science education, the experimentation process is considered as the most demanding task of the inquiry process. The main challenge, students face during experimentation, is the large number of practices/skills that are required to enact experimentation. Specifically, these practices/skills include (a) the identification of the variables under study, primarily the independent and the dependent variable, (b) the identification of the materials/equipment needed for executing the experiment, (c) the classification of variables in independent, dependent and control variables, (d) the execution of multiple experimental trials in order to produce a number of values concerning the dependent variable and (e) the organization of the data produced, usually in tables and graphs. The complexity of this sequence of tasks and the probability of an incorrect action or an omission during one or more of the aforementioned practices would negatively impact the experimentation process (e.g., [4], [5].

Several studies have shown that students fail to enact experimentation successfully and the difficulties that they encounter are related with the aforementioned practices/skills [6]. A common mistake that students make is that they design experiments that do not correspond to the research questions and/or hypotheses they want to address [7] [8]. Due to the difficulties that students face during the experimentation, the development and use of appropriate guidance is needed, in order to help students design and conduct valid experiments [9].

Previous research, revealed several types of guidance that were developed to provide support during the experimentation, such as prompts, performance dashboards, heuristics and scaffolds [9]. For example, van Joolingen and de Jong [10] have designed, developed and implemented a monitoring performance dashboard tool in the SimQuest computer-based learning environment, which allowed students to review and (re-)play experiments stored in a summary table. Chang et al. [11] used prompts during the experimental design, which guided students on how to conduct an experiment, whereas Lin and Lehman [5] designed and used prompts guiding students to reflect on their strategies when varying and controlling variables. In addition, the use of heuristics was found to benefit students' learning [12]. A very popular heuristic is the VOTAT (varying one thing at a time) heuristic, which has been documented by several researchers (e.g., [11], [13], [14]) for its positive influence in guiding students to design unconfounded experiments [9].

Finally, one of the rarest types of guidance found during experimentation are scaffold tools. According to a recent review on the types of guidance in computer supported inquiry learning environments [9], only one scaffold has been reported so far, namely the SCYED tool [15], in which students can create a stepwise procedure when designing an experiment by choosing the variables at task, assigning values to variables, and describing how to conduct the experiment. Thus, research on evaluating the learning value of experiment design tools in science education is quite scarce and inconclusive. In this study, we conducted a quasi-experimental research study to investigate the learning value of a newly developed computer-based tool for supporting the experimental design process, namely the Experiment Design Tool (EDT). The EDT was designed and developed in the context of the Go-Lab project and it can be found in the Go-Lab platform (http://www.golabz.eu/).

2 METHODOLOGY

For the purpose of the study a computer-based learning environment focusing on buoyancy was created and used in two conditions, namely the experimental and the control condition. In the experimental condition, the EDT was included in the learning environment, while in the control condition, the EDT was absent and all activities that would be undertaken with this tool were conducted by means of a simple note-taking tool. Before and after the educational intervention, students in both conditions completed pre- and post-tests, respectively, focusing on content knowledge and inquiry skills. Fig.1 presents the flow that has been followed in the study. More details about participants and materials are provided in the next sections.

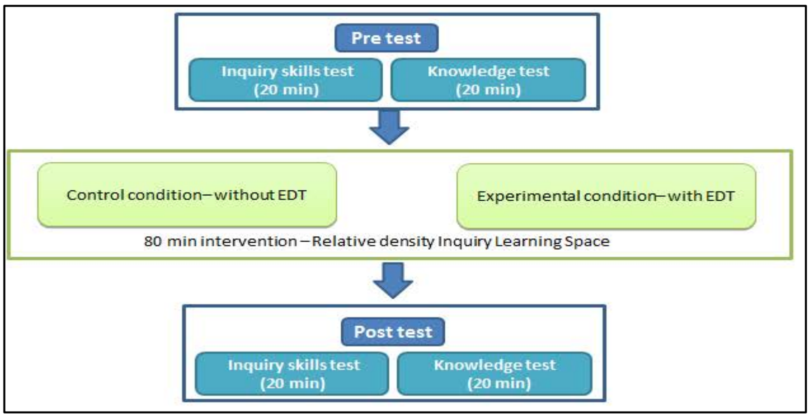


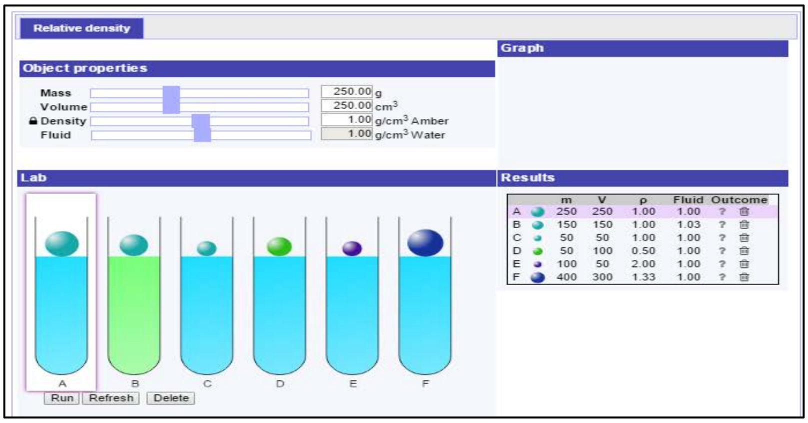
Figure 1. The flow of the study.

2.1 Participants

Eighth-graders were involved as participants in the study (23 students; 14-15 years old). These students came from two classes (N_{class1} = 11 and N_{class2} = 12) of a public high school in Nicosia, Cyprus. The first class (5 boys and 6 girls) was assigned to the experimental condition and the second class (5 boys and 7 girls) to the control condition. The selection of the school was based on the motivation of the teacher to participate in the study, while the two classes were selected because both contained students of mixed learning abilities. In addition, the students in both classes had been taught about sinking and floating in the sixth grade and they had advanced computer skills, allowing them to carry out learning activities in the computer-based learning environment.

2.2 Learning Environment

An Inquiry Learning Space (ILS) was created by means of the Go-Lab authoring tool [16]. The ILS was designed according to the framework of the inquiry cycle [1]. The ILS comprised five inquiry phases, namely, the *Orientation*, the *Conceptualization*, the *Investigation*, the *Conclusion* and the *Discussion* phase, focusing on elative density. In more detail, students learned about the relation of the variables of mass, volume and density and how density of an object influenced whether this object would sink or float in different fluids. During the activity sequence students conducted experiments in an online laboratory, the "Splash: Virtual Buoyancy Laboratory" (Fig. 2), which is available in the Go-Lab repository (http://www.golabz.eu/).



Mass 250.00 g
Volume 250.00 cm^3
Density 1.00 g/cm^3 Amber
Fluid 1.00 g/cm^3 Water

		m	V	ρ	Fluid	Outcome	
A	●	250	250	1.00	1.00	?	🗑
B	●	150	150	1.00	1.03	?	🗑
C	●	50	50	1.00	1.00	?	🗑
D	●	50	100	0.50	1.00	?	🗑
E	●	100	50	2.00	1.00	?	🗑
F	●	400	300	1.33	1.00	?	🗑

Figure 2. Splash: Virtual Buoyancy Laboratory.

In the *Orientation* phase, students predicted whether some objects would either sink or float by responding to a quiz. Afterwards, they watched a video that elaborated on the basic information about the main concepts of the lesson. In the next phase (*Conceptualization* phase), students became familiar with the Splash Laboratory and the variables that they could manipulate in that laboratory. Specifically, students could manipulate four variables, namely, the mass, the, volume and the density of an object, and the kind of the fluid in a container. They could add up to six containers and manipulate each one of them. When they would run the experiment, they would see what would happen in each container. All manipulations and outcomes were presented in a Results´ table in the right side of the tool´s interface.

The next step in the *Conceptualization* phase was the hypotheses formulation, which was undertaken by means of the Hypothesis Scratchpad (Fig.3). This tool contained predefined concepts and conditionals that were needed for generating hypotheses. Students could drag and drop the proper conditional and concepts in order to form their hypothesis in the form of an if-then statement. In addition, students had the opportunity to adjust their confidence level for each hypothesis, by changing the color of the "horseshoe" placed next to each hypothesis. If the "horseshoe" was blue, overall, that would have meant that a student was absolutely confident that his/her hypothesis was correct.

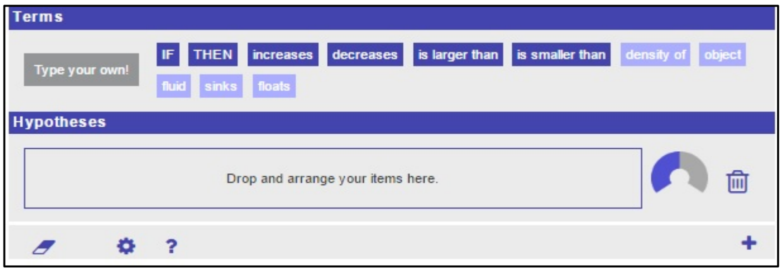
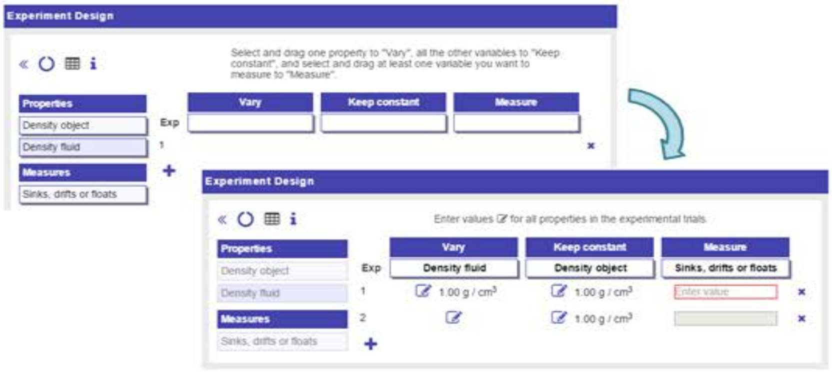


Fig.3. The Hypothesis Scratchpad.

After having formulated their hypotheses, students proceeded to the *Investigation* phase, where they designed and executed their experiments in order to address their hypotheses. Before using the Splash Laboratory for the execution of the experiments, students in the experimental condition used the EDT (Fig.4) to design and plan their experiments, while students in the control condition described their experimental design in a note-taking tool. In the EDT, students classified variables by dragging them in the proper column, so that to obtain an independent variable ("Vary" column), a dependent variable (“Mesure” column) and control variables (“Keep constant” column) (Fig.4; upper half). Once a design was completed, the next step was to specify the values of each variable and add experimental trials (Fig.4, lower half). When an experimental trial was conducted in the laboratory, students returned to EDT to enter their measurements. They had to do this for each experimental trial.



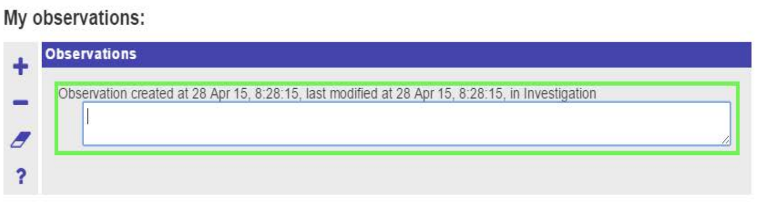
Select and drag one property to "Vary", all the other variables to "Keep constant", and select and drag at least one variable you want to measure to "Measure".

Enter values for all properties in the experimental trials.

	Vary	Keep constant	Measure
Exp	Density fluid	Density object	Sinks, drifts or floats
1	1.00 g / cm³	1.00 g / cm³	Enter value
2		1.00 g / cm³	

Figure 4. The Experiment Design Tool.

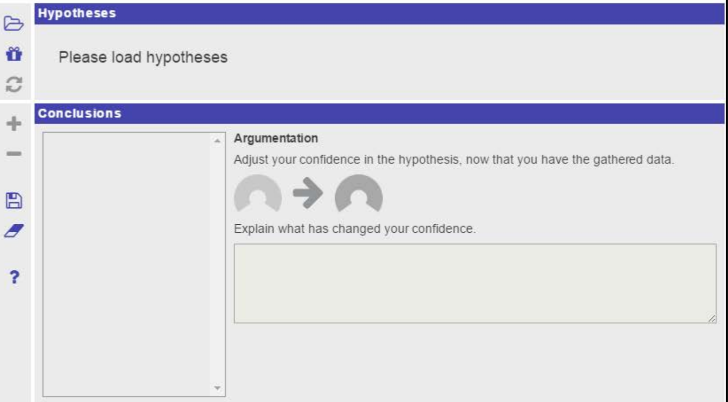
During the use of the Splash Laboratory, students were prompted to keep notes about ideas, thoughts and observations right after they had run their experiment. To do so, they used the Observation Tool (Fig.5).



Observation created at 28 Apr 15, 8:28:15, last modified at 28 Apr 15, 8:28:15, in Investigation

Figure 5. The Observation Tool.

When students collected enough data through experimentation, they moved to the *Conclusion* phase, in order to argue if their hypotheses should be confirmed or rejected. For that purpose, they used the Conclusion Tool (Fig.6), which allowed students to retrieve their previous work, specifically their hypotheses and observations, so that students would be provided with enough evidence to formulate their arguments while confirming or rejecting their hypothesis.



Please load hypotheses

Adjust your confidence in the hypothesis, now that you have the gathered data.

Explain what has changed your confidence.

Figure 6. The Conclusion Tool.

In the last phase of the learning environment, namely the *Discussion* phase, students discussed with the teacher and peers about their experiments and conclusions and performed reflection activities.

2.3 Data collection

We used two tests accessing content knowledge and inquiry skills of students. Both tests were administered to students before and after the educational intervention. The knowledge test was developed based on a revised version of Bloom's taxonomy of levels of knowledge, which have been termed: "*Remember*", "*Understand*", "*Apply*" and "*Think critically and creatively*" (more details in [16], [17]). The test consisted of six items: One open-ended item for "*Remember*", 2 closed-ended items for "*Understand*", one closed-ended item for "*Apply*" and two open-ended items for "*Think Critically and Creatively*". All items focused on density, the relation between mass, volume and density, and the role of density to sinking and floating of the objects in several fluids.

For the inquiry skills test, we selected and translated items included in TIPSII [18]. Thus, the inquiry skills test consisted of 24 multiple-choice items. Of them, 12 items addressed "*Identifying variables*", 9 referred to "*Identifying and stating hypotheses*" and another 3 items were related to "*Designing investigations*". The number of items in accessing each skill was the same as in the initial TIPSII instrument.

All tests were scored blind to the condition in which each student had been placed. For open ended items in the knowledge test, a rubric was used, which specified scoring criteria. Inter-rater reliability was calculated based on ratings of two independent coders who had reviewed 20% of all data available and the agreement was satisfactory (Cohen's Kappa = 0.95).

2.4 Procedure

The implementation was carried out by the same science teacher in both classes and lasted four class meetings of 40 minutes each. Before the implementation, the teacher participated in a face to face preparatory meeting, in which he became familiar with the ILS, the Splash Laboratory and the tools in each phase of the ILS. In addition, some practical issues were discussed and the role of the teacher during the intervention was clarified. Specifically, the teacher would offer technical support to students, anytime this was needed, and he would direct student attention to instructions and prompts included in the learning environment, so that students would be able to conclude their inquiry.

In the first and last meetings, both knowledge (20 minutes) and inquiry skills tests (20 minutes) were administered. In the second and third class meetings (80 minutes) each student worked on a computer and completed individually the learning activities of the ILS. At the beginning of the lesson, the teacher explained to the students the way they were supposed to work in order to go through all the activities of each phase of the ILS.

3 RESULTS

Non-parametric statistical methods were used (Wilcoxon Signed Ranks and Mann-Whitney tests), to explore learning gains in each group and to identify differences between the two conditions, in terms of student knowledge and inquiry skills.

A Mann Whitney test did not reveal any statistical difference between the two conditions in terms of their pre-test scores ($p > .05$). A Wilcoxon test showed that both conditions improved secondary school students' content knowledge ($p < .05$).However, students' post-test scores in the experimental condition were significantly higher than those of the students in the control condition ($p < .01$).

As for inquiry skills, a Wilcoxon test showed no statistical significant improvement in both conditions and across all inquiry skills under study, namely "Identifying variables", "Identifying and stating hypothesis", and "Designing investigations" ($p > .05$). A Mann Whitney test revealed no statistically significant difference between the two conditions across all inquiry skills ($p > .05$).

4 DISCUSSION AND CONCLUSIONS

Overall, this study showed that the integration of the EDT in a computer-based learning environment, such as the ILS in the Go-Lab platform, facilitated the advancement of content knowledge. It seems that when students are supported on how to proceed during the experimentation, they are more probable to conduct valid experiments, and this might lead to reaching valid conclusions (e.g., [2], [19]. Such a sequence of properly performed actions might contribute substantially to better understanding the relations between the variables of the phenomenon under study.

On the other hand, the fact that no statistical differences were found between the two groups, in terms of the inquiry skills, implies that the development of inquiry skills might require longer experience with such tools or learning environments. This is in line with the complexity inherent in the experimentation process (e.g., [20], [21]. Students might still face difficulties in designing their experiments, even if they were supported by scaffolds, such as the EDT employed in the present study. Given that the participants in the present study did not have any prior experience in using tools such as the EDT, might also be a factor that influenced our results. It might be that the level of familiarization with an experiment design tool affects the development of certain inquiry skills/practices. Our findings imply that further research should be pursued, with larger sample sizes and in different subject domains, in order to fully investigate the effect of the EDT on student knowledge and inquiry skills. In addition, using multiple data sources and analyzing multiple data sets would shed more light on the learning progression of students while using the EDT.

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