How Much Guidance Students Need When Designing Experiments in a Computer-Supported Inquiry Learning Environment

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***Abstract*—The aim of this study was to identify an optimum way to support students when designing experiments in a computer-supported inquiry learning environment. For this purpose, we evaluated the impact of two different configurations of an experiment design tool on students' content knowledge and inquiry skills in the context of electric circuits. The two configurations differed in the degree of guidance they offered to students. In the first condition the tool offered more structure during the design of the experiment by providing the variables at task, while in the second condition students were not provided any guidance in terms of the variables at hand. The sample of the study comprised of 41 ninth graders and the data were collected through the use of pre-and post-tests. The results showed that both conditions were conducive to student conceptual understanding; however, difference between conditions emerged for inquiry skills in favor of the second condition.**

***Index Terms*—inquiry learning, experiment design tool, scaffold, structuring, problematizing**

I. Introduction

Designing and running valid experiments is considered as one of the most important scientific practices involved in inquiry-based learning, since the outcomes of an experiment are necessary for the proceeding inquiry processes, especially for the data collection, analysis and interpretation [1]. In addition, it provides students the evidence needed in order to accept or reject a hypothesis [2], and subsequently draw their conclusions [3]. In the context of this study, we define inquiry according to the Pedaste *et al.* framework [3], which entails that inquiry-based learning involves five phases, namely *Orientation*, *Conceptualization*, *Investigation*, *Conclusion* and *Discussion*. In the *Orientation* phase students are introduced to the phenomenon at hand in order to get an idea of what the inquiry enactment will be about. In the *Conceptualization* phase, students identify the variables involved in the phenomenon under study and formulate research questions and/or hypotheses. In the *Investigation* phase, students design and conduct experiments, and analyze and interpret the data collected through these experiments. In the *Conclusion* phase, students are expected to draw conclusions in accordance with their initial research questions and/or hypotheses. Finally, in the *Discussion* phase, students communicate their results and reflect on the processes followed.

Considering that experimentation is a complex and demanding practice for students [1], [4], [5] it is important to provide them with appropriate guidance [1], [5]. In a computer-supported inquiry learning environment, guidance can be given in various forms (e.g., prompts, heuristics, scaffolds) [6]. In a recent review about examining what types of guidance can be incorporated in computer-supported inquiry learning environments that use virtual experimentation (i.e., experimentation through the use of computer simulations) [7], a number of guidance tools have been identified for the investigation phase. However, very few of these tools concern experimentation, which is one of the sub-phases of the investigation phase [7].

A type of guidance that can be used to support students when designing and executing their experiments are scaffolds. Scaffolds are fittingly designed technological applications that help students to carry out a learning process, by structuring the activities involved in the enactment of this process [8]. However, there is a limited number of scaffolds that guide students during online (virtual) experimentation and there are no empirical data to confirm their effectiveness [7].

A main challenge for the development of scaffolding software is whether scaffolds can offer a balanced guidance, taking into account the degree of structuring and problematizing needed for a student to complete a task at hand. On the one hand, structuring reduces the complexity of a task, while on the other hand, problematizing re-focuses student attention to certain aspects of the task that might remain unattended by students themselves [9]. In this way, useful cognitive load increases and facilitates learning [10].

The aim of this study was to examine the optimum balance between the two contradicting mechanisms, namely structuring and problematizing, for better enhancing students' knowledge and inquiry skills when designing an experiment in virtual lab of a computer-supported inquiry learning environment. For this purpose, the Experiment Design Tool (Fig. 1) from the Go-Lab

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platform[1] was used and configured in two conditions. In the first condition, the tool offered more structure during the task, while in the second condition, the tool problematized students. More details on the configuration of the tool in each condition can be found in the Methods section. The research questions of the study were: 1) What is the impact of each configuration on students' content knowledge and inquiry skills? 2) Are there any differences between the two conditions in terms of content knowledge and inquiry skills gains?

II. Methods

A. Participants

The participants of the study were 41 ninth graders from two classes of a public high school, randomly assigned to the two conditions of the study. In condition 1 there were 20 students (10 boys, 10 girls) and in condition 2 there were 21 students (10 boys, 11 girls). Students in both conditions had advanced computer skills and did not differ in terms of their prior knowledge (Pretest: Mann-Whitney $Z=-.302$, $p<0.05$) and inquiry skills (Pretest: Mann-Whitney $Z=-1.86$, $p<0.05$).

B. The Experiment Design Tool

The Experiment Design Tool allows students to determine the independent, the dependent and the control variables of their experiments by dragging them from the left side of the tool's interface to the proper column ("Vary", "Keep constant" and "Measure"). After the classification of variables students are prompted to add experimental trials by pressing the plus button and then specify the values of each variable in each experimental trial. After the execution of each experimental trial in the laboratory, students must return to the tool in order to enter the values of the dependent variable.

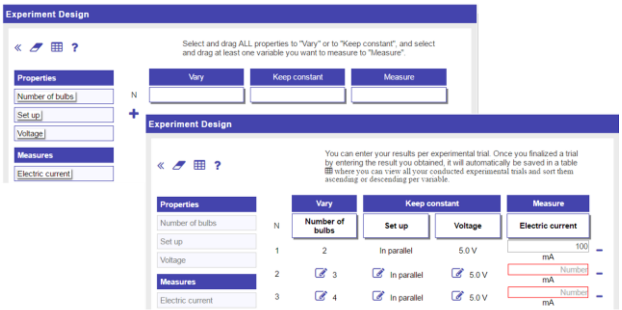

Figure 1. The experiment design tool

In condition 1, variable classification was provided (i.e., the independent, the dependent and the control variables of their experiments was provided by the experiment design tool). Hence, the students did not have to do anything concerning which variables to "Vary", "Keep constant" and "Measure". They only had to perform the next steps of the process, namely, the addition of experimental trials and the specification of the values of each variable in each experimental trial. In condition 2, variable classification was not pre-specified and students had to identify the independent, the dependent and the control variables and match them with the tool's variable categorization features (i.e., variables to "Vary", "Keep constant" and "Measure"). All of the other steps were the same as in condition 1 (i.e., addition of experimental trials and specification of the values of the variables in each experimental trial).

C. Learning Environment

For the present study, an Inquiry Learning Space (ILS) was created, which is an online learning environment based on the inquiry cycle design framework [3]. The creation of the ILS was done by the means of the Go-Lab platform authoring tool [11], [12] and involved the Electrical circuit virtual lab (Fig. 2). The ILS focused on the simple electrical circuit and circuits connected in series and in parallel and consisted of the five phases of the inquiry cycle, namely the *Orientation*, the *Conceptualization*, the *Investigation*, the *Conclusion* and the *Discussion* phase.

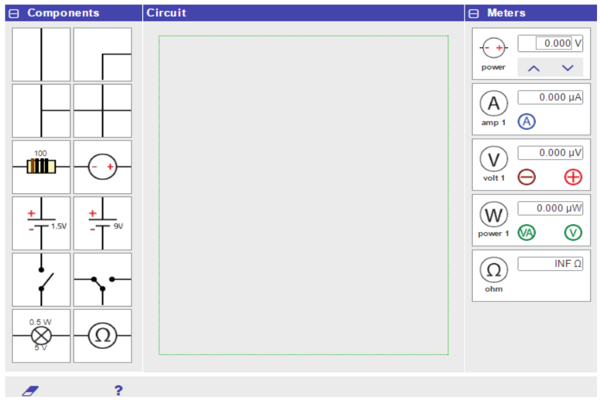

Figure 2. The electrical circuit lab (http://www.golabz.eu/lab/electrical-circuit-lab)

In the *Orientation* phase, students gathered information about the simple electrical circuit and the series and parallel circuits through videos, images and text. In the *Conceptualization* phase, they made their predictions on how the electric current changes when more bulbs were connected in series and in parallel. In the *Investigation* phase students first watched a video about the electrical circuit lab and how they can use it, and then, they designed and executed their experiments. In the *Conclusion* phase, they argued how the light fixtures in house are connected based on the data gathered from the previous phase. Finally, in the *Discussion* phase they performed reflection activities about the processes they had followed through the learning environment.

D. Assessment

The data collection involved two different tests, namely, the knowledge test and the inquiry skills test. For the creation of the knowledge test, a revised taxonomy of cognitive processes was followed (for more details see Ref. [13]). Cognitive processes included in the test were "remember" (1 item), "understand" (2 items), "apply" (2 items) and "think critically and creatively" (1 item). The items of the test focused on the definition of the simple

[1] Go- Lab platform is a repository of online labs, inquiry learning applications and inquiry learning spaces: www.golabz.eu

electric circuit and the differences between the two types of circuit setups (i.e., in series and in parallel), in terms of the brightness of the bulbs involved and the amount of electric current at any part of a circuit (see examples of knowledge items in Appendix A). For the inquiry skills test, items from the TIPSII instrument [14] were selected and translated. The test consisted of 18 multiple-choice items, addressing "identifying variables" (9 items), "identifying and stating hypotheses" (6 items), and "designing investigations" (3 items). Example of the items used can be found in Appendix B.

Before and after the implementation, both tests were scored blind to the condition in which each student had been placed. For the open-ended items in the knowledge test, a rubric was used, that specified scoring criteria for each item. Inter-rater agreement between two independent coders who reviewed 20% of the data was found to be acceptable (Cohen's Kappa= 0.93). For the inquiry skills test, one point was given to each correct response. Scores for knowledge and inquiry skill dimensions were rescaled to range between 0 and 1.

E. Procedure

The treatment in each condition was carried out by the same science teacher and they lasted three class meetings of 45 minutes each. Before the treatment, the teacher participated in a face to face preparatory meeting with the first author and became familiar with the ILS, the Experiment Design Tool and the Electrical Circuit Lab. In addition, some procedural issues were discussed and the role of the teacher during the lesson was clarified. In the first class meeting, students completed pre-tests (i.e., the knowledge and inquiry skills tests). The next meeting took place in the computer lab of the school, in order for each student to work with a computer and complete the activities of the ILS. At the beginning of the lesson, the teacher provided general guidance to the students, mainly explaining the way students were supposed to work in order to complete all the activities of the lesson. During the lesson, the only help students received from their teacher concerned some technical issues. Whenever technical issues appeared, they were solved without causing any delay to the completion of the lesson. Finally, in the last class meeting students completed the post-tests (i.e., the knowledge and inquiry skills tests).

III. Results

Table I presents the main results of the study. Concerning content knowledge, the students in both conditions improved their scores from pre- to post-test (Wilcoxon $Z_{condition\ 1}$=-3.32, $p<0.01$; Wilcoxon $Z_{condition2}$=-3.14, $p<0.01$). As for the inquiry skills, only the students in condition 2 improved their scores (Wilcoxon Z=-3.88, $p<0.001$). Conditions did not differ significantly neither in knowledge pre-tests nor in inquiry skills pre-tests. However, post-tests revealed a significant difference between conditions in terms of inquiry skills (Mann-Whitney Z=-2.17, $p<0.05$), where condition 2 was found to have higher rankings than condition 1.

TABLE I. Students' Overall Performance on Tests

	Condition 1	Condition 2	Mann-Whitney Test Z
Knowledge pre-test	0.298	0.301	-0.302
Knowledge post-test	0.420	0.407	-0.659
Wilcoxon signed ranks test Z	-3.32**	-3,14**	
Inquiry skills pre-test	0.616	0.498	-1.85
Inquiry Skills post-test	0.628	0.736	-2.17*
Wilcoxon signed ranks test Z	0.56	-3.88***	

Note: *p<0.05; **p<0.01; ***p<0.001

Further analysis was performed to examine effects on separate dimensions of inquiry skills in each condition. While there was no significant improvement in any of the inquiry skills dimensions in condition 1, in condition 2 there was a significant improvement across all dimensions of inquiry skills, namely "identifying variables" (Wilcoxon Z=-1.99, $p<0.05$), "identifying and stating hypotheses" (Wilcoxon Z=-3.54, $p<0.001$) and "designing investigations" (Wilcoxon Z=-3.33, $p<0.01$)

IV. Discussion and Conclusions

The two conditions we employed in the present study differed in the degree of guidance they offered to students when designing an experiment through the Go-Lab Experiment Design Tool. Although both conditions presented the experimental design procedure as a serial task (identification of variables, followed by experimental trials, followed by assigning values to variables in each experimental trial), which can be seen as an exemplary occasion of structuring student work [10], condition 2 did not include a pre-specified classification of variables, and therefore, was less structured than condition 1 and let more room for problematizing student inquiry. In other words, the students of condition 2 were left to problematize on which variables are at task and identify which of them is the independent, which the dependent and which the control ones. This process of reflection followed by the students of condition 2 concerning which variables to "Vary", "Keep constant" and "Measure", appears to be the key point for a successful implementation aiming for the enhancement of student inquiry skills. This finding becomes even more important, if someone considers the short time framework of the treatment. Given this, it becomes apparent that certain inquiry skills, such as "identifying variables", "identifying and stating hypotheses" and "designing investigations", could be enhanced in a very short time period. The latter has all sort of implication for the educational practice. Science educators have been struggling for years to identify ways for accelerating learning. This might be one of these ways. Of course, given the small sample of the study, further research is needed to ground this finding on a solid base of evidence.

Another important finding is that both conditions were equally conducive to student knowledge of the domain.

The latter implies that designing an experiment per se does not have an impact on student understanding of concepts, at least in the domain of electric circuits and for such a short intervention. Again, this has an implication on educational practice. Basically, it appears to imply that this is not a point to focus upon if conceptual understanding is at hand. Again, it remains to be seen through future research if this finding is valid.

Since knowledge outcomes did not differ between conditions, and since condition 2 resulted in significantly higher gains in terms of student inquiry skills, we can conclude that this condition is to be preferred over condition 1. To return to the continuum between structuring and problematizing student inquiry (see Ref. [9]), it seems that the serial processing of tasks within the experimental design procedure might suffice as a structuring approach, meaning that identification of variables, planning of experimental trials, and assigning values to variables has to be left to students to undertake.

APPENDIX A EXAMPLES OF ITEMS IN THE KNOWLEDGE TEST

Remember item: Which components are necessary to create a simple electric circuit? Describe how these components must be connected.

Apply item: What do the multiple electrical sockets, used for the operation of multiple electrical appliances, imply about the type of the connection? Please explain your reasoning.

APPENDIX B. EXAMPLES OF ITEMS IN THE INQUIRY SKILLS TEST

Identifying variables item: A football coach thinks his team loses because his players lack strength. He decides to study factors that influence strength. Which of the following variables might the coach study to see if it affects the strength of the players?

A. Amount of vitamins taken each day.

B. Amount of lifting exercises done each day.

C. Amount of time spent doing exercises.

D. All of the above.

Identifying and stating hypotheses item: A police chief is concerned about reducing the speed of cars. He thinks several factors may affect automobile speed.

Which of the following is a hypothesis he could test about how fast people drive?

A. If the drivers are younger, then they are likely to drive faster.

B. If the number of cars involved in an accident is larger, then it will be less likely people that are to get hurt.

C. If more policemen are on patrol, then the number of car accidents will be fewer.

D. If the cars are older, then they are likely to be in more accidents.

Designing investigations item: Jim thinks that the more air pressure in a basketball, the higher it will bounce. To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge. How should Jim test his hypothesis?

A. Bounce basketballs with different amounts of force from the same height.

B. Bounce basketballs having different air pressures from the same height.

C. Bounce basketballs having the same air pressure at different angles from the floor.

D. Bounce basketballs having the same amount of air pressure from different heights.

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