Scaffolding learners in designing investigation assignments for a computer simulation

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Abstract
This study examined the effect of scaffolding students who learned by designing assignments for a computer simulation on the physics topic of alternating circuits. We compared the students' assignments and the knowledge acquired in a scaffolded group (N = 23) and a non-scaffolded group (N = 19). The scaffold consisted of a Design Sheet that guided students through the different steps in the design of assignments (generate an idea, transform the idea into an assignment, and evaluate the assignment) and provided them with specific directions on how to perform these steps. On average, students in the non-scaffolded group designed more assignments than students in the scaffolded group, but the scaffolded students designed relative by more assignments about the relations in the domain, more often gave exact descriptions of the relations in the domain, and more often referred back to the computer simulation to explain their findings. No differences on knowledge tests, however, were found between the two groups of students. In the discussion, we give suggestions on how to adapt the scaffolding to improve not only the learning process but also knowledge acquisition.

Keywords
alternating circuits, computer simulation, guided discovery learning, learning by design, secondary school.

Introduction
Contemporary instructional approaches expect students to be active producers of knowledge. This creates a need for instructional tasks that can offer students opportunities for active or genuine learning. An example of such an instructional task is design problems (Kafai 1996). In design problems, students are asked to build artefacts (Janssen 1999; Crismond 2001; Roth 2001), models (Novak 1990, 1998; Riley 1990; Penner 2001; Löfner et al. 2003), or instruction (Harel 1991; Kafai 1996). The current study investigates ways to stimulate and support learning by the design of instruction. In designing instruction, students must think about what they and others should learn, and how this knowledge should be organized in order to be comprehensible and interesting (Harel 1991; Jonassen & Carr 2000).

In this study, the design of instruction as a learning method is integrated with scientific discovery learning with computer simulations. In simulation-based scientific discovery learning, a student is provided with a simulation of rules in e.g., physics, chemistry, or biology. Students engage in a process of scientific discovery by manipulating values of variables and observing the outcomes of their actions. This type of learning, however, is a difficult task in which students need guidance and support (De Jong & Van Joolingen 1998; De Jong in press). An example of such support is assignments, small exercises presented alongside the simulation that help students plan and focus on important aspects of the domain being explored. Overall, providing students with assignments together...
with a simulation has a positive influence on learning outcomes (De Jong & Van Joolingen 1998). Investigation assignments (see Van Joolingen & De Jong 2003), for example, are multiple-choice types of assignments that ask the learner to investigate the relation between two or more variables. An investigation assignment consists of a question, a number of alternatives, and feedback. A student who designs an investigation assignment is engaged in processes such as 'generating a question', 'finding answers and alternatives', and 'giving explanations'. Several studies have shown that these processes are instructive. By asking questions, students learn to focus on content and to concentrate on main ideas while checking whether content is understood (Palincsar & Brown 1984; Rosenshine et al. 1996), and generating explanations requires students to integrate old and new knowledge (Chi et al. 1994), which leads to performance gains (Bielaczyc et al. 1995).

A previous study (Vreman-de Olde & De Jong 2004), in which students were asked to design investigation assignments for a simulation in the physics domain of electricity, yielded promising results concerning the learning process. In this study, students had access to the simulation while designing assignments. Students designed assignments about facts, calculations, and observations made with the simulation. During this process, they not only retrieved and explained problem-solving steps but also studied the effects of changes in the simulation. We also, however, observed two problems. The first problem was that the assignments that the students created about observations were rather superficial; students mainly looked at and described simple effects. The second problem was that in designing assignments about facts and calculations, the students often used the simulation environment for checking the correct answer of their calculation assignment, but not for making discoveries about the relations of the simulated model. These issues point to the need to stimulate students to really use the simulation (performing experiments, drawing conclusions), to support them in designing assignments based on the observations made, and to guide them in integrating prior knowledge with newly gained knowledge. In the process of designing assignments for a computer simulation, three main activities can be distinguished: generating an idea for the assignment, transforming this idea into an assignment, and evaluating the assignment designed. Support for designing assignments can be structured around these three activities.

In the first step of the design task, generating the idea, the student initially uses the computer simulation in an exploratory way. In doing this, students should generate an idea based on a number of systematically performed experiments instead of on a simple, one-shot experiment. Providing students with heuristics supports them in performing systematic experiments (Veermans 2003; Zhang et al. 2004). Encouraging students to provide evidence for the conclusions they draw (Keys et al. 1999) can facilitate students in generating meaning from the findings they collect.

In the second step, students have to transform their idea into an assignment. An (investigation) assignment consists of a question, one correct and a number of incorrect alternatives, and feedback to all alternatives. To prevent students from asking simple observation questions, students should be oriented towards an understanding of the types of questions that must or can be asked about the findings (Olsher & Dreyfus 1999). One method is to ask them to start their questions in a particular way (e.g. ‘What if . . .’, ‘Why does . . .’, ‘Why are . . .’, or ‘How could . . .’), as such questions are more likely to lead to deep thinking than simple recall (White & Gunstone 1992). Another method is to prompt students to ask for relations between independent (input) and dependent (output) variables. To generate an answer, students can use the computer simulation to check the (correct) answer to the question that they have designed. In thinking of alternative answers to the question, students have to think of ‘answers that look like the correct answer, but in fact are false’. Appropriate feedback should describe the relation between concepts, use observation data, and present evidence and background knowledge (Webb & Palincsar 1996). In summary, in the second phase, the student should be encouraged to use the computer simulation, not only for finding a question to investigate but also for checking the correct answer, and for generating appropriate feedback.

In the third step of the design process, the evaluation of the assignment, the student has to look back at what has been designed. Evaluating products is a process that often does not occur spontaneously, so students should be encouraged to do so (Quintana
et al. 2004). If students succeed in articulating the knowledge presented in the assignment, this leads to a reflection process that has generally proven to be beneficial for learning in the context of inquiry learning (Land & Zembal-Saul 2003; Zhang et al. 2004; Moreno & Mayer 2005).

The use of a worksheet is an appropriate way of scaffolding students both in the overall structure and in the specific reasoning steps (Njoo & De Jong 1993; Lee & Thompson 1997; Kolodner et al. 2001; Pantambekar & Kolodner 2005). For the current study, we developed a paper and pencil tool that we called the Design Sheet, which guided students through the different design steps, while providing them with tips, examples, and background information. To evaluate the use of the Design Sheet in (learning by) the design of assignments, we performed a study in which a group of students, the scaffolded group, made use of the Design Sheet while designing assignments in a computer-based discovery-learning environment. Another group of students, the non-scaffolded group, was also asked to design assignments but they did not receive support for their design task. We expected the scaffolded group to design more assignments about relations in the domain, and to design assignments of a higher quality. Compared with the non-scaffolded students, we expected the scaffolded students to learn more about the relations in the examined domain, achieve a better knowledge of the formulae in the domain, and gain a better understanding of the different domain-related representations.

Method

Participants

Participants were 45 second-year students from a middle vocational school, technical training programme. Their average age was about 17 years. The students were randomly assigned to one of the two conditions. Not all students attended the second session of the experiment and as a result the scaffolded group contained 23 students and the non-scaffolded group contained 19 students. Before entering the experiment, all students had just completed a regular course about alternating voltage and current. There were no significant differences between the two groups on the exam marks. ($M_{\text{scaffolded}} = 5.36$, $SD = 1.41$, range = 5.2; $M_{\text{non-scaffolded}} = 5.95$, $SD = 1.91$, range = 7.3; $df = 40$, $t = 1.14$, $P = 0.260$).

The computer simulation-learning environment

In this study, a simulation-based learning environment on the physics domain of alternating circuits was used. In this simulation, five different simulations are available; Fig 1 shows one of them. The interface of the simulation shows the circuit under study: an input box, in which a student can change variables belonging to this circuit; and an output box, which shows the effects on different variables. The effects of changes in voltage and current are also represented in a graph, a circuit, and a vector diagram. The environment starts with three circuits that each contain only one element (a resistor, or a capacitor, or a coil). The fourth simulation, shown in Fig 1, contains a resistor, a capacitor, and a coil. The final simulation contains the resonance effect.

The Design Sheet

The Design Sheet was created as a paper and pencil task. In completing the tasks on this sheet, the student went through different steps in the design of an assignment, using the simulation in each step, and receiving advice at the appropriate moment. In Fig 2, we have depicted the interaction between simulation, Design Sheet, and support. In the centre of this figure, the three steps of designing assignments are presented: generate an idea, transform idea into an assignment, and evaluate the assignment. On the left, it is shown how the simulation can be used during the different design steps. On the right, the support, offered to the students, is presented. Part of this support is conceptual, e.g., in giving an example of an idea, or an example of a question. Part of it is procedural, e.g., in giving instructions on how to author and run an assignment, or in explaining how to perform experiments (heuristics). We will now present a more detailed description of the Design Sheet, thereby using the three steps in the design procedure.

Generate an idea for an assignment

In the phase of generating an idea for an assignment, students were asked to write down initial ideas for a question (brainstorming) and were advised to look for
relations between input and output variables. The instructions on the Design Sheet guided students in making notes of the experiments they performed. In this way, students could check and work out their ideas. Heuristics as ‘use equal increments between experiments’, and ‘change one variable at a time’, were provided to support student during experimenting.

**Transforming an idea into an assignment**
In this phase, students were guided in creating an assignment about their observations and conclusions. They were prompted to formulate a question, such that a peer student would be able to solve it with the use of the simulation (e.g. What happens to Imax if one doubles L?). Then, students had to find the correct
answer and some alternative answers that looked like the right answer but, in fact, were wrong. Finally, in generating feedback for each answer, students had to explain whether the answer was correct or not. Students were advised to make use of the conclusions of their experiments, the different representations in the simulation (Cox 1999; Aleven & Koedinger 2002), and their prior knowledge (Webb & Palincsar 1996).

Evaluating the assignment

The learning environment that we used was created with the authoring system SIMQUEST (De Jong et al. 1999; Van Joolingen & De Jong 2003). We asked our students to create the assignments in this authoring environment (this means filling in a predefined form for the assignment; instructions for doing this were given on the Design Sheet). Upon completing this task, students could run their assignment as part of the software and check whether the assignment behaved in the way they intended. On the Design Sheet, we asked our students to describe how their knowledge had changed as a result of the design of an assignment, and to formulate what they wanted a fictitious student to learn from their assignment.

In addition, both scaffolded and non-scaffolded groups were given some basic support in a Hypertext. This text was incorporated into the simulation-learning environment. This text dealt with (1) the main concepts and formulae of the domain, because providing direct access to this kind of permanently available information seems to be an effective instructional feature in learning with simulations (De Jong & Van Joolingen 1998); and with (2) the representations in the domain, as it is important that students understand what is represented in the simulation and the relation between the representations used (Ainsworth et al. 1997; Van der Meij & De Jong in press).

Design

This study used a one-way between-groups design, with the treatment condition (design support vs. no support) serving as the independent variable. Students in one condition, the scaffolded group, designed assignments for a simulation-learning environment with the help of the Design Sheet. Students in the other condition, the non-scaffolded group, designed assignments without extra support. The simulation-learning environment was the same for both conditions. Dependent variables concerning the assignments designed were the number of assignments created and the quality of the assignments (operationalized as the type of assignments designed, the description of the relation in the assignments, and the different types of feedback in the assignment). Dependent variables concerning domain knowledge were represented by tests with items measuring knowledge of relations, understanding of formulae, and understanding of representations.

Instruments

Learning processes in terms of the design activity were assessed by analysing the assignments that the students created. In the assignments, we first looked at the type of knowledge that was asked for. A question created by a student such as ‘What happens to the current I if one enlarges the resistance R?’ asks for a relation. In the question ‘What is the current at T = 0.5 s?’ one is asked to read the graph. In categorizing the questions, we discriminated between questions involving conceptual and procedural knowledge. Conceptual knowledge means knowledge about concepts, like definitions, formulae, and relations. Procedural knowledge is the knowledge of how to perform a task, e.g., carrying out a calculation with a formula, reading a graph. The categories are displayed in Table 1. In this categorization, we made a distinction between ‘reading a number from a graph’ and ‘reading the phase difference from a graph’ as these categories address different kinds of knowledge. In the first category, questions like ‘What is the maximum current?’ are asked. These questions can be answered without knowledge of the domain – one only needs to know how to (graphically) determine the maximum value of a sine function. To answer questions in the category phase difference, one needs to know what phase difference is and how to determine this in the interface. This category belongs to the type ‘conceptual – procedural’, as it combines both conceptual and procedural knowledge. For assessing the inter-rater agreement for the type of assignment, 10% of the assignments were judged independently by two raters. An inter-rate agreement of 0.91 (Cohen’s κ) was reached.
Relations between variables describe the essential aspects of a domain. In our further analysis of the learning processes, we therefore focused on correct assignments about relations. An assignment was correct when the answers and the feedback were correct from a domain point of view. To analyse the quality of the correct assignments about relations, we looked at how students described their relations in the domain, and how students used different types of feedback in the assignment. For the description of the relation we distinguished three categories: a simple statement of the existence of a relation, a qualitative relation, and a quantitative one. Inter-rater agreement between two judges on ten percent of the correct assignments for judging the description of the relations into these three categories reached 1.0 (Cohen's $\kappa$). For the different types of feedback, we distinguished four categories: ‘correct’, ‘write relations in own words’, ‘refer to simulation’, and ‘use prior knowledge’. Using the same procedure as above, the inter-rater agreement reached 0.87 (Cohen’s $\kappa$).

Knowledge of relations was measured by a causal relation test and a WHAT-IF test. The first test was paper and pencil and comprised nine multiple-choice items. In this test, students were asked for the consequence of or the reason behind a change in the circuit. The WHAT-IF test was a computerized test that consisted of 25 items. This type of test (Swaak & De Jong 2001) was created to measure intuitive knowledge about the causal relations between variables in the domain.

Understanding of formulae was measured by a definitional knowledge test comprising 17 multiple-choice items. In this test, students were asked to select the correct formulae for e.g. the capacitive resistance, the frequency, or the current through a resistor.

Understanding of representations was measured by the representational test comprising five items. In this computerized test, each item contained a representation of voltage and current in a graph, and three alternative representations of the same voltage and current in a vector diagram. Students were asked to choose the vector diagram that corresponded to the graphical representation.

### Procedure

Each experimental session lasted 2 h each. The first session consisted of 1 h instruction and 1 h designing assignments. The second session consisted of 1 h designing assignments and 1 h knowledge test. During instruction, students worked with a SIMQUEST simulation on the physics domain of bending moments, so that students could become familiar with a SIMQUEST simulation. All students were shown how to author an assignment in the SIMQUEST authoring environment. After these instructions, students in the scaffolded group received a set of Design Sheets. Students in the non-scaffolded group received a paper with instructions about how to author an assignment in the simulation. At the end of the first session, all designed assignments were stored and all the paper materials were collected. At the beginning of the second session (which took place 7 days after the first one), all materials and assignments were returned to the students.
Results

The assignments

On average, students in the non-scaffolded group designed more assignments (total = 95, mean = 5.00, SD = 1.4) than students in the scaffolded group (total = 86, mean = 3.74, SD = 1.6) (t = 2.7, df = 40, P = 0.01).

In determining the different types of assignments designed, we looked at the type of question that was stated (see Table 1). Scaffolded students designed most of their assignments about relations (63) and formulae (9). Non-scaffolded students designed most of their assignments about relations (34), the phase difference (15), and reading numbers from a graph (13). In analysing the differences in the type of assignment, we wanted to take into account both the difference in the number of students per group and the difference in the total number of assignments designed. Therefore, for each student we calculated the fraction (= relative portion) of the total number of assignments designed for each category. Next, we determined the mean fraction for each category in both groups. As the assumptions for a t-test (normality, equity of means) were not met, we used a Mann–Whitney U-test to analyse our data. The results of this non-parametric test (see Table 2) show that students in the scaffolded group designed a higher mean fraction of assignments about relations than students in the non-scaffolded group (Z = 3.319, P = 0.001), and that the reverse was true for the assignments about definitions (Z = -2.15, P < 0.05), reading number from a graph (Z = -2.06, P < 0.05), reading the phase difference in the graph (Z = -2.62, P < 0.01), and the category miscellaneous (Z = -2.20, P < 0.05).

As Table 2 shows, both groups of students designed most of their assignments in the category ‘relations’. Approximately the same percentage of these relations was correct in the scaffolded group (84%) and the non-scaffolded group (82%). In total, this implies 53 and 28 correct assignments about relations, for, respectively, the scaffolded and the non-scaffolded group. Three typical (correct) assignments about relations are presented in Fig 3. In these examples, the alternative answers and the feedback on those alternative answers are omitted. Our analysis of correct assignments about relations focused on the variables ‘description of the relation’ and ‘different types of feedback’.

Three categories concerning the description of the relation in the correct assignment were identified:

<table>
<thead>
<tr>
<th>Example 1</th>
<th>Existence: there is a relation between… and …</th>
</tr>
</thead>
<tbody>
<tr>
<td>question</td>
<td>What influence does the resistance have on the vectors?</td>
</tr>
<tr>
<td>correct answer</td>
<td>Only the red vector changes in length</td>
</tr>
<tr>
<td>feedback</td>
<td>Correct. You can try this by diminishing the resistance in the simulation. You’ll see that the red vector (current) changes length.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example 2</th>
<th>Qualitative: If… becomes larger than … becomes larger/smaller.</th>
</tr>
</thead>
<tbody>
<tr>
<td>question</td>
<td>What happens if the capacitor is changed to a larger value?</td>
</tr>
<tr>
<td>correct answer</td>
<td>The current becomes larger</td>
</tr>
<tr>
<td>feedback</td>
<td>Great!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example 3</th>
<th>Quantitative: If … becomes 2x larger than… becomes 2x larger/smaller</th>
</tr>
</thead>
<tbody>
<tr>
<td>question</td>
<td>What happens if you make the resistance R two times smaller?</td>
</tr>
<tr>
<td>correct answer</td>
<td>The current becomes two times as big.</td>
</tr>
<tr>
<td>feedback</td>
<td>If the resistance R is halved, the current Imax becomes two times as big because</td>
</tr>
<tr>
<td></td>
<td>Imax = Umax/R = 10/2 = 5A</td>
</tr>
<tr>
<td></td>
<td>Imax = Umax/R = 10/1 = 10A</td>
</tr>
</tbody>
</table>

Fig 3 Three examples of assignments about relations.
‘existence’, ‘qualitative’, and ‘quantitative’. The first example from Fig 3 is about a relation between resistance and the length of a vector. The students wrote that by diminishing the resistance, the vector would change length; however, he did not describe what this relation looked like, and only the existence of a relation was given. In the second example, the student asked for the effect of enlarging the capacity and answered that the current will become larger. This student gave a qualitative description of the relation without indicating the size of the changes. The final example shows a quantitative description of a relation (if one variable becomes two times larger, another variable becomes two times smaller).

In total, scaffolded students designed 22 assignments in which they described the relation qualitatively, whereas the non-scaffolded students designed 17 assignments in this category. For the category ‘quantitative’ these numbers were 20 and 7, respectively. Again, in our analysis we took into account the difference in group number and the number of correct assignments about relations. Seven students did not design any correct assignment about relations; these students were not taken into account in determining the means.

On average, students in the non-scaffolded group mostly described the relation qualitatively; the fraction for this category is about 0.70, whereas students in the scaffolded group described their relations either qualitatively (fraction 0.41) or quantitatively (fraction 0.45). A Mann–Whitney U-test ($n_1 = 23, n_2 = 12$) revealed significant differences between the two groups on the category ‘qualitative’ ($Z = -2.18, P < 0.05$) and on the category ‘quantitative’ ($Z = 2.35, P < 0.05$).

Four categories with respect to the different types of feedback were identified: ‘correct’, ‘write relation in own words’, ‘refer to the simulation’, and ‘use prior knowledge’. In the first category, the feedback on the correct answer just contains ‘correct’ or ‘great’ (see example 2, Fig 3). In the second category, the feedback contains a description of the relation the student saw in the simulation (see example 3). In the third category, the feedback contains a reference to the simulation (see example 1), and in the fourth category, the feedback contains formulae to justify or explain the relation (see example 3).

In total, in the feedback of 12 out of 53 assignments scaffolded students just wrote ‘correct’, whereas non-scaffolded students designed 14 out of 28 assignments in this category. In the feedback, scaffolded students repeated the relation in 30 assignments, made reference to the simulation in 15 assignments, and used prior knowledge in 14 assignments. For the non-scaffolded group, these numbers are 10, 6, and 6, respectively. Again, we determined the mean fractions for each category. The results of a Mann–Whitney test showed a significant difference for the category ‘correct’ ($Z = -2.35, P < 0.05$), meaning that non-scaffolded students relatively wrote ‘correct’ in the feedback more often compared with scaffolded students. Furthermore, there is a tendency that the scaffolded group more often wrote the relation in their own words in the feedback, more often referred to the simulation and more often used prior knowledge compared with the non-scaffolded group. A Mann–Whitney U-test revealed no significant differences.

**Knowledge test**

The students scored 50% correct on the knowledge tests, on average, which indicates that both groups did not perform very well. Cronbach’s $\alpha$ for the whole test is 0.71, which is satisfactory. There was a positive correlation between the grade on the teacher’s exam and the score on the total test ($r = 0.414, P < 0.01$). We found no differences between the two groups on the total score of the test.

**Discussion**

Scaffolding is traditionally defined as the process by which a teacher or more knowledgeable peer provides assistance that enables learners to succeed in problems that would otherwise be too difficult (Collins et al. 1989). For example, a teacher may provide strategic guidance, help learners set appropriate goals, or perform difficult parts of a task. In educational design, the intention in scaffolding is that the support not only assists learners in accomplishing tasks, but also enables them to learn from the experience (Reiser 2004). Recent design research has adapted the notion of scaffolding and included scaffolding with (software) tools (Edelson 2001; Linn et al. 2003; Quintana et al. 2004). In designing a scaffolding tool, one should start with an analysis of the learners’ needs and of the ways in which the tool can help learners to overcome these challenges (Soloway et al. 1994; Reiser 2004). The
study described in this paper presented a scaffolding tool, the Design Sheet that supported students in designing assignments alongside and with the help of a computer simulation. Our study, on the effect of using this tool, revealed differences in amount, type, and quality of the assignments designed by the scaffolded and non-scaffolded students.

Concerning the amount of assignments students in both groups designed, we found that, on the average, non-scaffolded students designed more assignments than scaffolded students. Most probably, scaffolded students needed time to go through the Design Sheet, performing the systematic experiments, and to write the more extended feedback, which may have been the cause for the lower number of designed assignments.

The analysis of the different types of assignments that students designed revealed significant differences. Students in the scaffolded group designed more assignments about relations in the domain. This group was scaffolded to write down the experiments performed, to formulate a conclusion, and to ask a question about it. The data suggest that these instructions helped students to focus on relations in the domain and to design assignments about them. Students in the non-scaffolded group designed more assignments on ‘definitions’ and the ‘read graph number’ and ‘read graph phase difference’. These students often just clicked the start-button in the simulation and designed assignments about concepts and procedures triggered by watching the interface, e.g., students asked about a formula, but did not use the simulation to check the formula.

Comparing the quality of the correct assignments about relations designed by both groups, we looked at how students described the relation in their assignment and at the different types of feedback. These analyses suggest that students were inclined to describe their relation in a qualitative way, but that the scaffolds on the Design Sheet guided students to give a more exact description of the relation. Furthermore, the analyses show a tendency that, in giving feedback, scaffolded students more often repeated the relation they discovered, referred more often to the simulation, and used prior knowledge more often. The notes on the experiments, made on the Design Sheet, gave them the advantage that they could look back on and use the data obtained.

Our overall conclusion is that the Design Sheet supported students in the process of designing assignments. Scaffolded students went beyond the superficial characteristics and the simple effects of the simulation, performed systematic experiments, and were able to put into words the results of their findings. In the design process, the simulation became a tool to gain knowledge with the goal of designing assignments. In this way, designing assignments could provide students with a more concrete target to work for in an otherwise rather open inquiry environment. Other type of targets could also play this focus role, for example, the design of a concept map (Gijlers 2005) or a runnable model of the simulated domain (Penner 2001; Löhner et al. 2003).

In the whole design task, students were involved in ‘generating questions’, ‘finding answers’, and ‘giving explanations’. The positive effects of generating questions (e.g. Davey & McBride 1986; Chin et al. 2002), and explanations (e.g. Chi et al. 1994; King 1994; Webb & Palincsar 1996; Coleman et al. 1997; Reimann & Neubert 2000) are reported in the literature. We, therefore, hypothesized that students in the scaffolded group would perform better on the knowledge tests. Our study revealed, however, that overall scores were not very high and (therefore) learning effects were still small. One reason for this might be that in the design process, students were focused on the task, the design of assignments, rather than on inquiry learning goals (cf. Schauble et al. 1995). Another reason might be that the knowledge tests, especially the ones measuring knowledge of relations, were too abstract for students from a secondary vocational school. Thinking about the dynamics of relations in electrical (alternating) circuits is a difficult mental process and it takes time to develop (intuitive) knowledge of those relations (Booth & Sterman 2000). A careful adaptation between the learning process and assessment of learning result will be necessary, together with a longer treatment. An improvement might be that part of the scaffolding might be performed by the teacher on such aspects as integrating the doing (performing experiments) and the reflection (understanding of the circuit under study) (Hmelo et al. 2000, p. 273), or by providing feedback on the design process (Liu 2003).

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