LOOK
EXPERIMENT
DESIGN

LEARNING BY DESIGNING INSTRUCTION

Cornelise Vreman-de Olde

The research reported in this thesis was funded
by the Netherlands Organization for Scientific Research
(grant number 411-21-101)

This research was carried out in the context of the Interuniversity
Centre for Educational Research

ISBN: 90-365-2399-0

Druk: Gildeprint Drukkerijen, Enschede

LOOK EXPERIMENT DESIGN

LEARNING BY DESIGNING INSTRUCTION

PROEFSCHRIFT

ter verkrijging van
de graad van doctor aan de Universiteit Twente,
op gezag van de rector magnificus,
prof. dr. W.H.M. Zijm
volgens besluit van het College voor Promoties
in het openbaar te verdedigen
op woensdag 27 september 2006 om 13.15 uur

door

Gezina Cornelise Vreman-de Olde
geboren op 6 januari 1968
te Almelo

Dit proefschrift is goedgekeurd door de promotor:
prof. dr. A.J.M. de Jong

Table of contents

Appendices

1

Learning by designing instruction

1.1 Introduction

You surely remember the joy about creating something yourself. It might have been a house made of LEGO blocks with a door, some windows and a roof. Or a birdhouse built with some boards, or a statue made from clay at school. It gave joy because you managed to create something yourself, it gave a feeling of ownership because it was yours, and perhaps even a feeling of pride because you managed to give expression to your thoughts, your feelings. If we think back about our creations and about the way we made them, we may realize that we learned about the materials used. We learned about the clay, which might have been red or white, drying in an oven or in open air. In thinking about the process of making our creation we realize that it took time to make the LEGO house; we had to figure out how to connect the blocks, how to make the opening for a window and how to make a firm roof. While making our creation, we had to make plans and overcome obstacles; we had to learn how to draw a plan for our birdhouse and think about the order of assembling the separate parts. We learned the painful lesson of hammering the nail and not the thumb.

'Learning by designing something yourself' is also used in educational settings. The research presented in this thesis focuses on a specific kind of design, namely: learning by designing instruction for peer students. In the studies described in this thesis, students are asked to design instruction for their peers in a scientific discovery computer simulation. Throughout the studies, our research focus is on gaining insight into the learning processes that are induced by designing instruction for peer students and, in addition, on investigating how the process of designing instruction can be supported so that students gain understanding of the simulated domain. Participants in our studies are students from technical secondary vocational schools. In the current chapter, we first present the theoretical background for learning by designing, followed by a description of the learning environment that was used in our studies. We proceed with a general depiction of the type of school that participated in our studies. Finally, we present our research question and an outline of the thesis.

1.2 Learning by designing

The rationale behind 'learning by designing' originates from constructivism. Constructivism is a view of learning that stresses the active, constructive, and cumulative nature of learning (Shuel, 1988). It is *active* in the sense that learners are encouraged to construct their own knowledge, rather than receiving it from an authority, be it a book or a teacher (de Jong & Pieters, in press). It is *constructive*, in the sense that new information must be elaborated and related to other information in order for the learner to retain the information and to understand complex material. It is *cumulative*, as knowledge is constructed in relation to prior knowledge, abilities, expectations, and desires. In other words, knowledge structures are built by the learner rather than transmitted by the teacher. Papert (1980) supports this constructivist idea, but he added the idea that building knowledge structures (‘in the head’) goes especially well when the student is engaged in building material structures (‘in the world’), as children do with construction sets like Lego.

1.2.1 Learning by designing – three different forms

Learning by designing can take place in different ways. First, learners can *learn by designing an artefact* that attempts to embody their current thinking. Roth (2001) described a ‘simple machines curriculum’ in which students were engaged in technological design activities. During the process of designing and testing artefacts, students learned to talk about the physics of the machines. Hmelo, Holton, and Kolodner (2000) reported on a design experiment in which children designed artificial lungs and build partial working models. Through this process, children learned about the structure of the human respiratory system and the functions of its components. Hmelo et al., found that the children who designed learned more than the children who received direct instruction; they learned to view the respiratory system more systematically. Crismond (2001) described a project in which several designers investigated and redesigned a nutcracker and a jar opener. All designers engaged in analysing the characteristics of both devices, describing new ‘ideal versions’, and making a conceptual version of their improved design. Crismond concluded that scaffolding questions are needed to focus the learning of science in design-oriented activities. In sum, learning by designing an artefact offers students the opportunity to study a good design and redesign the artefact themselves. In this way they can gain a deeper understanding of how, for example, a natural phenomenon or a technical apparatus works.

Second, learners can learn by *making a model of the domain*. An example in this field is the work of Novak (1990, 1998); he asked students to make concept maps of a domain. A concept map is a tool for organizing and representing one’s knowledge of a domain. A concept map is composed of concepts, usually enclosed in circles or boxes of some type, and relationships between concepts, indicated by a connecting line between two concepts. In de Vries (2004), children created concept maps of biological systems, thereby focusing on relations, for example, between the form of an ant and the functions it should fulfil. Students can even go further with computer modelling. Students can build, test and evaluate qualitative models without a need to know the underlying calculus driving these models (Fretz, Wu, Zhang, Davis, & Krajcik, 2002; Löhner, Van Joolingen, & Savelsbergh, 2003; Manlove, Lazonder, & de Jong, 2006). They can create models that represent their theories about scientific phenomena and run simulations in order to test their models. Penner (2001) states that creating computer models can be an effective tool for supporting students’ construction of physical models. These models are then available for students to discuss, explain, and reflect upon. In sum, by designing a model, e.g., concept maps or executable computer models, students can learn more about the relations in a domain.

Third, learners can learn by *designing instruction*. 'Learning by designing instruction' resembles both 'Reciprocal Teaching' (Palincsar & Brown, 1984) and 'Lernen durch lehren' (Martin, 2002), or 'Learning by Teaching'. The idea in these instructional approaches is that the student takes the role of a teacher. In Reciprocal Teaching, teacher and students take turns leading a dialogue concerning sections of a text, increasing students' comprehension of that text. In Learning by Teaching, the student becomes a teacher, teaching other students lessons on, for example, foreign languages. In this way, both student motivation and student knowledge of the foreign language increased dramatically (Skinner, 1994). One of the first studies using computers for designing instruction was performed by Harel (1991). She conducted a long-term study in which children engaged in designing computer programs with instructions about fractions. A few years later, Kafai extended these studies by engaging children in creating their own educational multimedia applications, e.g., games for mathematics (1996a), and multimedia resources about astronomy (1997). In sum, placing the student in the role of a teacher seems an interesting and promising approach. Researchers in the field of 'Learning by designing instruction' take this line of reasoning further by placing the student in the role of instructional designer. Up until now, only a few studies have investigated the learning effects of designing instruction. In the next section, we present some of these studies.

1.2.2 Learning by designing instruction

In this section, we present a few studies in which learning by designing instruction is implemented. This will develop a sense of what students might learn by designing instruction.

In introducing her research, Kafai (1996b) wrote: "For many children today, the first interaction with technology is at home playing computer games. By asking them to program software for other children, we are turning the tables and placing children in the active role of constructing their own programs. More promising is that children in this way not only learn about programming and technology, but that it is also supportive for other types of learning" (p. 38). Kafai (1995) conducted a study in which children designed games about fractions for younger children. The goal was for children to engage in significant mathematical thinking and learning. Kafai found that, compared to control classes who were taught programming and fractions by other pedagogical means, the design class learned significantly more about programming and fractions.

In a study by Lehrer, Erickson, and Connel (1994), students worked with HyperAuthor, a tool for making hypermedia presentations. In this study, students were asked to develop a hypermedia presentation about a topic in American history for use as an educational tool by their peers. Results of this descriptive study showed high levels of student effort and involvement, and students used HyperAuthor to create fairly complex documents about American history. Along the way, students developed a number of skills, such as finding and interpreting information, articulating and communicating knowledge, and using a computer as a tool for representing knowledge.

In an attempt to understand how a learner-as-designer environment could affect students' motivation and knowledge of design, Liu (1998) engaged students in designing multimedia programs for a real audience. During this one-year project student motivation and knowledge of design skills were measured three times. Liu found that, during the project, students became intrinsically more motivated and had more self-confidence. Students also acquired more understanding of several design skills. The results indicated that working with clients is strongly motivational for students and makes the learning process more authentic and exciting.

In these studies, learning by designing instruction seems to be an approach that offers students the opportunity to gain domain knowledge and/or to design processes. However, there are also a number of issues that need attention. A growing point of concern is that in designing instruction, students' attention is diverted too much to such aspects as design aesthetics and technology. In this way, students might lose sight of the domain for which the instruction is designed (Kafai & Ching, 2001). Therefore, it is necessary to search for ways in which students can be supported in staying focused on domain knowledge while designing instruction. The next issue is the domain used for learning by designing instruction. It seems a rather curious fact that physics has been a domain of study in learning by designing an artefact or a model, but never in learning by designing instruction. The third issue is connected with this, namely the learning environment used for designing instruction. Hypermedia and programming environments as LOGO have been used as a learning environment for designing instruction. Up to now, the inquiry learning environments appropriate for learning physics have not been used as environments in which students design instruction. In the next section, we work out the idea of implementing learning by designing instruction for a physics topic in an inquiry learning environment. The issue of 'staying focused on domain knowledge while designing instruction' is part of our research question.

1.3 The learning environment

In asking students to design instruction for peer students, the type of instruction and the environment in which students design the instruction need to be specified. In the previous section we have seen students design presentations in such environments as hypermedia and multimedia. As far as we know, inquiry learning environments have not been used as a context for students to design instruction for peer students. Inquiry learning is an 'approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding' (National Science Foundation, 2000). Inquiry learning underscores the idea that learning is more than just memorizing facts and information; students need to know how to get and make sense of a large set of data.

In the present section, we describe 'inquiry learning' and 'inquiry learning environments'. Taking a concrete example of an inquiry learning environment, we illustrate what kind of instruction students could design in such an environment. Along the way, we present a few reasons why we think inquiry learning and the inquiry learning environment we describe form a fruitful context for learning by designing instruction.

1.3.1 Computer simulations and inquiry learning

Computer simulations are programs that incorporate a model of, for example, rules in physics, chemistry, or biology. These rules consist of variables and relations between those variables. In the simulation interface, learners can manipulate values of input variables and observe the resulting changes in the values of output variables. In such an environment the domain is not directly offered to the student; rather, the student has to induce the characteristics of the domain from experiments. This process of building knowledge of a simulated model is called inquiry learning or scientific discovery learning. On the one hand, scientific discovery learning is a *difficult* approach. Scientific discovery learning is difficult, as students engage in a number of unfamiliar processes that might easily lead to making mistakes. On the other hand, scientific discovery learning is a *promising* approach. Scientific discovery means that students have to activate their existing knowledge structures and actively adapt them or construct new structures. The potential of scientific discovery learning is that students experience the exciting feeling of discovering knowledge by themselves, which might lead to deeper and more meaningful knowledge. In addition, the *process* of discovering something by themselves might enhance the chances of a scientific discovery in another place or at another time.

In scientific discovery learning, two main classes have been distinguished (de Jong, 2006b; Njoo & De Jong, 1993): *transformative processes* and *regulative processes*. Transformative processes, which directly yield knowledge, consist of five main categories: orientation, hypothesis generation, testing of hypothesis by performing experiments, drawing conclusions concerning the outcomes of the experiments, and making an evaluation. Regulative processes are processes that manage the learning process and comprise planning and monitoring. Learners often experience problems in scientific discovery learning (de Jong, 2006b; de Jong & van Joolingen, 1998); therefore, scientific discovery learning should be combined with support for the learner (Mayer, 2004). 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).

A scientific discovery learning environment can be a suitable environment for students' taking the role of designers of instruction. After all, it is an environment in which it is quite natural to incorporate support (de Jong, 2006b), it is an environment in which students are supposed to be active learners, and finally, a discovery learning environment could be an environment in which the learner becomes the teacher of peer students by explaining the knowledge and processes discovered. In the next section, we describe the discovery learning environment that was used in the studies described in this thesis.

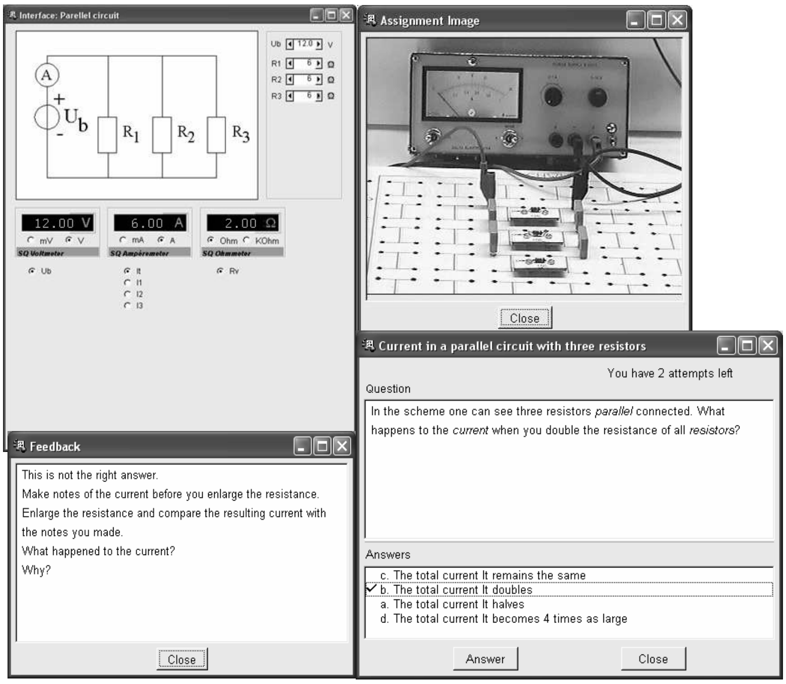
1.3.2 SimQuest

The scientific discovery computer simulations used in our studies were created with SIMQUEST. SIMQUEST is an *authoring environment* in which authors can create SIMQUEST-simulations for their learners. Subsequently, these simulations can be run in the SIMQUEST *learning environment*. First, we give a sense of what a typical SIMQUEST simulation looks like. Next, we show some details of the authoring environment. Finally, we will present more specific information about the instruction to be designed by students in our studies, namely 'assignments'.

The SIMQUEST learning environment

Figure 1 shows a typical example of a SIMQUEST learning environment. On the left side of this figure, the simulation interface is shown. The interface contains a simulation of an electrical circuit with three resistors in parallel connection. In the interface, the student can manipulate the values of the resistors and of the input voltage, and observe the effects on the current I_t and the voltage U_b. The student can measure the current through one of the resistors, for example R_1, by clicking the button before I_1. This positions the ammeter above the resistor R_1, and the output of the ammeter gives the current through R_1.

On the right side of Figure 1, a photo of a parallel connection is added to relate the assignment with reality. Underneath this assignment image, the assignment is shown. In this window, the question for investigation is presented together with a list of alternative answers. Upon selecting one of the alternatives, the student will immediately receive feedback upon the correctness of the selected alternative. Feedback on a wrong alternative provides hints for finding the correct answer. In Figure 1, alternative b was selected; the feedback belonging to this answer is shown on the left side of the assignment.



You have 2 attempts left

Question

In the scheme one can see three resistors *parallel* connected. What happens to the *current* when you double the resistance of all *resistors*?

Answers

c. The total current It remains the same
✓ b. The total current It doubles
a. The total current It halves
d. The total current It becomes 4 times as large

This is not the right answer.
Make notes of the current before you enlarge the resistance.
Enlarge the resistance and compare the resulting current with the notes you made.
What happened to the current?
Why?

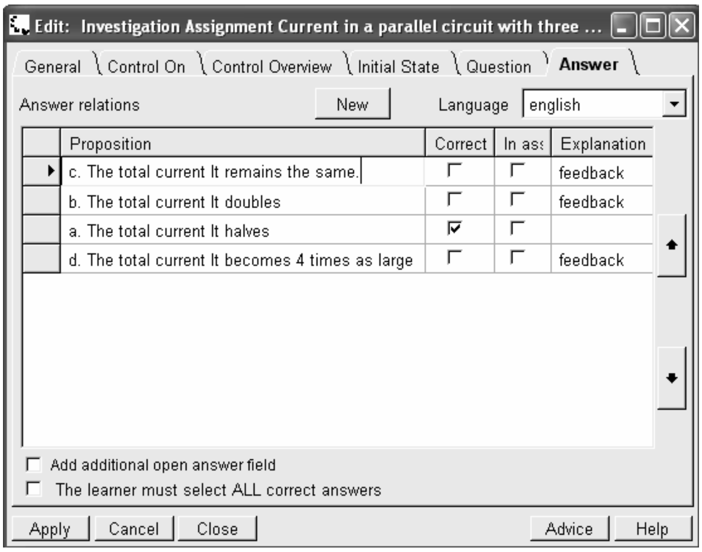
Figure 1 Example of a SIMQUEST learning environment. Shown are, clockwise, the simulation interface (top left), an assignment image, an assignment, and the feedback.

In SIMQUEST, assignments are an important instructional means for supporting the user in learning from the environment. We decided to ask our students to design *assignments* for peer students. In designing an assignment, students are involved in processes such as generating a question, finding the correct answer and alternative answers, and giving explanations. In the introductory sections of Chapter 2 and 3 we explain more about the instructional value of these processes. We now present the process of authoring assignments in SIMQUEST.

Creating assignments in the SIMQUEST authoring environment

The SIMQUEST *authoring environment* offers authors the possibility of creating learning environments without the need for programming knowledge or specific pedagogical knowledge (de Jong et al., 1999; van Joolingen & de Jong, 2003). For authoring an assignment, the author uses a building block such as the one shown in Figure 2. On the tab sheets of this building block, the author can write the question, a correct answer, a number of alternative answers and the feedback.

Once authors have finished the editing of the assignment, they can *run* the assignment from the authoring environment. The assignment will appear to them as the learner would see it (as in Figure 1). The author can inspect the assignment and see whether it is the way it was intended to be. Should authors want to make changes in the assignment, they can easily switch back to the authoring environment and re-open the building block.



Language: english

	Proposition	Correct	In ass	Explanation
▸	c. The total current It remains the same.	☐	☐	feedback
	b. The total current It doubles	☐	☐	feedback
	a. The total current It halves	☑	☐	
	d. The total current It becomes 4 times as large	☐	☐	feedback

☐ Add additional open answer field
☐ The learner must select ALL correct answers

Figure 2 The SimQuest assignment editor, showing the tab sheet for editing the answers.

1.4 The educational setting

In this section, we take a look at the educational setting of our research, namely technological secondary vocational schools. We first sketch the 'genesis' of this type of education in the Netherlands, followed by an overview of innovations in the teaching process. In this way, we give a sense of the type of school and the type of students that participated in our studies.

1.4.1 The historical background

The development of secondary vocational education in the Netherlands closely relates to the needs expressed by the society. Due to growing industrial activity in the 19th century, a need was felt for factory employees who could function between the level of craftsman and engineer. Such employees should have a broad, theoretical education combined with practical training. The first school at this level was the nautical college in Amsterdam (1878) (Makkink, 1994).

Secondary vocational education was, at first, a private initiative. Due to increasing costs, the private investors demanded support from the government. In 1919, this governmental support was arranged in the 'Nijverheidswet'. This law prescribed that in 'domestic science and technical education' practical and theoretical education should be in line with demands from the society. This law gave rise to a growing number of vocational schools in diverse industries, like electronics, car engineering, and tailoring (Makkink, 1994).

In 1996, with the introduction of the Law on Education and Vocational Training (Wet Educatie en Beroepsonderwijs – WEB), schools for vocational training, education for adults, and apprenticeship systems were combined in Regional Education Centres (Regionaal OpleidingsCentrum ROC). Despite all the changes the secondary vocational school has gone through, the two main components of its education remain *theoretical education* combined with *practical training*.

The number of students in secondary vocational education in the Netherlands is about 454,000; this means that this is the biggest educational sector in secondary education in the Netherlands (Dutch department of Education, 2005).

1.4.2 Education at secondary vocational schools

Recently, innovation of the teaching process in secondary vocational education has gained more attention (de Bruijn et al., 2005; Seezink & Van der Sanden, 2005). The reason for this increasing attention dates back to the European Union meeting in Lisbon in March of 2000. In that meeting, the European Union expressed the ambition to become a powerful economic region in the world, based on an advanced knowledge intensive economy. The Netherlands want to have a leading position within this region. As an advanced, competitive knowledge economy requires a high qualified labour force, this ambition has had immediate implications for vocational education.

First, there has been a call for ways to increase the number of students in science and technology studies (see for example the NWO Casimir Brochure 2005).

Second, there has been a push to decrease the percentage of drop-outs (about 15% in the Netherlands) to about 10% - this has led to a search for attractive learning material to increase learner motivation and independent learning (de Bruijn et al., 2005).

Third, the number of students moving on from secondary vocational education to higher education needs to increase. This means that secondary vocational schools now have a double qualification task: on the one side, a diploma should offer a starting position at the job market; on the other side, a diploma should offer preparation for higher vocational training (de Bruijn, van de Berg, & Onstenk, 2004).

Students at secondary vocational schools are from very diverse backgrounds (Dutch department of Education, 2005; Slaats, Lodewijks, & van der Sanden, 1999), generally sharing the characteristic of being ‘do-ers’ and visually oriented students, who learn by experience and have problems with abstract theoretical models and methods. Recent developments in technology make it possible for learning to be increasingly related to virtual reality environments, simulations etc. Virtual reality is already a relevant part of students’ life via the world of games, chat and simulations. A computer simulation seems to be an environment that fits both the recent technological developments and the visual orientation of our students. The learning activity of designing instruction in a simulation might be a suitable activity for students who learn by acting.

We have decided to develop simulations about electrical circuits, because the domain of electricity is generally considered as a difficult domain. For students it is, for example, difficult to reason with abstract concepts such as current and voltage (Shipstone, 1985). In simulations about electrical circuits these concepts can be represented in a visual way. It is likely that this visual representation supports (visually oriented) students in gaining more insight in the concepts of electricity.

In this section, we have looked at the recent developments in secondary vocational education. We discussed the need for attractive learning material in the domain of science. We also discussed students' general characteristics of being do-ers, their visual orientation, and their ability to use modern technology. Given these general characteristics, it seems that students at secondary vocational schools are excellent participants for our research.

1.5 Overview of this thesis

In this chapter we have examined '*learning by designing'* as a learning approach. We have shown that in this way, students can learn about the relations between concepts of a domain, the working of an apparatus, design processes, or gain insight in a domain. We focused our introduction on 'learning by designing instruction', a learning approach in which students take the role of a teacher and explain instructional material to peer students. Literature shows the potential of this approach.

Second, we looked at a *learning environment* in which 'learning by designing instruction' could be implemented. We first introduced 'inquiry learning' as a way of learning by performing investigations. Next, we introduced SIMQUEST, an authoring environment in which one can develop simulations based on inquiry learning. In SIMQUEST simulations, assignments are a typical form of support. Assignments consist of a question, some alternative answers and a correct answer, and feedback on these answers. Literature (see Chapter 2 and 3) shows the learning potential of designing assignments for peer students.

Third, we had a look at the *educational setting* of our research, namely technical secondary vocational schools. These schools have a long tradition of combining practical and theoretical training. Nowadays, they are caught up in major educational changes. Because of these changes, there is a search for attractive learning material that supports the student in independent learning.

With regard to our studies, our students are young and inexperienced instructional designers. Assignments in SIMQUEST are normally designed by instructional designers or teachers. Limbach, de Jong, Pieters, and Rowland (1999) found that these adult designers need support in the process of designing instruction. There is no doubt that our students will need support for designing assignments. Therefore, when we ask students to design assignments in a scientific discovery computer simulation, the question is how to support students in this design process so that they will be able to design assignments *and* learn about the simulated domain.

The problem addressed in this thesis concerns both the design process and the learning effects and can be formulated in the following research question:

> *How can we support students in learning by designing assignments so that they a) are able to design assignments for peer students, and b) learn about the domain simulated in the learning environment?*

In the following chapters, the studies performed to answer the research question are described. To find an answer to our research question, we first wanted to gain insight into how students tackle such a design task. We, therefore, performed an exploratory study (see Chapter 2) designed to reveal how students approach the instructional design task and the decisions they make in their designs. We also expected to learn more about how we could support students in learning by designing assignments.

The findings of the first study were used to develop a scaffolding tool for supporting students in the design of assignments and in learning from the design task. The scaffolding tool consisted of a Design Sheet that guided students through the different steps of designing assignments. In Chapter 3, we describe our second study, which was performed to evaluate the effect of this tool. In that study, we compared the assignments designed by students in a scaffolded group with those designed by a non-scaffolded group. We also compared the knowledge acquired by both groups.

Findings from the first two studies were used to improve the support for our students. This resulted in the design approach 'LOOK EXPERIMENT DESIGN'. This approach will be explained in Chapter 4. In this chapter we also report on a study in which we compared 'learning by designing assignments' with learning in the traditional way.

In Chapter 5, we discuss the results of the three studies in light of the central research questions formulated above. This chapter concludes with suggestions for educational practice and future research.

2

Student-generated assignments about electrical circuits in a computer simulation[*]

Abstract

In this study, we investigated the design of assignments by students as a knowledge generating activity. Students were required to design assignments for ‘other students’ in a computer simulation environment about electrical circuits. Assignments consisted of a question, alternatives, and feedback on those alternatives. In this way, students were encouraged to engage in processes such as ‘generating questions’, ‘discriminating between examples and non-examples’, and ‘generating feedback’. The resulting assignments were analysed and different types of assignments were identified. Information on the design process was collected from think aloud protocol data. Results showed that students not only designed assignments about facts or procedures, but also about observations made with the simulation. During the design process, students actively used their prior knowledge. Students seemed to strengthen their domain knowledge by retrieving and explaining problems solving steps, and focus on the dynamic characteristics of the simulated circuits.

---

[*] This chapter is an adapted version of: Vreman-de Olde, G.C. & de Jong, T. (2004). Student-generated assignments about electrical circuits in a computer simulation. *International Journal of Science Education* 26, 859-873

2.1 Introduction

In recent years there has been a call to shift from more teacher-centered learning activities to learning activities which make the learner more responsible for their own learning (Bransford, Brown, & Cocking, 2000). Learners are currently expected to make a strong contribution to the way they manage information and educational tasks. The rationale for this approach is that the more opportunities learners have, and the more actively engaged they are, the richer their understanding becomes. In powerful learning environments (de Corte, 1990; Jonassen, 2000) learners learn to construct their own knowledge, rather than repeat the designer's and/or teacher's interpretation of the world. Kafai (1996a) takes this line of reasoning further by suggesting that learners should be engaged in designing complex, interactive, pieces of software for learning about a particular student area. This 'learning through designing' is based on the constructionist approach that sees learners as builders of their own knowledge – a process that happens best when students build external and shareable artefacts such as computer programs, machines, or games (Harel, 1991; Papert, 1980). Others (Collins, Brown, & Newmann, 1989) have also stressed the importance of self-directed, personally meaningful, and cognitively complex design projects as a means for students' learning success. The idea here is that the person who benefits most from the design is not the user but the author (Harel, 1991). This is supported in a study by Lehrer, Erickson and Connell (1994), in which students worked with HyperAuthor, a tool developed to make hypermedia presentations. The students created fairly complex documents about American history as an educational tool for their peers. Lehrer *et al.*, showed that students participating in design activities explored topics deeply, developed personal interests and involvement, conversed substantively about the topics, and began to develop critical standards for knowledge.

In the present study we investigated the design of assignments for peer learners in the physics domain of electricity. We asked the students to design assignments about electrical circuits in the context of a computer simulation on this topic. Assignments consisted of a question, alternative answers, and feedback on those alternative answers. Students, therefore, had to 'think of a possible question about an electrical circuit', 'determine alternatives answers', and 'write feedback on these answers'. Based on literature, we expected each of these three aspects to contribute to the student's knowledge acquisition processes.

The process of *generating questions* is considered an important strategy for fostering comprehension (Palincsar & Brown, 1984). Composing questions focuses students' attention on content and makes them concentrate on main ideas while checking if content is understood. Chin, Brown, and Bruce (2002) and Davey and McBride (1986) have shown that students' questioning contributes to their cognitive development, mainly as a result of their involvement in the generation and formulation of the questions. Students start to think more deeply and to hypothesize, predict, seek and generate explanations for the things which puzzled them.

In *thinking about alternative answers* to their questions, students have to think about possible mistakes that can be made. In learning concepts, the learner learns to discriminate between examples of the concept and non-examples that may share some features with the concepts but do not share the critical, or 'criterial' attributes that make an instance a member of that concept's class (Smith & Ragan, 1999). We expect that when the students think of alternatives, they have to think about examples and non-examples as answers to their question.

Positive effects of *generating feedback* to the alternatives in the assignment are expected because in constructing adequate feedback students have to integrate prior knowledge and new knowledge (King, 1994). Webb (1989) found that giving high-level elaborations of material to other members of the group was positively related to achievement. Also Coleman, Brown, and Rivkin (1997) reported that giving explanations to peers had positive effects. They asked students to explain or summarize a text to a peer. Overall, explainers outperformed summarizers on a far transfer task dealing with the domain. It seems to be the case that in constructing an explanation, one must differentiate what is understood from what is not understood as well as reorganize the material in an efficient manner so that the learner can understand it. This cognitive restructuring of material may help the student who explains to understand the material better, develop new perspectives, and recognize and fill in gaps in his or her understanding (Webb & Palinscar, 1996).

Although overall the positive effects of design tasks are well known, much is still unknown about specific aspects of designing assignments. In the current study we focused on three aspects of the design of assignments: the question, the alternatives, and the feedback. In the study we had students design assignments for a fictitious peer student. Our first source of information were the *products* of our students, this is the assignments that were designed. More specifically we examined the nature of the assignments and the role of prior knowledge in the design. Our second source of information was *think aloud protocol data* gathered from students while engaged in the design task. From these sources of data we analysed how students chose their questions, motivated the alternative answers, and how students motivated their reasons for choosing specific feedback. A specific characteristic of the current study was that the design of assignments was done in the context of a computer simulation that students could explore. We, therefore, specially examined how the presence of a simulation helped or hindered the students in designing assignments. Finally, we examined the advantages and disadvantages of a computer tool for the creation of the assignments as it was used in the current study.

2.2 Method

2.2.1 Participants

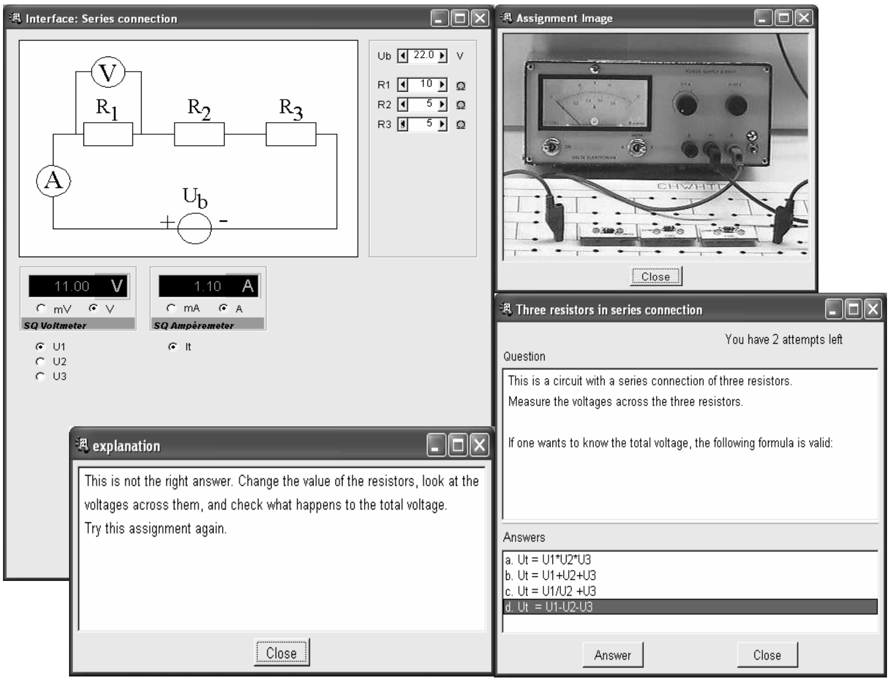
Nineteen students participated in this study. They were first year students from a secondary vocational technical school in the Netherlands, 16 to 18 years old, and all were male. They had just completed a course on electrical circuits. The main topics in this course were: simple direct current electric circuits, diode, load line, and parallel non-ideal voltage power suppliers. Students participated on a voluntary basis and received compensation for their participation.

2.2.2 Learning environment

In this study SIMQUEST is used. SIMQUEST is an *authoring environment* for creating learning environments (de Jong et al., 1998; de Jong et al., 1999; van Joolingen & de Jong, 2003). SIMQUEST *learning environments (applications)* are based on a simulation of, for example, rules in physics, chemistry, or biology. Learners can engage in a process of discovery by manipulating values of variables and observing the outcomes of their actions. To support the learners in their discovery process SIMQUEST applications offer several forms of instructional support, including assignments. An assignment provides a learner with a short-term goal like finding a relation between two variables or observing the behaviour of the simulation. After reading the assignment the learner is expected to explore the simulation and after having done so, the learner may select an alternative answer from a list of predefined alternatives. Feedback is given for the alternatives chosen. In this study a simulation environment in the domain of electricity was used. This application is called Electricity and is based on the rules of Kirchhoff and Ohm[*]. An example of an assignment in this application is shown in figure 1. This example shows a simulation of a circuit with three resistors in a series connection and an assignment that asks the learner to investigate the relation between the voltages across the resistors and the voltage of the power supply. An image of three resistors connected to a voltage supply is added to relate the assignment with reality. In the simulation window the diagram of the circuit is shown. The independent variables, which can be changed by clicking on them, are placed to the right of the diagram. The dependent variables, which can be measured by clicking on them, are shown underneath the diagram of the circuit. The learner is expected to use the simulation and select an answer from the list, based on his experiments. Feedback is given to him, correcting or confirming the answer that was given. In our study we asked the students to design assignments about one or more circuits.

---

[*] Kirchhoff states that $\Sigma I_{\text{stream towards}} = \Sigma I_{\text{flow of}}$ for a junction; $\Sigma U = 0$ in a closed circuit. Ohm states that $R = U/I$, with the symbols R for resistance, U for voltage and I for current.



Interface: Series connection

Ub 22.0 V

R1 10 Ω

R2 5 Ω

R3 5 Ω

SQ Voltmeter: 11.00 V (○ mV ● V)

SQ Ampèremeter: 1.10 A (○ mA ● A)

● U1
○ U2
○ U3

● It

Three resistors in series connection

You have 2 attempts left

Question

This is a circuit with a series connection of three resistors.
Measure the voltages across the three resistors.

If one wants to know the total voltage, the following formula is valid:

Answers

a. Ut = U1*U2*U3
b. Ut = U1+U2+U3
c. Ut = U1/U2 +U3
d. Ut = U1-U2-U3

explanation

This is not the right answer. Change the value of the resistors, look at the voltages across them, and check what happens to the total voltage.
Try this assignment again.

Figure 1 Example of a SIMQUEST simulation. Shown are, clockwise, the simulation interface (top left), an assignment image, an assignment, and the feedback (to answer d).

2.2.3 Authoring in SIMQUEST

The SIMQUEST *authoring environment* offers authors the possibility of creating learning environments without the need for programming knowledge. In Chapter 1 of this thesis, we showed the process for authoring an assignment in SIMQUEST. In the present study, the main task for our students was to think of an assignment and to write the assignment in the building block.

In figure 1 one of the circuits used in the application Electricity is shown; it contains a circuit with a series connection. The other circuits in this application contained parallel circuits; mixed circuits; a circuit with a diode; a circuit with two resistors and a graph with a load line; and a circuit with two non-ideal parallel voltage power suppliers. In total 16 different circuits, with different levels of difficulty, were available for the students.

Although the authoring process in SIMQUEST might complicate the design of an assignment, and we could have offered the students the circuits on paper, we think that the use of SIMQUEST has clear advantages. The first advantage of the use of the simulated circuits is that the students can do experiments in the simulation, and in this way gain new knowledge, or be reminded of prior knowledge. Another important aspect is that while students are making an assignment they can actually run it, and see whether the assignment looks like what they intended it to be. In addition, the simulation quite often allows students to check the correctness of their alternatives.

2.2.4 Procedure

First session

The study consisted of two sessions. In the first session students became familiar with SIMQUEST, both its learning and authoring environment. They also worked with a SIMQUEST application, so they would see what assignments in SIMQUEST look like. In a normal class situation assignments normally focus on calculations of unknown variables, whereas in SIMQUEST assignments the focus is on the effect of changing variables. During the first session our students therefore received instruction about ‘what is a good assignment in SIMQUEST’. In this first session they also learned how to author assignments with the use of the authoring environment.

Second session

At the beginning of the second session each student received a short review of the first session. This second session, which took about one and a half hours, was a ‘one-on-one session’: a student designed assignments while being observed by one person. Students used the SIMQUEST application Electricity for this session. The student was asked to design assignments that stimulate the use of the simulation (by the ‘fictitious’ peer who should do the assignment) and he was free to choose what circuit he wanted to use for an assignment. To get a quick overview of the available circuits, a small booklet with the circuits in the application Electricity was given to each student. Each student received a sheet of paper to make notes on. Students were asked to think aloud during the design process. At certain moments in the design process, after a long silence and/or after completing an assignment, process questions were asked. These are questions like: ‘How did you get an idea for the assignment?’; ‘What’s the reason for your alternatives?’; ‘What should the peer learn from your assignment (learning goal)?’ This method resembles the red-dot method used by Ferguson-Hessler and de Jong (1990) to investigate learning processes while reading text. The answers on the process questions and the think aloud protocol were all recorded on tape. The students were allowed to ask for technical help about working with the SIMQUEST authoring environment. The observer made notes of special actions performed by the student, e.g., using the calculator, or as a record of the answer to the process questions e.g., the experimenter saw *how* the simulation was used, whereas the student only said he had used the simulation. The assignments designed by the students were saved on disk.

2.3 Results

The results section presents analyses of the assignments designed by the students and of the think aloud data obtained from students engaged in the design task. In the first part of this section, we present the different types of assignments created by the students and we zoom in on the different aspects: the question, the alternatives and the feedback. For the second part of this section, think aloud data and observations made by the experimenter are used to present how our students approached the design task.

2.3.1 Types of assignments created by students

The students designed a total of 57 assignments, with on average 3 assignments made by a student (SD=0.8). The assignments that students designed showed remarkable differences. In most assignments questions were posed that could be solved without using the simulation. In fact, a peer would only need a picture of the circuit to be able to solve the assignment. In these assignments the peer was mainly asked to do calculations (in 30 of the 57 assignments, that is 53%). We called these assignments *calculation assignments*. A few times the question was about conceptual prior knowledge (8%). These assignments were called *knowledge assignments*. Finally, different kinds of questions that involved the use of the simulation were posed (39%). These assignments were called *simulation assignments*. In these assignments students asked for the effects of *changing variables* (14%, e.g., double the voltage of the power supply), or asked to *reach a specified state in the simulation* (14%, e.g., try to find the threshold voltage of the diode), or asked for the effect of *toggling a switch* (11%, e.g., upon toggling a switch a bulb is taken out of the circuit, or a resistor is added to the circuit). In these simulation assignments the peer was asked to observe effects of changes, measure dependent variables, and/or to compare the initial values to the final values of states in the simulation.

Table 1 gives a summary of these findings. From this table it can be concluded that in most assignments questions about calculations or about knowledge were posed (61%). This is explicable because students are used to these kinds of questions during the normal lessons. In calculation assignments, the student remembers and reproduces the procedure of a calculation he learned. For these assignments the value of the simulation is that a student can easily check the right answer or find ‘right’ numbers for the input variables. The table also shows that in simulation assignments, students asked questions that focused on ‘what happens if I change variables’, ‘what happens if I toggle a switch in the circuit’, or ‘how can I reach a certain state in the circuit’. This kind of question is new to our students. It shows the value of the simulation in supporting students to discover the dynamic effects of the circuit (‘if I change U then…..’, or ‘upon shortcutting a bulb….’). Thinking of questions about these effects, forces the students to have a close look at what happens, find the right answer, make interpretations, and explain it to fellows. In the next three examples we show differences between assignments. In these examples we zoom in on the question, the alternatives and the feedback.

Type of assignment	*Feature*	*Number of appearance*	*(%)*
Calculation assignment	Do a calculation	30	(53%)
Knowledge assignment	Retrieve knowledge	5	(8%)
	Change variables	8	(14%)
Simulation assignment	Reach specified state	8	(14%)
	Toggle switch	6	(11%)
Total		**57**	**(100%)**

Table 1 Assignments designed by our students divided in three main categories, together with the main feature and the number of assignments in each category (within parentheses the percentage of total).

(i) Example of a calculation assignment.

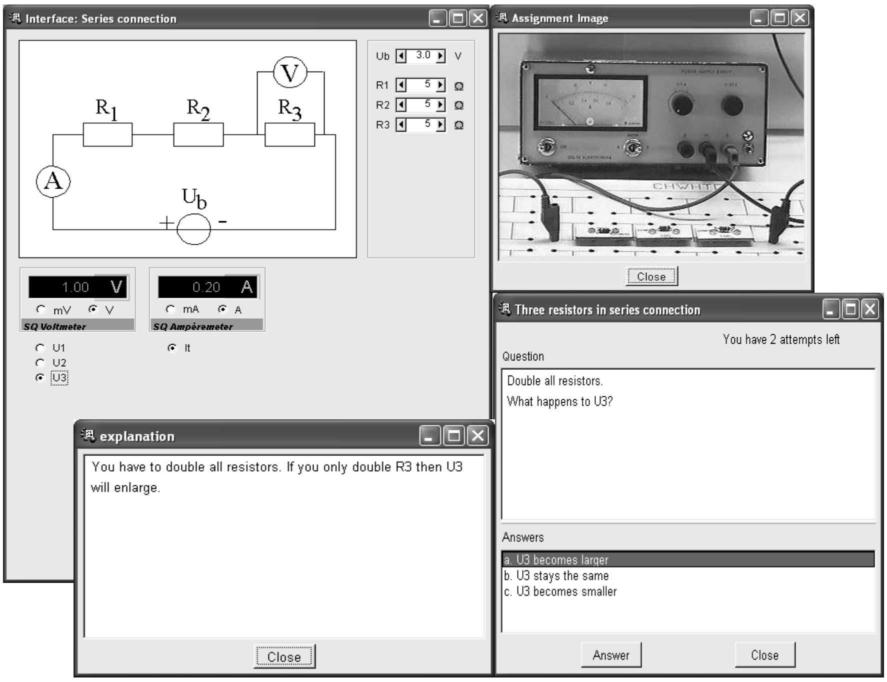
A number of calculation assignments were about mixed circuits. During regular lessons, students were asked to calculate the total resistance of a mixed circuit. An example of a question about a mixed circuit posed by one of our students was: 'Calculate the total resistance if R_1=20 Ohm, R_2=30 Ohm, and R_3=15 Ohm and the total voltage is 30V'. (Note that the value of the voltage is not necessary for the calculation). The alternatives were numbers that 'might be possible', e.g., 65 Ohm. As the student wrote in his feedback, this alternative is wrong because 'you are not allowed to add parallel resistances'. In the feedback on the right answer, he explained how to calculate the total resistance in a mixed circuit. The questions in this type of assignments were often quite complex ('puzzle work' as one of the students said). To find the right answer one needs to perform a multi-step calculation procedure.

(ii) Example of a knowledge assignment.

The feature of a knowledge assignment is that it cannot be solved with the use of the simulation: the answer simply needs to be known. One of our students remembered a rule he found very useful because he used the rule for checking the calculation of the total resistance in a parallel circuit. His question was: 'With what rule can you check your calculation of the total resistance?' His distracters were rules that looked like the right rule. His feedback was a statement of the correct rule. This assignment shows that the student remembered the rule correctly. However, it would have been more instructive if he had tried to apply this rule in the simulation.

(iii) Example of a simulation assignment.

An example of a simulation assignment designed by one of our students is shown in figure 2. This assignment is about a circuit with three resistors in a series connection. In the question the student asked 'Double all resistors. What happens to U_3?' (Note: U_3 is the voltage measured across resistor R_3). The student had thought of discriminating alternative answers, which uses as background mistakes a peer could make.



Ub 3.0 V

R1 5 Ω

R2 5 Ω

R3 5 Ω

1.00 V

○ mV ● V

○ U1

○ U2

● U3

0.20 A

○ mA ● A

● It

You have 2 attempts left

Question

Double all resistors.
What happens to U3?

Answers

a. U3 becomes larger
b. U3 stays the same
c. U3 becomes smaller

You have to double all resistors. If you only double R3 then U3 will enlarge.

Figure 2 Simulation assignment designed by one of our students. Simulation interface and assignment image were given; the student designed the text for the assignment.

In figure 2 the feedback belonging to answer A (U_3 becomes larger) is shown. In this feedback the student pointed to a mistake the peer could have made: not enlarging *all* resistors. The right answer is that the voltage does not change (answer B). The feedback is: 'This is right because U = I*R. The initial state is: I = 0.20A and R = 5 Ohm and 0.20*5 = 1.00 Volt. If you double the resistors to 10 Ohm then the current becomes 0.10 Ampere and 0.10*10 is also 1.00 Volt'.

While designing his assignment, the student often used the simulation: he measured the different voltages, doubled resistances, and measured voltages again. He discovered (see feedback on A and C) what happens if one does not change all resistances (alternative A and C). With the help of the simulation he found that the right answer is that U_3 stays the same. Using his knowledge about Ohm's law and combining this with the observations in the simulation, he wrote a thorough explanation.

2.3.2 Ways in which the students approached the task

Students not only differed in the nature of the products designed, they also approached the design task in different ways. Some students saw a circuit in the simulation and were reminded of facts they learned before. Others used the simulation which gave them inspiration for an assignment. We will first give two examples of how students designed assignments. Then we will present on overview of how the students approached the design task and what seem to be the effective aspects in it.

Example 1: Remember a question done in a test
The student studied the booklet with the interfaces and chose a circuit about which he remembered a question from a test once done. In the simulation he changed variables, measured the values of other variables, and chose easy numbers so the answer would be easy to calculate. He calculated the right answer himself and checked it with the simulation. The student thought about wrong calculations on which he based his alternatives. In the feedback, the student presented the formula needed to perform the calculation.

Example 2: Do experiments
The student opened the interface and started to change variables. He measured different variables, changed them again and again. During this process he obtained an idea for a question. He formulated his question and used the simulation to find the right answer. He based his alternatives on numbers that are two times larger or smaller; he also checked it in the simulation. In the feedback he wrote about what he had seen in the simulation.

An important aspect of a design task is *getting an idea for the design*. In this study the students were asked how they obtained ideas for their designs. Many students did some experiments with the simulation and observed interesting effects or even discovered new knowledge. These observed effects, or the newly gained knowledge, formed the basis of their assignments (25 times in 57 assignments, that is 44%; respectively 4 times in 57 assignments, that is 7%; see last column of table 2). Other students obtained their ideas by looking at a circuit and being reminded of a question done before in a test or a book (27%) or of well-known facts or procedures (23%). Recall of procedures often resulted in questions that asked for the calculation of an unknown variable. The students liked their products because of the ‘puzzle work’ (trying to find the right answer). Recall of facts often resulted in assignments in which the student tried to transfer his knowledge: in the feedback he showed what he knew about the circuit.

	Thought				
Inspiration source	Just put idea into question	Find appropriate numbers	Check idea with simulation	Think about transfer of knowledge	Percentage (%)
Observed effects	7	6	7	5	44%
New knowledge				4	7%
A question	9	4	2		26%
Facts/procedures	4		2	7	23%
Total	**20**	**10**	**11**	**16**	**100%**

Table 2 Thoughts of students for transforming their idea into a question (total is 57 assignments).

After the students obtained an idea for an assignment, they *formulated a question*. Students used different methods in formulating their questions (see table 2). Some thought about appropriate numbers for the variables, others checked their ideas with the simulation, and a large group of students thought about how they could transfer their knowledge. These processes seem to be important: students check their prior knowledge in a new environment and think about how to transfer and explain that knowledge in their own words. About one third (20 out of 57) of the students just formulated the idea they had into a question without deliberately working it through.

Prior knowledge is essential in designing an assignment. We now present some examples of how prior knowledge was used during the design of assignments.

(i) Prior knowledge and a discovery

Sometimes a student combined prior knowledge with a discovery made in the simulation. E.g., a student saw a series connection of bulbs and an option to shortcut the middle bulb. The student knew that upon shortcutting the middle bulb, the other bulbs remain burning. In the simulation of this circuit he *discovered* that the other bulbs burned brighter.

(ii) Prior knowledge and formulation of question

Another student opened the simulation of a diode and remembered that a diode starts to conduct current when a certain amount of voltage is applied across it. The protocol shows how the student used this knowledge to formulate a question. ‘Let’s have a look when the diode conducts current. You can see it here: 0,72Volt’. He wrote his question in the authoring environment: ‘When does the diode conduct current?’ ‘Umm, that’s a short question. I think it’s better to say: *At* which voltage does the diode conduct’.

(iii) Prior knowledge about common errors

A few times student's own former problems with the domain became the theme of an assignment. E.g., confusion about which formulae to use ($U=I*R$ or $P=U*I$), or how to perform a complex calculation. It shows that some students are able to anticipate common errors, which provides good evidence of their own understanding

In formulating the *alternative answers* to their question, the students had several motives:

- The alternatives are numbers around the right answer or a mix of right and wrong answers (74%).
- The alternatives are based on wrong calculations of peers (14%) (e.g., problems in the calculation of the total resistance).
- The alternatives are based on diverse reasons: possible misreading of meters, other numbers on the screen or just numbers (12%).

Because of the fact that the alternatives were mostly possible options, one can conclude that the students did their best to think of good alternatives. Students, who chose their alternatives around the right answer, mostly motivated this by saying that they wanted the peer to really measure or accurately calculate the right answer. This meant that the student himself also had to do the calculation or measurement correctly and accurately. Others had as reasons for their alternatives wrong calculation procedures of their peers. The peer should think and discriminate between the right and wrong answer. These alternatives were tough work for the student: he had to think about what someone can do wrong or what he himself used to do incorrectly.

That the student himself has to do the calculation correctly becomes clear from the following part of a protocol. The student designed an assignment about a mixed circuit. His question was to calculate the current through the three resistors. 'Let's have a look for the answers'. (He used the simulation). 'Hum, the current I_1 is not measured. Oh that's of course the same as I_t, which is 1.33 Amps. Let's have a look, $I_1 = 1.33A$, $I_2 = 0.67A$, $I_3 = 0.67A$. That's right. One can measure the voltage across R_1 and R_2. The current through R_1 can be calculated with R_1 and U_1. U_2 can be measured with the voltmeter, divide by R_2 and you know I_2'. We asked him for the goal of his assignment and he said: 'Well, if one has two parallel connected resistors and one knows the total current and the current through one of the two resistors, than you know the current through the other resistor too'. This part of the protocol shows that the student has a correct understanding of current behaviour in this mixed circuit.

What became clear from the *feedback* the students designed was that they really wanted the peer to learn. They gave hints to reach the right answer by giving the formula or explaining the procedure (29%), others gave hints to use the simulation (12.5%). Many students explained the right answer by executing the calculation

(27%). In cases where the assignment was about a potential peer mistake, the feedback was about this mistake (12.5%). Some just wrote that the answer was wrong (11%). Others just gave the right answer or gave no explanation (8%).

By giving those explanations the students themselves must have had a clear view on the key to their own question: they wanted their question, the alternatives, and the feedback all to contribute to the goal of the assignment. Students used their knowledge in a new learning environment, which was instructive to them. For example: a student had learned that in a simulation with the diode one should change the voltage of a power supply to discover the threshold voltage of the diode. This discovery became the goal of his assignment. In the feedback he gave the advice to change the voltage of the power supply, so the peer could make the same discovery.

2.3.3 Working with a computerized authoring environment

Our last research question concerned the use of a computerized authoring environment (in this case SIMQUEST) as a design tool. Our question was whether students are able to work in the authoring environment and at the same time think about assignments. We saw that while working on the first assignment, all students needed help in the authoring environment. While working on the other assignments, their calls for assistance diminished, especially for students who had computer experience. We also saw that students were able to combine this technical task of working in the authoring environment with the conceptual task of designing assignments. They often switched between the authoring environment and the learning environment, so they could see 'what their assignment looked like' and evaluate their product. Seeing their assignment 'working' helped them to evaluate their product and inspired the students during this task.

2.4 Conclusions and discussion

Previous work has established that *generating questions* about a text focuses the student's attention on content. It involves concentrating on main ideas, while checking if content is understood (Palincsar & Brown, 1984; Rosenshine, Meister, & Chapman, 1996). Despite the difference in learning domain and environment, in our study we also found that students focused on main points in the domain. When we asked the students for the *goal* of their assignments this often revealed what they found important about the circuit involved. The few students who were not able to ask a question about an important aspect of the circuit seemed also to be less competent in the domain of electricity. Designing assignments in our study made the students examine interesting aspects of circuits (e.g., why a bulb dims), think about problems they had formerly had (e.g., mixing up two formulae), consider problematic points in a calculation (e.g., total resistance in a mixed circuit, or the current through an element in the circuit), or ponder about dynamic characteristics of circuits (e.g., 'how should I change the variables so the diode starts to conduct current', or 'how is the current going in this circuit').

In our study we found that in *thinking about alternatives* students reflect on the procedure for the solution and think about possible mistakes that can be made. When thinking about mistakes, students seem to realize better what they themselves used to do wrong. This can help them to avoid making these mistakes again. E.g., a student asked to measure the current in a special situation in the circuit. His alternatives were numbers obtained by wrong measurements. The student who designed the calculation assignment discussed before knew that some peers had problems doing the calculation of the total resistance in a mixed circuit correctly. His alternatives were based on those problems.

In *generating explanations* students must differentiate what is understood from what is not understood as well as reorganize the material in an efficient manner so that the peer can understand it (Coleman et al., 1997). It also seems plausible that the construction of an explanation requires the integration of prior and new knowledge (Chi, de Leeuw, Chiu, & Lavancer, 1994). What we saw in this study is that our students often remembered prior knowledge, be it by just looking at the simulation, or by doing experiments with the simulation. Sometimes students discovered new knowledge, more often they rediscovered knowledge. A student who rediscovered the Law of Ohm (U=I*R) did some experiments and noticed that the effect of enlarging the resistance is that the current diminishes. The student had made many calculations with this law before, but he did not seem to recognize it immediately in the simulation.

We found that our students designed two main types of assignments, namely *calculation* and *simulation* assignments. In a different context Chin, Brown and Bruce (2002) found similar results. In their study, students designed questions about basic information (facts and procedures, similar to our calculation assignments) and wonderment questions (e.g., comprehension, prediction, similar to our simulation assignments). Chin et al. stated that wonderment questions are associated with a deep approach in learning science, whereas basic information questions are associated with a more surface approach. We now will discuss some differences between those two types of assignments.

When writing the feedback on the procedure of a *calculation assignment*, students often were concerned that the peer should be able to understand it. This meant that they did not just write down what they knew, but tried to organize it in such a way that it would be understandable. A long-standing goal of educational research is to help students avoid shallow learning, and try to help them explain acquired knowledge in their own words (Aleven & Koedinger, 2002). What we saw in the assignments our students designed is that in the calculation assignments, the students often wrote down in the feedback the procedures they learned before during normal classes. They often said ‘it all comes back’, meaning that, as one student put into words: ‘you have to do the calculation again and then you have to think how to explain it’. The student had to remember the whole procedure and do the calculation himself again. Some did a procedure consisting of 3 or even 4 steps by heart. This suggests that designing calculation assignments can go with retrieving and explaining problem solving steps, meanwhile strengthening procedural knowledge.

While designing a *simulation assignment*, students used the simulation. The students changed variables, observed effects, and seemed to be more interested in the effect of changing a variable than in the exact value of that variable. This is a kind of knowledge that Swaak and de Jong (1996) in the context of simulation based learning have called 'intuitive knowledge'. This knowledge mainly concerns knowing what happens upon a change in the simulation. In this case, students are not interested in the *exact value* of e.g., a resistor, but more in the *effect* of changes in its value. Student look at the simulation, perform experiments, and design an assignment about what they have seen. Because of the fact that students make a simulation assignment, which they have never done before, they can not use the formulations they used before (as was done in the calculation assignments). They have to find new ways of gaining knowledge (namely using the simulation), but also new ways of giving hints or explanations. In their hints, students advise their peers to check whether they have made correct adjustments in the simulation, advise about how to find the threshold voltage of the diode, etc. The feedback in these assignments sometimes contains good explanations, but in cases where the students give hints, the feedback becomes rather simple. It seems that by designing simulation assignments students can get a better insight in the dynamic characteristics of the simulated circuits, and that they can learn to focus on 'what happens in a simulation' and on 'cause and effects in circuits'. These (dynamic) effects are not often studied during regular lessons. The fact that students are able to design assignments about dynamic effects in circuits confirms the finding of Russell and Harlen (1990), who found that children can learn to ask investigable questions about practical tasks.

From the present data it is not possible to draw conclusions about the overall learning effect of designing assignments for peers. What is obvious from the results is that the students remembered the rules, facts, and procedures they learned before and used this knowledge in a new environment. Moreover, some discovered new knowledge; others made relations between circuit and reality (e.g., a series circuit and Christmas tree lighting). However, the present study makes clear that we can expect beneficial effects given making improvements to SIMQUEST's learning environment.

Our study has provided us with ideas on how to improve the learning environment, on how to include scaffolds for students in the learning by design approach, and on how to measure learning effects. A long standing finding is that students asking questions is not common (Graesser & Person, 1994). Our students confirmed this by saying that the teacher normally asked the questions and they were not used to doing so. White and Gunstone (1992) state that the essence of what is needed for successful promotion of student questions is a way of structuring and focusing the task. They proposed asking students to begin questions with ‘What if…’, ‘Why does…’, ‘Why are...’, or ‘How could…’, as such questions are more likely to be based on deeper thinking than simple recall (King, 1994; Webb & Palinscar, 1996). Olsher and Dreyfus (1999) found that students were able to ask questions relevant to the processes they studied after some intense scaffolding. These authors concluded that the students first had to learn the different types of questions that one should ask about the observed scientific processes, before they can ask meaningful questions that drive their learning. Based on these recommendations and our experiences in the current study students could be provided with question stems that are suitable for the simulation: e.g., ‘what happens if…’, ‘what’s the effect of…’ In our study, we also found that about one third (20 out of 57; see table 2) of the students just formulated their idea into a question without really working it through. It could be more instructive to think about the values of the variables to be used, to check the idea with the simulation, and/or to think about what to transfer to the peer.

As second strategy White and Gunstone (1992) proposed was to provide a stimulus on which questions are to be based. They suggest that students learn to ask questions based on a given piece of information or a set of ideas, e.g., a diagram, or a table of data. One possible measure is to support students with background information about (elements in) the circuits. This background information can contain hints for the analysis of a special circuit. Students can, for example, be prompted to analyze and relate all the effects of taking out a bulb (students often just looked at one effect). White and Gunstone’s strategy also corresponds to our ideas to guide students more in the direction of designing simulation assignments instead of calculation assignments. In designing simulation assignments the student can do experiments, observe effects, and obtain data. These observations and data can be used as the basis (or stimulus) for meaningful assignments.

This last strategy also opens ways in which learning gains could be measured. In stimulating the design of simulation assignments, the focus becomes more on the use of the simulation and the interpretation of data. We expect that the students will gain knowledge about ‘what happens upon changing a variable’. This knowledge has been successfully measured with the ‘WHAT-IF’-test developed by Swaak and de Jong (1996). Therefore, stimulating the students to design simulation assignments and supporting them with hints on how to do good experiments are potential ways of improving the learning by design process.

Shepardson and Pizzini (1991) found that questions in science textbooks, regardless of discipline, emphasize recall of information and lack questions asking for drawing relationships. In the books used by our students, many questions focused on the steps to perform a calculation. A higher level of questions is desirable so students can learn to integrate prior knowledge about facts and procedures with knowledge about relationships in the circuits. Results from the present study suggest that having students design these questions themselves is feasible. The next steps will be to find, based on the process analysis in this study, the optimal support for students in the design process and to evaluate the effects on knowledge acquisition.

3

Scaffolding learners in designing investigation assignments for a computer simulation[*]

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 phases 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 phases. On average, students in the non-scaffolded group designed more assignments than students in the scaffolded group. The scaffolded students designed relatively 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 suggest on how to adapt the scaffolding to improve not only the learning process but also knowledge acquisition.

---

[*] This chapter is an adapted version of: Vreman-de Olde, G.C. & de Jong, T. (2006). Scaffolding learners in designing investigation assignments for a computer simulation. *Journal of Computer Assisted Learning,* 22, 63-73

3.1 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, 1996a). In design problems, students are asked to build artefacts (Crismond, 2001; Janssen, 1999; Roth, 2001), models (Löhner et al., 2003; Novak, 1990; Novak, 1998; Penner, 2001; Riley, 1990), or instruction (Harel, 1991; Kafai, 1996a). 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 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 for example, 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, 2005; de Jong & van Joolingen, 1998). 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 (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 few 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 if content is understood (Palincsar & Brown, 1984; Rosenshine et al., 1996). Generating explanations requires students to integrate old and new knowledge (Chi et al., 1994), which leads to performance gains (Bielaczyc, Pirolli, & Brown, 1995).

In our first study (Vreman-de Olde & de Jong, 2003; 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 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 explore the simulation (doing experiments, drawing conclusions), to support them in designing assignments based on the observations performed, and to guide them in integrating prior knowledge with newly gained knowledge. In 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.

The first phase of the design task is *generating the idea* for an assignment. In this phase, we would like our student to explore the simulation and to generate an idea based on a number of systematically performed experiments. Providing students with heuristics can support them in performing systematic experiments (Veermans, 2003; Zhang, Chen, Sun, & Reid, 2004). Encouraging students to provide evidence for the conclusions they draw can facilitate students in generating meaning from data and making connections among procedures, data, evidence, and claims (Keys, Hand, Prain, & Collins, 1999).

In the second phase, students have to *transform* their idea into an assignment. An (investigation) assignment consists of a question, one correct and a few 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, for example ‘What if…’, ‘Why does...’, ‘Why are…’, or ‘How could…’. 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 & Palinscar, 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 phase 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, therefore students should be encouraged to do so (Quintana et al., 2004). In this reflection process, students might be asked to articulate what they learned from the design of the assignment. When students succeed in articulating the knowledge presented in their assignment, this might be engaged in a reflection process that generally has proven to be beneficial for learning in the context of inquiry learning (Land & Zembal-Saul, 2003; Moreno & Mayer, 2005; Zhang et al., 2004).

The use of a worksheet is an appropriate way of scaffolding students both in the overall structure and in the specific reasoning steps (Kolodner et al., 2001; Lee & Thompson, 1997; Njoo & De Jong, 1993; Puntambekar & 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 phases, while providing them with tips, examples, and background information.

Our research goal, for the study described in this chapter, was to investigate how well the Design Sheet supported students in learning by designing assignments. In this study, a group of students, the *scaffolded group,* made use of the Design Sheet while designing assignments. Another group of students, *the non-scaffolded group,* was also asked to design assignments but they did not receive support for their design task. Both groups designed assignments in the same computer simulation. 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.

3.2 Method

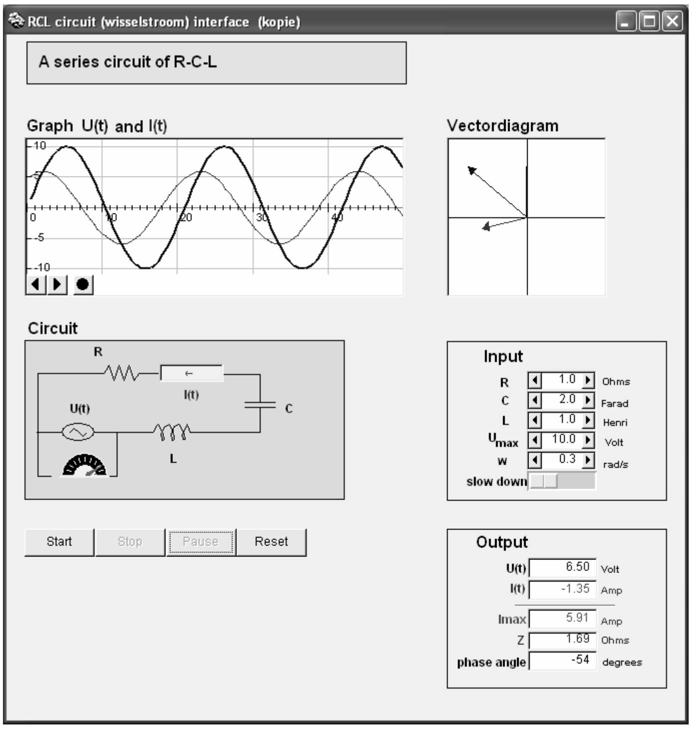
3.2.1 Participants

Participants were 45 second year students from a secondary vocational technical school. 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. ($M_{scaffolded}$=5.36 SD =1.41, range=5.2; $M_{non\text{-}scaffolded}$ = 5.95, SD=1.91, range= 7.3; df=40, t=1.14, p=0.260).

3.2.2 Material

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; Figure 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. 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 Figure 1, contains a resistor, a capacitor, and a coil. The final simulation simulates the resonance effect for different values of the frequency.



A series circuit of R-C-L

Input
R 1.0 Ohms
C 2.0 Farad
L 1.0 Henri
U_{max} 10.0 Volt
w 0.3 rad/s
slow down

Output
U(t) 6.50 Volt
I(t) -1.35 Amp
Imax 5.91 Amp
Z 1.69 Ohms
phase angle -54 degrees

Figure 1 Screen shot of one of the five simulated circuits in the learning environment.

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 phases in the design of an assignment. The student was expected to use the simulation in each phase and received advice at several moments in the design process. In Figure 2, we have depicted the interaction between simulation, Design Sheet, and support. In the centre of this figure, the three phases 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 phases. 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 do experiments (heuristics). We now present a more detailed description of the Design Sheet, thereby using the three phases 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 (for example, ‘What happens to I_{max} if one doubles L?’). Next, 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 (Aleven & Koedinger, 2002; Cox, 1999), and their prior knowledge (Webb & Palinscar, 1996).

Evaluating the assignment

The learning environment used in this study 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.

Use of the simulation learning environment	**Phases in the Design Procedure**	**Support implemented in the Design Sheet**
	Generate an idea	
- Explore the simulation - Perform systematic experiments	Students are asked to generate an idea for an assignment and to perform experiments to work out their idea.	- Advice to make notes of experiments - Examples of idea for assignment - Heuristics to support students in performing experiments - Advice to draw conclusion based on experiments
	Transform idea into assignment	
- Search for relations between input and output parameters to ask a question about - Find correct answer - Watch and use representations to be used in feedback	Students are asked to formulate a question based on the conclusions of their experiments. Students are asked to give the correct answer and some alternative answers. Students are asked to write feedback on all answers.	- Example of a question - Question starters - Tips for finding alternatives - Tips for writing feedback
	Evaluate assignment	
- Fill in assignment in authoring environment - Run assignment in learner environment	The student is asked to evaluate their assignment and to formulate what they learned by designing this assignment.	- Explanation about how to author and run the assignment. - Questions to support the evaluation.

Figure 2 Overview of the three phases in the design process. On the left, it is shown how the student can use the simulation in each phase. On the right, it is shown how the student is supported in the design process.

For our students, authoring assignments implied filling in a predefined building block for the assignment (see Chapter 1). On the Design Sheet, students received instructions for this authoring process. Upon completing this task, students could run their assignment as part of the software. In this way, they could 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 and contained the following information. First, main concepts and formulae of the domain were presented in this text, as 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). Second, we explained the representations in the simulation, as it is important that students understand what is represented in the simulation and how the several representations are related (Ainsworth, Bibby, & Wood, 1997; van der Meij & de Jong, 2006).

3.2.3 Design

This study employed 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 (operationalised 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.

3.2.4 Instruments

Analysis of the assignments

Learning processes in terms of the design activity were assessed by analysing the assignments 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 categorising 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, for example, doing a calculation with a formula, reading a graph. The categories discerned are displayed in Table 1. In this classification, we made a distinction between ‘reading a number from a graph’ and ‘reading the phase difference from a graph’ since 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 ten percent of the assignments were judged independently by two raters. An inter-rate agreement of 0.91 (Cohen's Kappa) was reached.

Knowledge type	Type of assignment	Description	Example
Conceptual	Definition	Ask for a definition.	What does resonance mean?
	Formula	Ask for a formula.	What's the formula for I(t)?
	Relation	Ask for a relation between two variables.	If you double R, what happens to I?
Procedural	Calculation	Ask to do a calculation.	Calculate Imax in this circuit.
	Graph (number)	Ask to read a value from the graph.	What's the current at T=0.5 s?
Conceptual-procedural	Graph (phase difference)	Ask to read the phase difference from a graph.	What's the phase difference in this circuit?
Miscellaneous	None of the other categories	Nonsense; Or only possible to answer if one can try the answer alternatives.	Change all variables until Z=1 and I=10A. What's the phase difference?

Table 1 Classification scheme for analysing the type of assignment.

Relations between variables describe 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 inter-rater agreement reached 0.87 (Cohen's Kappa).

Knowledge tests

Knowledge of relations was measured by a causal relation test and a WHAT-IF test. The first test was paper and pencil and comprised 9 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 5 multiple choice 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. In Appendix A, we present an example item for each of the knowledge tests.

3.2.5 Procedure

The two experimental sessions lasted two hours each. The first session, consisted of 1 hour instruction and 1 hour designing assignments. The second session consisted of 1 hour designing assignments and 1 hour 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 each 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.

3.3 Results

3.3.1 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 on type of assignment, we wanted to take into account both the difference in number of students per group and the difference in 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=3.32, p=0.001), and that the reverse was true for the assignments about definitions (Z=-2.15, p<.05), reading number from a graph (Z=-2.06, p<.05), reading the phase difference in the graph (Z=-2.62, p< 0.01), and the category miscellaneous (Z=-2.20, p<.05). (A positive Z means that the mean rank for the scaffolded condition was higher than for the control condition).

Type of assignment	**Condition**				**Mann Whitney test**
	Scaffolded 23 students M		Non-scaffolded 19 students M		Z
Definition	0.02	(*0.06*)	0.08	(*0.13*)	-2.15*
Formula	0.09	(*0.20*)	0.05	(*0.10*)	0.30
Relation	0.76	(*0.28*)	0.38	(*0.36*)	3.32***
Calculation	0.05	(*0.15*)	0.12	(*0.25*)	-1.43
Graph – number	0.04	(*0.11*)	0.14	(*0.22*)	-2.06*
Graph – phase	0.03	(*0.08*)	0.15	(*0.17*)	-2.62**
Miscellaneous	0.02	(*0.06*)	0.09	(*0.13*)	-2.20*

Table 2 Mean fractions per type of assignment for the two conditions. Standard deviations are given within parentheses. The last column shows the results of a Mann Whitney U test (<.05; **<.01; ***<.001).*

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 Figure 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’.

Example 1: Existence: there is a relation between… and …	
Question	What influence does the resistance have on the vectors?
Answer	Only the red vector changes in length.
Feedback	Correct. You can try this by diminishing the resistance in the simulation. You’ll see that the red vector (current) changes length.
Example 2: Qualitative: If… becomes larger than … becomes	**larger/smaller**
Question	What happens if the capacitor is changed to a larger value?
Answer	The current becomes larger
Feedback	Great
Example 3: Quantitative: If … becomes 2x larger than… becomes 2x	**larger/smaller**
Question	What happens if you make the resistance R two times smaller?
Answer	The current becomes two times as big.
Feedback	If the resistance R is halved, the current Imax becomes two times as big because Imax = U_{max}/R = 10/2 = 5A Imax = U_{max}/R = 10/1 = 10A

Figure 3 Three examples of correct assignments about relations are presented. These examples show that students described relations in different ways and used different types of information in the feedback of their assignments.

Three categories concerning the *description of the relation in the correct assignment were* identified, namely: ‘existence’, ‘qualitative’, and ‘quantitative’. The first example from Figure 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. This student, however, did not describe what this relation looked like, 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 (n1=23, n2=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, namely: '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, Figure 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. 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 more often wrote 'correct' in the feedback, compared to 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 to the non-scaffolded group. A Mann-Whitney U-test revealed no significant differences.

3.3.2 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.

3.4 Discussion

Scaffolding traditionally is 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, Clark, & Slotta, 2003; Quintana et al., 2004). In designing a scaffolding tool, one should start with an analysis of the learners' needs and of ways that the tool can help learners to overcome these challenges (Reiser, 2004; Soloway, Guzdial, & Hay, 1994). The study described in this chapter, presented a Design Sheet as scaffolding tool. This tool 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. The reason for the lower number of designed assignments most probably is that scaffolded students needed time for going through the Design Sheet, doing the systematic experiments, and for writing the more extended feedback.

The analysis of the different *types* of assignments that students designed revealed significant differences. Students in the scaffolded group designed, on average, relatively more assignments about relations in the domain. This group was scaffolded to write down the experiments performed, to draw 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 the investigated relations. 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 more often used prior knowledge. 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 (Löhner et al., 2003; Penner, 2001).

In the whole design task students were involved in ‘generating questions’, ‘finding answers’, and ‘giving explanations’. Positive effects of generating questions (Chin et al., 2002; Davey & McBride, 1986), and explanations (Chi et al., 1994; Coleman et al., 1997; King, 1994; Reimann & Neubert, 2000; Webb & Palinscar, 1996) 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 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 (Schauble, Glaser, Duschl, Schulze, & John, 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 Sweeney & Sterman, 2000). A careful adaptation between learning process and assessment of learning result will be necessary, together with a longer treatment. An improvement could be that part of the scaffolding is performed by the teacher on aspects as integrating the doing (performing experiments) and the reflection (understanding of the circuit under study) (Hmelo et al., 2000), or by providing feedback on the design process (Liu, 2003).

4

LOOK EXPERIMENT DESIGN an approach for designing assignments

Abstract

This study compares learning by designing instruction in a computer simulation with learning from expository teaching. The LOOK EXPERIMENT DESIGN (LED) approach was developed to support students in designing assignments for a computer simulation. LED aims to support students in orienting themselves in the simulation (Look), in performing Experiments to gain more insight in the simulated domain and in Designing assignments about the simulated domain. The domain of instruction was the electricity domain of high pass and low pass filters. In the experimental condition (N=21) students followed the LOOK EXPERIMENT DESIGN approach to design assignments for a computer simulation. Students in the control condition (N=28) received instruction in the traditional way. After a series of 3 x 2 hour lessons, all students were administered a test measuring insight in the domain and knowledge of calculation procedures. Results of this study showed that students in one class who learned by designing assignments performed significantly better on test items measuring insight in the domain than students who learned from traditional instruction. In a second class no differences on this test were found. No differences were found on the calculation test.

4.1 Introduction

The study in this chapter compares learning by designing assignments for a computer simulation with learning from expository teaching. ‘Learning by designing assignments’ as a learning activity is a relatively new learning approach. In the previous chapters, we described two studies in which we explored this learning activity and tried to find ways in which we could support students. In our first study (see Chapter 2; Vreman-de Olde & de Jong, 2003; Vreman-de Olde & de Jong, 2004) students were prompted to design assignments for a computer simulation on electrical circuits. About two-third of the assignments designed were about calculations and definitions. Those assignments resembled the students’ regular textbook assignments, since in textbooks students are often asked to perform calculations and to give definitions. One-third of the designed assignments were about the discoveries students made with the simulation. In fact, students were engaged in inquiry learning and in working out their findings in the assignments designed. Their assignments, however, were still rather superficial and mainly described simple effects. To prompt and support students in discovering the more complex relations and effects in the simulated domain, we developed a support tool in the form of a Design Sheet (Vreman-de Olde & de Jong, 2006). This Design Sheet was a paper-and-pencil tool developed to support students in both the inquiry process and the design process. In our second study we investigated the effect of this support tool on the assignments designed and on the knowledge gained. Students using the Design Sheet designed more assignments about relations in the simulated domain than students who designed assignments without a support tool. In addition, supported students described the relation more precisely and with more explanations in those assignments than the non-supported students who designed assignments without a Design Sheet. We found, however, no differences between the two groups of students on a knowledge test about relations. We concluded that the Design Sheet helped our students in the inquiry and design processes, but that the learning effect of designing assignments was still small. For the present study, we wanted to focus on an improvement of the learning effect of designing assignments. To this end, we analysed our experiences from the first two studies again, and used them to develop a new support.

4.2 Lessons learned from the studies

Our aim in the first two studies was to understand more about the process of designing assignments, and to understand how well the support, in the form of a Design Sheet, helped our students to learn by designing assignments. In this section, we discuss our lessons learned. First, we learned more about the specific support students needed during the design task. Second, we learned more about the software implementation of the design task, in particular that authoring assignments takes considerable time. Third, we discovered more about the students’ capabilities for working with the simulation, in particular that students’ ability to design assignments about a circuit is related to the number of independent variables in the domain. Fourth, we drew some conclusions about how to assess the resulting knowledge.

4.2.1 Lesson one: Need for more diverse support

In our second study, support focused on the design of assignments about relations and consisted of several prompts, heuristics, examples, and hints (see Chapter 3). We found that heuristics such as 'vary one variable a time' seemed to support students in describing relations on the Design Sheet and in designing assignments about these relations. This support could be reused for the current study. Observations from our previous studies taught us that when students designed assignments about knowledge types such as definitions and formulae, they were not able to use the simulation in explaining the concept. For example, in an assignment about the definition of 'resonance in an electrical circuit', students correctly explained this principle; however, they did not refer to the simulation. It seems that students experience difficulty in understanding how a simulation illustrates (all the aspects of) a concept. As we focus on an improvement of learning results for the present study, we want our students not only to learn more about relations, but also to gain more understanding of concepts, e.g., impedance. This implies that we have to adapt our support.

4.2.2 Lesson two: Authoring the assignment designed

In our second study, we introduced three phases in the design of assignments. In the first phase, students oriented themselves in the simulated domain, created ideas for assignments, and performed experiments to gather data for the design of their assignments. In the second phase, students transformed their ideas into an assignment, and thus thought of a question, one correct answer and three alternative answers, and about feedback for these answers. In the third phase, students authored the assignment in the simulation so they could actually run their assignment. From our observations, we learned that authoring the assignment took quite some time. In addition, this authoring part seems to be not easily carried out in practical school settings, as it requires technical knowledge about authoring. We decided, therefore, to skip this 'authoring' part in the current study; this meant that students had to write their assignment on paper. For the present study, the assignment to be designed consisted of a question, a correct answer, and the explanation of that answer. In this new format for assignments, students no longer had to think of alternative answers and feedback for those answers. The changes in the design phase gave students the opportunity to spend more time on orienting themselves in the simulation and for making discoveries in the simulated domain. In section 4.3, we present the new phases and the goals for each phase.

4.2.3 Lesson three: the simulation should be challenging, not demanding

In our first study, we used a simulation about series and parallel circuits. Students considered those circuits to be quite easy, and had problems creating good ideas for assignments. They stated that the environment was not challenging enough: ‘We already know it’. For our second study the subject of our simulation was, therefore, changed to a more difficult one, namely ‘alternating current’. In this simulation, five circuits were simulated; three of them contained one element (resistor, coil, or capacitor), while two circuits simulated the resonance effect and contained three elements. Students were able to generate and design assignments about the first three circuits. It seemed that those circuits were challenging enough. However, in designing assignments about the other two circuits, students experienced difficulties. Despite the support, students were not able to deal with the (relatively) large number of independent variables and they were not able to design assignments about the resonance effect. We concluded that the number of independent variables should not be so low that the environment does not challenge the students to perform investigations, and not so high so that it prevents any discovery attempt. For the present study, we searched for a simulation about a relevant topic in electricity containing one or two elements and decided to use the topic of ‘high pass and low pass filters’. Filters are electrical circuits that contain two elements; for these circuits it is important to understand the relation between input and output, and how its elements contribute to the working of the filter. The simulation we developed about this topic is described in the Method section (section 4.5.2).

4.2.4 Lesson four: measuring knowledge gained

The scores on the knowledge tests in the second study were moderate, though not high. We attributed this to a number of reasons. First, the knowledge tests, especially the one measuring knowledge of relations (WHAT-IF test), turned out to be too abstract for students from a secondary vocational school. Second, the duration of the treatment was rather short, whereas thinking about the dynamics of relations in electrical (alternating) circuits is a difficult process and it takes time to develop (intuitive) knowledge of those relations (Booth Sweeney & Sterman, 2000). Third, in the design process, students focused on the task, the design of assignments, rather than on the inquiry learning (Schauble et al., 1995).

Based on this lesson, we made some decisions. First, we changed the knowledge test so that the abstract tests were replaced by test-items that are more familiar to students from secondary vocational school (see section 4.5.3). Second, we made the treatment longer, so that students received more time for their design task. Third, we paid more attention to the inquiry process before designing the product. In our revised approach for designing assignments, students can spend relatively more time on investigating the simulated domain by *Looking* around in the simulation and performing *Experiments*. Then the student will be asked to *Design* an assignment about the knowledge just gained.

4.3 Towards improved support for designing assignments

Based on the lessons learned, we decided to give students relatively more time for the inquiry process before designing the assignment. To structure the overall design task, the task is divided in three phases. In the first two phases, students will be supported in making a broad exploration of the domain, and in performing experiments. In the third phase, students will be supported in designing an assignment for the simulation. We named this revised design approach LOOK EXPERIMENT DESIGN (abbreviated as LED). We now describe what we expect our students to do in each phase, discuss the problems students might encounter in performing those activities, and we discuss options for supporting students in overcoming those obstacles.

4.3.1 First phase: LOOK

When students first encounter a scientific discovery learning environment, they can orient themselves in the domain by running some experiments to explore variables and relations, and studying the representations in the simulation. In this way they make a broad analysis of the simulated domain. Characteristic problems in this phase are that students don't know which variables to change, or what to look at in the representations (de Jong, 2006b). In conventional class situations, the teacher solves this problem by directing students' attention so that they know what to look at and how to interpret the observations. In a computer-based learning environment, printed instructions or instructions presented in a text window next to the simulation interface could be used to direct students' attention. For making exploratory observations, instructions might ask, for example,: 'When the velocity of the car is increased, the total distance covered will……?' Such an instruction tells the student what to do, namely to increase the velocity of the car, and what to look at, namely the total distance covered. In our study, we have called these sentences '*observation starters'* (Slotta, 2004).

In this Look phase, students are supposed to perform *simple experiments* for exploring the domain. Providing students with heuristics while they have to perform experiments can improve their learning (Veermans, van Joolingen, & de Jong, 2006). In addition, in our second study (Chapter 3), heuristics such as 'use equal increments between experiments', and 'change one variable at a time' seemed to support students in *performing and describing experiments* as their notes on the work sheets about the experiments performed were often correct.

After making a broad exploration of the simulated domain, students are invited to analyse the domain in a more systematic way. In other words, they continue with the Experiment phase.

4.3.2 Second phase: EXPERIMENT

The second phase is the Experiment phase. The goal of this phase is to gather more knowledge and to gain a more integrated understanding of the domain under study. Compared with the previous phase, students are now invited to perform more complex experiments.

In *performing a series of systematic (and complex) experiment*s, a student has to decide which variable to manipulate and which output variables to inspect.

Problems with systematic design of experiments and with keeping an overview of this whole process are to be expected (Klahr, Fay, & Dunbar, 1993). During regular lessons, our students do use tables for keeping an overview of calculations and measurements. In these tables, students write values of the independent variable and the (measured values of the) dependent variables in one row for each experiment. We decided to use this table-format to support students in performing and in keeping an overview of the experiments.

In *drawing a conclusion*, students make a statement about the results of the experiments performed. Although students often experience difficulty drawing correct conclusions (Klahr & Dunbar, 1988), results of our second study showed that about 80% of students' conclusions about the experiments were correct (Chapter 3). In that study, students were guided in performing systematic experiments and were shown examples of correct conclusions. For the present study, we transformed the examples of correct conclusions into '*conclusion starters*' to support students in drawing conclusions after a series of experiments. These semi-structured sentences start with the variable that was changed (focus on the independent variable), followed by the amount of change (make changes quantitative), and end with the output variable that is to be observed. An example of a conclusion starter could be 'When the force on an object is doubled, the acceleration will…..'. Conclusion starters resemble the sentences we use to guide students in making observations and predictions.

In this phase we also want our students to *gain more insight into the concepts of the domain*. In a simulation, different types of (dynamic) representations exist. Each representation can show specific aspects of the domain to be learned (Ainsworth & Labeke, 2004). For example, diagrams are well suited for presenting qualitative information, whereas formulae and numerical representations can be used to show quantitative information. Using different representations in a simulation can support learners in building abstractions that may lead to a deeper understanding of the domain (Ainsworth & Labeke, 2004). In the Look-phase, students made (qualitative) observations of relations between variables. In the present phase, students *perform calculations* about the same relation as a means to gain a more quantitative understanding of the relation. During regular lessons, teachers *draw diagrams* to explain certain phenomena. In the present study, we ask students to *draw (simulation) diagrams* as a means to gain more insight into the concept represented in that particular diagram.

Finally, in *making a prediction*, students make a statement about an expected outcome of an experiment. Students can be supported in stating predictions by providing them with semi-structured sentences in which they can fill in slots. This is done, for example, in WISE (Slotta, 2004) where students receive sentences concerning predictions. Students have only to fill in the dots in these sentences to generate a verifiable prediction. An example of such a *prediction starter* could be: ‘When the velocity increases, the total covered distance will …..’.

When students have gone through this Experiment phase, they are challenged to design an assignment about their observations and investigations in the Design phase.

4.3.3 Third phase: DESIGN

The third phase in designing assignments is the Design phase. In this phase, students are challenged to design an assignment for the simulation, based on the notes and observations they have made. In this way, newly acquired (tacit) knowledge is verbalized and made explicit. Designing assignments gives students a concrete target to aim at in an otherwise rather open inquiry environment. Other targets could also play this focal role, for example, the design of a concept map (Gijlers, 2005) or a runnable model of the simulated domain (Löhner et al., 2003; Penner, 2001). To support students in making their knowledge explicit, we asked our students in the second study to frame a question based on the conclusion of the experiments performed. For generating an explanation, we advised them to make use of data obtained, prior knowledge, and of the representations in the simulation. As students seemed to profit from those guidelines, we decided to reuse them for our present study.

4.4 Research questions

In the present study, we compared the learning effects of two kinds of instruction. In the *experimental condition*, students followed the LOOK EXPERIMENT DESIGN - approach to design assignments for a simulation. A *control condition* was composed of a group of students who received conventional instruction. In this condition, students received instruction in the traditional way: the teacher used the blackboard for explaining the domain and students were invited to complete calculation exercises in their textbook. During these lessons, students did not use a computer simulation.

Our research question focused on learning differences between the two conditions. After students completed a series of lessons in their condition, they were administered a knowledge test with different types of test items. We assumed that, compared with the control group, the experimental group would perform better on test items measuring insight into the cause-effect relations of the examined domain. The rationale behind this assumption was that, in designing assignments, students in the experimental condition would gain insight into those relations. Second, we assumed that, compared with the experimental group, students in the control condition would perform better on a knowledge test with calculation items. The underlying reason for this assumption was that students in the control condition would have had more practice in performing calculations.

4.5 Method

4.5.1 Participants

Participants were 50 students from the technical training programme at a middle vocational school. Their average age was about 17 years. Students were from two intact classes. These two classes came from two different educational tracks within technical vocational training, namely Electronic Engineering (Class 1) and Automotive Engineering (Class 2). For their regular 'practical lessons' the teachers had already split up each of the classes into two groups. One group from each class participated in the experimental condition, the other group in the control condition. This resulted in the following four groups. From Class 1, 25 students participated in the experiment, 12 students in the experimental and 13 in the control condition. From Class 2, 25 students participated, 10 students in the experimental condition, 15 in the control condition. Students from both classes who were in the same condition did not have the lessons together, but in their own class with their own teacher. This means that both the experimental lessons and the control lessons were run twice. One student in the experimental condition of Class 1 was absent during the test, resulting in 11 students for the experimental condition in Class 1. As a result, the total experimental group consisted of 21 students; the total control group consisted of 28 students.

4.5.2 Material

The computer simulation learning environment

In this study, a SIMQUEST application was used (for a description of SIMQUEST see de Jong et al., 1999; van Joolingen & de Jong, 2003). In the SIMQUEST application, one electrical high-pass filter and two low-pass filters were simulated. A low-pass filter is a circuit offering easy passage to low-frequency signals and difficult passage to high frequency signals, whereas a high-pass filter's task is just the opposite. Filters are built with two elements: a resistor (R) and a coil (L), or a resistor and a capacitor (C). In general, the theme of filters and the passage of signals is a difficult subject, as changes in the frequency affect the working of the capacitor and the coil, which in turn affects the output signal. In designing the application, therefore, we decided to increase the complexity of the interface gradually. We used a series of four interfaces for each filter. Each series started with a simple interface, presenting only the elements of the filter, so that students could learn how the individual elements react to frequency changes.

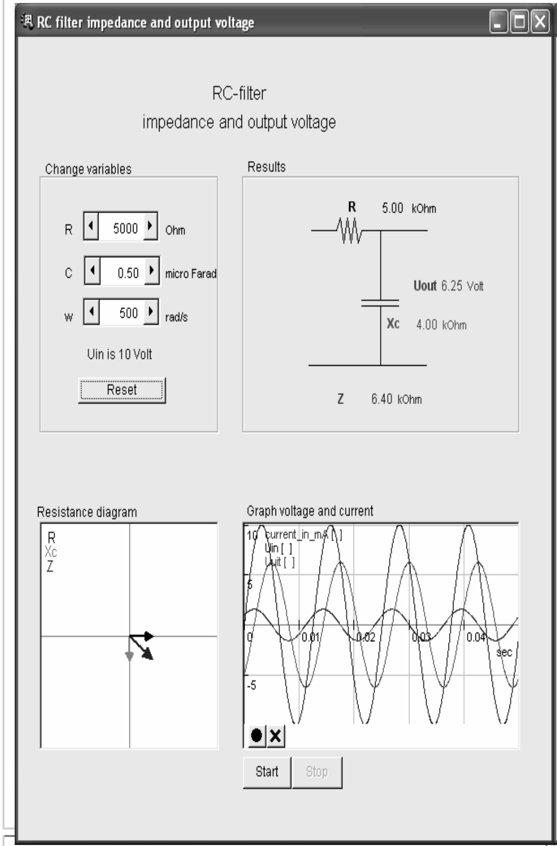
The second interface, which gives the additional option of measuring the current I and the voltage U_{out}, is shown in Figure 1a. In the 'change variables' box one or more variables can be changed. The Results box shows the output variables integrated in the diagram of the filter. In addition, output variables are visible in the 'resistance diagram' and in the graph. The third interface gives students the opportunity to investigate U_{out} for the whole frequency range. The fourth interface shows a graphic representation of the transfer function (the transfer function plots

U_{out}/U_{in} as a function of the frequency). The order in the series of interfaces is the same for each filter.

The support

The support that we developed was distributed over the simulation environment and a paper-and-pencil worksheet, which we called the LED-sheet. The support in the simulation consisted of assignments, tips, and overviews. This support was available in a window next to the simulation interface, as shown in Figure 1b. Support in the simulation environment was complemented on the LED-sheet. For example, if students were asked to investigate a certain relation, instructions on the LED-sheet supported students in making notes about the investigations. Figure 1c presents part of an LED-sheet.

In section 4.3, we explained what we expect students to do in the successive phases of the design task. We also dealt with some problems students might encounter and we discussed some solutions for those problems. In this section, we explain how we supported our students in designing assignments – the information presented in Table 1 functions as a guide during our explanations. Table 1 gives an overview of the support in each phase of the design process. In the first column, the (support) goals for each phase are summarized. The second and third column present the support integrated in the simulation environment and the support implemented in the LED-sheet, respectively. Going through each phase, we now explain the developed support in more detail,



R 5000 Ohm

C 0.50 micro Farad

w 500 rad/s

Uin is 10 Volt

1a. Screen shot of simulation interface.

Look

In this simulation you can see what happens to the impedance if you change the frequency. You can also observe what happens to U_{out} and the current.

Choose a value for R and C.
Look at what happens to Uout and the current upon enlarging the frequency w.
Look at what happens to the (ratio) Xc and R.

Advice: what happens to the current is visible in the graph.
Click the Start button to draw a graph.
You can save the graph by pushing the button with dot in the graph.
You can erase the graph by pushing the button with the cross.

Write down on the Design Sheet what happens.

1b. Integrated support in the simulation environment.

Simulation – Impedance and Uout
Look

In this simulation you can see what happens to the impedance upon changing the frequency ω. You can also see what happens to U_{out} and the current.

When the frequency is increased, U_{out} will…..

To investigate what happens to the current I, you can use the graph. When the frequency ω is increased, the current I will….

Empty space for making notes:…

1c. Integrated support on the LED-sheet (paper and pencil tool).

Figure 1 Screen shot of simulation interface and the integrated support.

Goals for each phase in LED	**Support integrated in the simulation environment**	**Support implemented in the LED sheet**
LOOK		
Students are supported in looking at what happens when changes are made in the simulation.	- An overview of the interface is presented, in which the general goal for the interface is described. - An investigation task e.g., what happens to X_C, R and Z when changes are made in ω. - Heuristics for performing experiments - Ideas for further investigation, combined with advice to make notes.	- Complete the *observation-starters*. - Empty space for making notes and drawing diagrams about the suggested ideas.
EXPERIMENT		
Students are guided in performing complex experiments, making careful observations of changes in numbers and representations. In this way students gain more insight into concepts, causal relations, and formulae. They gather information that can be used for designing assignments.	- Goal for the filter under study. - Perform complex measurements to gain more insight into a set of causal relations. e.g., measure U_{out}, I, X_c, Z for increasing values of ω. - *Careful observation of representations* to gain more insight into concepts. 1. *formulae* - use formulae to perform calculations to gain more insight in formula and relation. e.g., calculate X_c for two values of ω.	- Complete the *partly-filled in table* and complete *conclusion starters*. - Support for taking notes: 1. Formulae are given, students perform calculations and complete conclusion starters.

	2. *diagram* - e.g., draw resistance diagram for two different values of ω. - Assignment to make predictions.	2. Space reserved for making drawings and completing conclusion starters. - Complete *prediction-starters.*
DESIGN		
Students are asked to design an assignment (question, answers, and explanation of answer) for a peer student about the data gathered.	- Summary of what was visible in the simulation. - Task of designing an assignment about it.	- Tips for ideas for an assignment, checking the answer, explaining the answer. - Empty space for question, answer, feedback.

Table 1 Overview of the support in each phase of the design process. The first column lists the support goals for each phase; the second column presents the support implemented in the simulation learning environment and the third column gives the support implemented in the LED-sheet. Italicized words are explained in detail in the text.

First phase: LOOK

In the Look-phase, the main goal in supporting our students is to guide them in exploring the domain. This implies that students receive support in looking at what happens when changes are made in the simulation. In the simulation environment, the support starts with an overview of the specific learning goals for the interface. To support students in reaching those learning goals, investigation tasks give concrete target goals so that students can perform specific inquiries, whereas heuristics support the students in performing the experiments correctly.

On the LED-sheet, observation starters support the student in making notes of their observations. An observation starter, resembling the conclusion starter introduced before, is a semi-structured sentence, starting with a given focus of observation and ending with some dots to be filled in. An example is: “If R increases, then…….”. By giving students this starter, observations are structured (change only R), focused (it is important to change R), and note taking is ensured (they have to be completed).

Second phase: EXPERIMENT

In the first phase, students have made qualitative observations of relations. In the present phase, students are invited to transform these notes into more exact descriptions of the relations. Students will also be guided in discovering complex causalities in the domain, and in gaining more understanding of important concepts. Support of students in these activities was realized in several ways.

First, for understanding the working of a filter, students have to gain insight into the complex causal link between the frequency ω and the output voltage U_{out}. To this end, students need to perform a series of systematic experiments and keep an overview of those measurements. To support students in this process, we included a *partly-filled-in-table* on the LED-sheet. In this table, the (increasing) values of the independent variable and a number of dependent variables are already given. It is the students' task to complete the table. To support students in drawing conclusions concerning the relations investigated, students are asked to complete conclusion starters. Sometimes we linked two conclusion starters so that the role of the filter would get more attention; for example, if the frequency is increased, the total impedance in the filter will increase/decrease*, and therefore the total current becomes smaller/larger*. (* Means: cross off the wrong alternative).

Second, to support students in making an exact formulation of a relation and gaining more insight into important concepts, students are prompted to take *a careful look at representations* such as formulae and diagrams. In the first phase, students made qualitative observations, for example, of the relation between the frequency ω and the impedance X_C (The resistance of a capacitor is dependent on the frequency of the alternating current and is called impedance). In the present phase, this qualitative observation will be transformed into a more quantitative formulation. First, students are asked to calculate the impedance for two (doubling) values of the frequency ω. Then a conclusion starter concerning this relation supports the students in formulating the exact relation between ω and X_C.

To support students in gaining more insight into the simulated concepts, we focused their attention on the diagrams used in our simulation. In our simulation, the concept 'impedance' is represented in a resistance-diagram (see Figure 1a). This diagram shows that the total impedance Z of the RC-filter (the diagonal arrow) depends on R and X_C. Careful observation of this diagram for different values of the frequency might support students in gaining more insight into the total impedance Z. Namely, in drawing the diagram for two extreme values of the frequency, students can focus on similarities and differences between the two diagrams. In addition, they might discover that Z is not a simple, linear addition of R and X_C. Again, conclusion-starters are used to support students in drawing conclusions.

Third, to support students in thinking about the consequences of a change, for example thinking about the effect on the current of increasing the frequency, we gave them *prediction-starters*. Although a prediction starter looks like a conclusion starter, they differ in the possibility of checking the correctness of the statement. When the student is asked to make a prediction in our support tool, he cannot use the simulation to find the correct answer, as the answer cannot be obtained from the current interface. The only way to complete the statement is to think about it deliberately and fill in the predictions.

Third phase: DESIGN

For the students, the goal in this phase is to design an assignment about the observations made and the knowledge acquired during previous phases. The support in this phase concentrated on helping students use that knowledge and make it explicit. In generating a question, we instructed them to pose a question about the observations made. In writing the answer, we advised them to check the correctness of the answer with the help of the simulation. And in generating the explanation for their assignment, we advised them to explain the answer in detail, and to make use of calculations, representations, and observations.

Each time students design an assignment about an interface, they go through these three phases. The support developed to guide students through the Look and Experiment phase is adapted to each interface. This means that for one interface, students might be asked to draw representations, whereas for another interface they might be asked to complete the partly filled-in table. The support for the design phase, however, is the same for each interface. In Appendix B we present three simulation interfaces together with the integrated support. In Appendix C we present examples of the instructional supports developed for the LED-sheet.

4.5.3 Knowledge test

The knowledge test was a paper-and-pencil test. The results of this test also counted for the students' examination. The test-items measured different types of knowledge.

Knowledge of *calculation procedures* was measured by test-items in which students were asked to perform calculations. Students received points for the calculation procedure and the correct answer. There were 6 calculation items in total. The maximum score on this test was 15 points. Reliability analysis of this test resulted in a reliability of 0.64 (Cronbach's alpha). Inter-rater agreement between two judges for judging the answers on ten percent of the data reached 0.76 (Cohen's Kappa). An example of an item is presented in Figure 2.

Knowledge of *insight into the cause-effect relations* in the domain was measured by items in which students were asked to predict or explain the effect of a change. In the example shown in Figure 3 the student not only has to choose an outcome, but also has to give a reason for the choice. Students received points for correct answers and for their reasoning. There were 28 'insight in relation'-items (abbreviated as relation-items) in total. The maximum score on this test was 50 points. Reliability analysis of this tests resulted in a reliability of 0.80 (Cronbach's alpha). Inter-rater agreement between two judges for judging the answers on the reason test on ten percent of the data reached 0.70 (Cohen’s Kappa).

The adjoining diagram shows an LR-filter.
Calculate the output voltage U_o at ω= 300 rad/s and at ω= 3000 rad/s

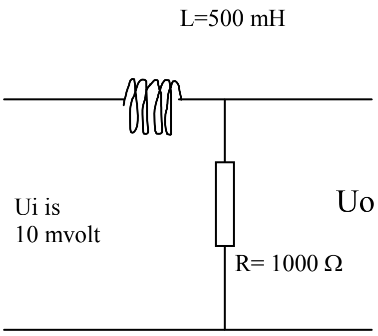
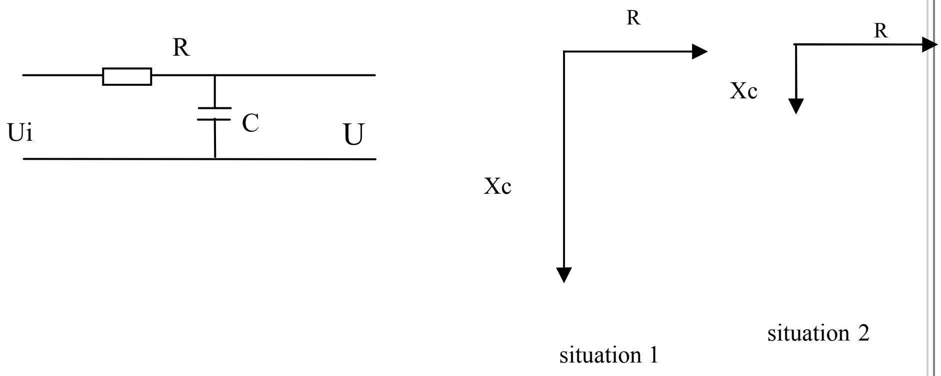


Figure 2 Example of knowledge item measuring knowledge of calculation procedures.



The adjoining diagram shows the scheme of an RC-filter.
The impedance diagram is drawn for two different frequencies.

In which of the two situations is the current larger?
Why?
In the RC-filter the output voltage is measured across C.
In which of the two situations will this voltage be larger?
Why?

Figure 3 Example of knowledge item measuring insight into causal relations.

On an exam, test-items addressing general domain knowledge are sometimes used as an introduction to other test-items. This general domain knowledge is presented in both instructional conditions equally well. Our knowledge test contained nine of these *introductory-test items*. Students received points for their explanations and for the correct answer. The maximum score on this test was 15 points. Reliability analysis of this test resulted in a reliability of 0.43 (Cronbach's alpha), which is too low. Therefore, results of this test are not taken into account.

4.5.4 Procedure

The whole experiment lasted for four lessons of two hours each. Both conditions had three weekly two-hour lessons on the subject of low pass and high pass filters. The fourth lesson was used to administer the knowledge test. Class 1 (both experimental and control group) was the first class that participated in the study, and a few months later Class 2 (again both an experimental and a control group) participated. The same procedure was followed for both classes.

In three weekly two-hour sessions, students in the *experimental condition* went through the simulations of the three filters. At the beginning of the first lesson, the experimenter introduced the students to the SIMQUEST learning environment. With regard to the design task, she explained the three phases in the design approach and told the students how to use the LED-Sheet. During the first lesson, students worked with the simulation of the first filter. At the end of each lesson, all LED-sheets were collected. At the beginning of the second and the third lesson, the LED-sheets were returned to the students and students continued where they had stopped the lesson before. Near the end of third lesson, students were asked to have a look at the transfer functions of each filter (they were not supposed to design an assignment about this filter). At the end of the third lesson, LED-sheets were collected. The teacher was available during all experimental lessons, for answering students' questions.

In three weekly two-hour sessions, students in the *control condition* received the regular lessons from their own teacher. The teacher taught his students in a traditional way, that is, the teacher used the blackboard for making notes, often asked questions of the students, and gave them time for completing the calculation assignments in the book. While students completed these assignments, the teacher walked through the class, so that students could ask for clarification about the taught material or the assignments. Informal observations of activities in the class were made during all lessons.

4.6 Results

In the results section, we first present the exam marks for both conditions in each class. Next, we present the results of the knowledge tests. Finally, we present a qualitative analysis of the effect of the support developed for the experimental condition.

4.6.1 Exam marks

Table 2 gives an overview of the means of the exam marks in the subject electricity for both conditions and each class. Exam marks for these lessons were composed of the marks on a number of regular tests. The way the exam scores were determined in both classes was not similar, which makes it difficult to compare exam scores between classes.

Exam mark and number of students	Condition						t-test	
	Experimental		Control		Total		t	p
	M	N	M	N	M	N		
Class 1	5.9*(1.2)*	11	5.4*(1.9)*	13	5.6*(1.6)*	24	-.789	(.438)
Class 2	6.4*(1.6)*	10	6.8*(1.5)*	15	6.6*(1.5)*	25	.663	(.514)

Table 2 M represents the mean of the exam marks for each condition and class. Standard deviations are given within parentheses. N represents the number of students for each condition and class. The last column shows results of a t-test (p values are given within parentheses).

4.6.2 The knowledge tests

Table 3 shows the mean scores on the relation items and the calculation items. A one-way ANOVA showed no significant results between conditions. No significant interaction was found between condition and knowledge tests. We found a significant correlation between the exam marks and the total score on relation and calculation items (Class 1: r=0.443, p=0.030; Class 2: r=0.404, p=0.045).

All students	Condition				t-test	
Knowledge items	Experimental 21 students M		Control 28 students M		t	p
Relation items	29.7	(8.5)	26.7	(8.0)	-1.270	.210
Calculation items	7.2	(4.1)	8.4	(4.4)	.972	.336

Table 3 Mean scores on the knowledge tests for the two conditions across both classes. Standard deviations are given within parentheses. The maximum scores on the relation and calculation tests were 50 and 15, respectively. The last column shows results of a t-test.

Because students came from two different classes with different backgrounds, we performed an analysis of the results on the knowledge tests for the two classes separately.

Class 1

Statistical tests for detection of outliers showed that one student in the experimental condition appeared to be an outlier for the relation-items (his score was more than 2sd below the mean score). The score of this student on the relation test was deleted from our data set. Table 4 shows the results of the knowledge tests for the two conditions in Class 1. The t-test showed a significant difference between the two conditions on relation items.

Class 1	Condition				t-test	
Knowledge items	Experimental 11 students M		Control 13 students M		t	p
Relation items	33.9	(7.8)	25.2	(6.5)	-2.9**	.008
Calculation items	8.1	(4.6)	8.0	(4.9)	-.047	.963

*Table 4 Mean scores on the knowledge tests for the two conditions within Class 1. Standard deviations are given within parentheses. The maximum scores on the relation and calculation tests were 50 and 15, respectively. The last column shows results of a t-test (**<.01).*

In this class there was no significant difference in exam marks between the two conditions. Nevertheless, because of the difference of almost half a grade point, we performed an ANCOVA. The ANCOVA with the exam mark as covariate also revealed a significant difference between the two conditions for the relation items (F (1,23) = 7.57, p=0.012).

Class 2

Statistical tests for detection of outliers showed that one student in the experimental condition appeared to be an outlier for the relation items (his score was more than 2sd above the mean score). The score of this student on the relation test was deleted from our data set. Table 5 shows the results of the knowledge tests for the two conditions in Class 2.

Class 2	Condition				t-test	
Knowledge items	Experimental 10 students M		Control 15 students M		t	p
Relation items	26.1	(4.3)	28.0	(9.1)	.580	.568
Calculation items	6.3	(3.4)	8.8	(4.0)	1.620	.119

Table 5 Mean scores on the knowledge tests for the two conditions within Class 2. Standard deviations are given within parentheses. The maximum scores on the relation and calculation tests were 50 and 15, respectively. The last column shows the results of a t–test.

There was no significant difference in exam marks between the two conditions in this class. Nevertheless, because of the difference of almost half a grade point, we performed an ANCOVA. The ANCOVA with the exam mark as covariate also showed no significant differences between the two conditions on the knowledge tests. This implies that the significant difference found in Class 1 for relation items is not duplicated in Class 2.

4.6.3 Qualitative analysis of the instructional supports

In the Method section, a number of instructional supports were described. These supports were developed to assist students in designing assignments. We expected that they would support students in making observations, performing complex experiments, drawing conclusions, studying the representations in more detail, and in stating predictions. In an attempt to gain insight into the effect of those supports, we made a qualitative and informal analysis of the notes students made on the LED-sheet. For each instructional support, we analysed whether the notes were correct or not. In this section, we present the results of this exploratory analysis.

Observation starters

We hypothesized that observation starters would support students in making careful observations in the simulation and in taking notes about their observations.

The answers to the observations starters were mostly correct, implying that students changed the correct independent variable and made observations of the dependent variables we wanted them to study.

In addition, we saw that on (intentionally left) empty spaces, some students went beyond the focus of the observation starters and described their own observations. For example, they expressed their surprise about the effect of the frequency on the impedance diagram or about the increasing number of sine pulses for increasing frequencies.

Partly-filled-in-table and conclusion starter

We hypothesized that the partly-filled-in-table would support students in performing systematic experiments, keeping an overview of their measurements and in drawing conclusions about the examined relations.

We analysed the tables and found that students often filled in correct measurements of the dependent variables. In addition, the completed conclusion starters concerning the examined relations were mostly correct. During the lessons, students asked the teacher for clarification about the connected conclusion starters used to focus students' attention on the role of the filter. Students did not know how to complete those connected conclusion starters. If the student asked for clarification, the teacher explained the causal relations. About 80 percent of the filled in connected conclusion starters were correct.

Representations (1): Calculations and conclusion starter

We hypothesized that the combination of calculations and conclusion starters would help students formulate a more quantitative relation. For each filter, the most important linear relation is the relation between X_C and ω (or X_L and ω). Students were asked to calculate X_C (X_L) for two (doubling) values of the frequency ω, and to fill in the conclusion starter concerning this relation: "If the frequency doubles, X_C will….."

We found that students' answers to the calculations were mostly correct. Almost all students formulated a correct quantitative relation between the variables.

Representations (2): Diagrams and conclusion starter

We hypothesized that drawing diagrams would support students in gaining a deeper understanding of the represented concepts. When students studied the resistance diagram we asked them to draw the diagram for two values of the frequency ω, so that they would discover the dependence of Z on the frequency ω (Figure 1a shows the diagram students were asked to draw).

In the two drawings of the resistance diagram, almost all students used equal lengths for the resistance. For increasing frequencies, all students drew a shorter arrow for X_C and Z (both are correct). Some students added notes about the Pythagorean formula - this formula can be used to calculate Z from X_C and R.

In addition, we saw that students started to draw representations on the LED-sheets when they made their own observations. Next to that, students used representations in explaining their assignment answer.

Prediction starters

Lastly, we hypothesized that prediction starters would support students in thinking about effects of the frequency on the output voltage and the current. We also expected that, in a following phase of the design process, students would reflect on the correctness of their predictions.

In analysing the notes made on the LED-sheet, we found that students' predictions were often not correct. Next to that, we found no reflections about the correctness of the predictions.

4.7 Discussion

In this study, we compared the learning effect of two kinds of learning environments. In one learning environment, which formed the *experimental condition*, students designed assignments for peer students in a scientific discovery computer simulation. In their design task, students went through the three design phases of LOOK EXPERIMENT DESIGN, as described in this chapter. Along the way, students were supported so that they would gain more insight into the simulated domain. In the other learning environment, which formed the *control condition*, students had conventional instruction. These students received instruction in the traditional way: the teacher used the blackboard for explaining the domain and students were invited to complete calculation exercises in their textbook. Students did not use a computer simulation during these lessons. We used a knowledge test to measure learning differences between the two conditions. This test contained calculation items, measuring knowledge of calculation procedures, and relation items, measuring insight into causal relations. The two classes that participated in our study were divided in two groups; one group from each class participated in the experimental condition and the other group in the control condition.

Overall, we found no differences on the calculation and relation items between the two conditions. Looking at the two classes separately, we found that students in the experimental condition of Class 1 performed significantly better on the relation-items than students in the control condition. This result, however, was not repeated for Class 2. This might have been caused by the difference in computer simulation experience between the two classes. During their regular lessons, students in Class 1 had used the program Multisim. Multisim is a program in which students build and simulate circuits themselves. Although SIMQUEST-simulations are fairly easy to use, experience in using other types of simulations might have helped the students from Class 1 in learning from a simulation.

Concerning the calculation-test, we expected the control condition to perform better on the calculation test. We found, however, that students in both conditions of Class 1 performed equally well on the calculation items. It seems that students in the experimental condition of Class 1 could be engaged in learning by designing assignments for some lessons and, compared with the control group, still perform equally well on the calculation test. For Class 2, students in the control condition had a higher score on the calculation items compared with the students in the experimental condition. This difference, however, was not significant.

The learning environment for the experimental condition of our study was a rather open scientific discovery learning environment. In this environment, students had to induce the characteristics of the domain from experiences or experiments. Data obtained in this inquiry process was to be used for the design of assignments. As both the inquiry process and the actual design process are complicated processes, we developed support for our students. Several instructional supports were developed and integrated in the learning environment (see Appendix C for some examples of these supports). The goal of these supports was to assist students so that they would be able to explore a domain, perform experiments, gather data for the design of their assignments and formulate the newly acquired knowledge in assignments. Students made notes on their LED-sheets during the whole process,. Analysis of those notes and the observations we made during the lessons revealed that the effects of these instructional supports look promising.

First, the instructional supports of 'observation starter' and 'drawing representations' seemed to give students ideas about how to start an investigation and what to look at in an interface. Both the notes on the LED-sheet and the observations during the lessons showed us that students started to perform their own investigations. In addition, students used the representations to formulate the explanations in their assignment. Drawing representations of the total impedance in the circuit also made students remember the Pythagorean formula used to calculate the total impedance. Second, the 'partly filled-in table' (developed to support students in planning and monitoring a series of experiments) helped students perform a series of measurements and draw conclusions about those measurements. It seems that this relatively straightforward table helped our students keep an overview of their measurements and enabled them to focus on the investigated relations. Third, in following the supporting instruction to 'perform calculations', students performed two calculations with a formula and used the outcomes of their calculations for describing a relation between the variables. With hindsight, we could have exploited this instructional support by linking the calculations and the resulting quantitative relation more explicitly with the (qualitative) observations of the same relation in the Look phase. In this way, students might have realized that careful observations in a simulation can be used to check one's understanding of a formula.

A point of concern, however, is that many predictions as formulated in the 'prediction starters' were not correct. Neither were students inclined to reflect on the correctness of their predictions - a process which might have given rise to interesting learning moments. It seems that students need extra support in reflecting on their work.

In general, it can be concluded that designing assignments for a simulation with the LOOK EXPERIMENT DESIGN approach opens opportunities for students to gain insight into the simulated domain. Prior experience in working with simulations might well be an essential condition in this learning process. With respect to the instructional supports, we found that these supports were relatively easy to use and seemed to assist our students in learning from the simulation and formulating the knowledge acquired in their assignments.

Conclusions and Discussion

5

5.1 Introduction

At the start of this thesis, we introduced the idea of 'learning by designing'. For example, adults can learn how to make a jar of clay and, while playing and building, children learn how to construct a LEGO house. In this way, one not only learns *how* to design something, but one might also learn more about the material one is working with or about the product that has been designed. For example, the child playing with LEGOs might discover that a building block has holes on one side and pegs on the other. And a person working with clay might learn more about the way clay hardens.

In the first chapter of this thesis, we described the application of 'learning by designing' in schools. Students can learn by designing artefacts such as artificial lungs (Hmelo et al., 2000) or by designing a model describing the relations in a domain (Löhner, 2005; Manlove et al., 2006; Novak, 1990; Novak, 1998; de Vries, 2004). In our research, we focused on another type of design, namely the design of instruction. Students in our studies designed instruction for their peers in a scientific discovery learning environment. The participants in the studies were students from a secondary technical vocational school. The students were asked to design assignments for computer simulations about electrical circuits.

We expected that 'designing assignments' could be an instructive task for students. After all, the assignments consisted of a question, a correct answer and some alternative answers, and feedback on those answers. Designing assignments, therefore, is a task that engages students in processes such as 'generating a question', 'finding answers', and 'giving explanations'. Several studies have shown that these processes are instructive. In the process of generating a question, students can learn to focus on domain content and to concentrate on main ideas, while checking if the content is understood (Palincsar & Brown, 1984; Rosenshine et al., 1996). In finding answers, students have to come up with the correct answer and find alternative answers. In thinking about alternative answers, which are answers that resemble the correct answer but in fact are false, students might think about mistakes that could be made. This can help them avoid making these mistakes again. In the process of giving explanations, students can learn to integrate old and new knowledge (Chi et al., 1994), which might lead to performance gains (Bielaczyc et al., 1995).

However, research has shown that designing instruction for a computer simulation is a complicated task. Limbach (2001) found that adult designers need support in the process of designing instruction. Therefore, we expected that students would need support in designing assignments for a computer simulation.

The main goal of our research was to investigate how we could support students in *learning by designing assignments* for a computer simulation. This problem concerns both the design process and learning effects, as expressed in the following research question:

> *How can we support students in learning by designing assignments so that they a) are able to design assignments for peer students, and b) learn about the domain simulated in the learning environment?*

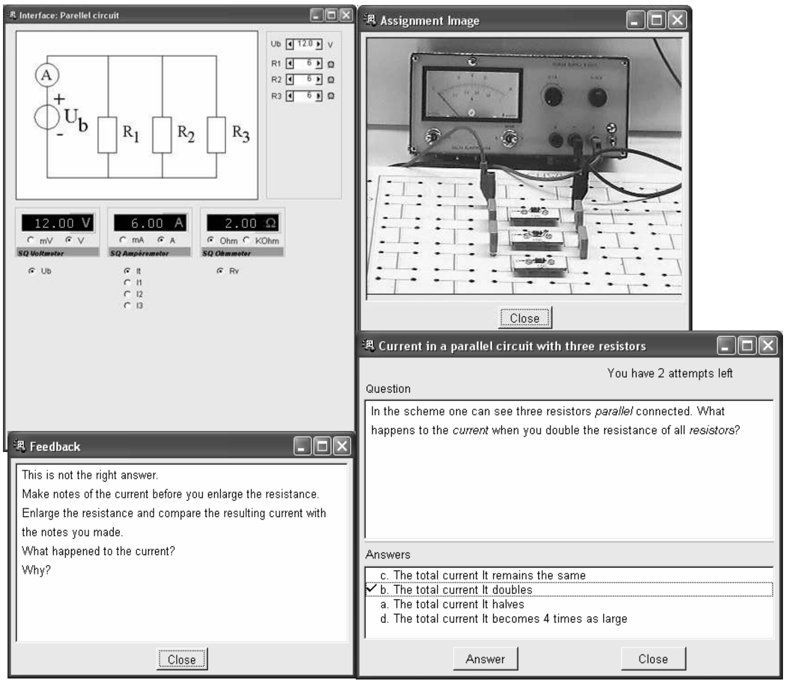
In the last chapter of this thesis, we look back at the three studies that were performed to answer the research question. In the following section, we present a summary of the main results of the studies. In section 5.3, an answer to the research question is presented. In sections 5.4, 5.5 and 5.6, we situate our research in the themes dealt with in the first chapter of the thesis, namely 'learning by designing', 'inquiry learning' and 'the educational setting' respectively.

5.2 Summary

5.2.1 The learning environment

The scientific discovery computer simulations used in our studies were created with SIMQUEST (de Jong et al., 1998; van Joolingen & de Jong, 2003). SIMQUEST is an environment for *building* and *running* simulations. In Figure 1, a SIMQUEST simulation of an electrical parallel circuit is shown. In the simulation interface, one can manipulate input variables (e.g., the resistor R_1, the voltage U) and observe the effect on the output variables (e.g., the current I, or the total resistance R_t). To support learners in their discovery process, assignments are added to the simulation. These assignments give the learner a short-term goal like finding the relation between two variables. In Figure 1, the assignment asks the learner to observe the effect of doubling the resistance of all resistors. The learner is expected to explore the simulation and select the correct alternative from the list of predefined alternatives. The learner receives feedback on the alternative chosen. Overall, providing students with assignments together with a simulation has a positive influence on learning outcome (de Jong & van Joolingen, 1998).

These assignments are normally designed by instructional designers. In our studies, students were placed in the role of instructional designers and were asked to design assignments for their peers. The rationale behind this idea is that in designing instruction (here the assignments), students must think about what they and others should learn, and about how this knowledge should be organized to be comprehensible and interesting (Harel, 1991; Jonassen & Carr, 2000).



Ub 12.0 V
R1 6 Ω
R2 6 Ω
R3 6 Ω

12.00 V ○ mV ● V
6.00 A ○ mA ● A
2.00 Ω ● Ohm ○ KOhm

● Ub
● It
○ I1
○ I2
○ I3
● Rv

You have 2 attempts left

Question

In the scheme one can see three resistors *parallel* connected. What happens to the *current* when you double the resistance of all *resistors*?

Answers

c. The total current It remains the same
✓ b. The total current It doubles
a. The total current It halves
d. The total current It becomes 4 times as large

This is not the right answer.
Make notes of the current before you enlarge the resistance.
Enlarge the resistance and compare the resulting current with the notes you made.
What happened to the current?
Why?

Figure 1 A screenshot of a SIMQUEST simulation interface and an assignment.

The participants in our studies were students from a secondary, technical vocational school. Students of secondary vocational schools are from very diverse backgrounds (Dutch Department of Education, 2005; Slaats et al., 1999), generally sharing the characteristic of being 'do-ers' and having a visual orientation. They are students who learn by experience and have problems with abstract theoretical models and methods. For these students, the domain of electricity is an important though abstract domain. Concepts such as current and voltage are difficult to understand, but can be visualized and manipulated within simulations. The domain of the simulations in our studies has been the physics domain of electricity.

To find an answer to our research question, we wanted to gain insight into how students tackled the task of designing assignments for a simulation. We decided to first perform an exploratory study in which we observed students while they were designing assignments. In this way, we expected to learn more about students' decisions and considerations in designing assignments. We also expected to learn more about the instructional benefit of designing assignments and about how we could support students in learning by designing assignments. This study was described in Chapter 2. Results of this study yielded promising results concerning the learning process of designing assignments. The findings from this study were used to develop a tool for supporting students in the design of assignments and in learning from this design task. In Chapter 3, we described the study performed to evaluate the effect of this tool. Results of that study showed that the tool supported students in designing assignments. The use of this tool, however, did not have a measurable effect on learning. Findings from the first two studies were used to develop an improved approach for learning by designing assignments, called LOOK EXPERIMENT DESIGN. In our final study, we compared the learning effect of ‘learning by designing assignments’ with learning in the traditional way. Results of this study showed that, students in one class who learned by designing assignments performed significantly better on test items measuring insight in the domain than students who learned from traditional instruction; in a second class no difference was found. Both the design approach and the final study were presented in Chapter 4. In the following sections, a more detailed summary of the studies is presented.

5.2.2 Study 1: Exploring ‘learning by designing assignments’

To investigate how students tackle the design task, we first performed an exploratory study (see Chapter 2). In this study, students (N=19) worked with a SIMQUEST simulation on the domain of moments and received instruction about how to author assignments in the SIMQUEST authoring environment. After this whole class introduction, students participated in a one-on-one session in which each student was asked to think aloud while designing assignments for a simulation about series and parallel circuits. This simulation was available for the students to work with.

Concerning the assignments designed, it was found that most of the assignments were about calculations. In their assignments, for example, students posed such questions as calculating the total resistance of a circuit with three resistors. In explaining the answer to such questions, students often presented the procedure for performing this calculation. This suggests that designing assignments about calculations can help students in retrieving and explaining problem solving steps, while strengthening their procedural knowledge. In creating assignments, students also often referred to the simulation. Students asked, for example, about the effect of toggling a switch to shortcut a bulb in the simulation. In their assignments, students asked about the effects they discovered in the simulation and referred to what they had seen. When students designed these types of assignments, they used the simulation and often made discoveries themselves. The assignments, however, were often rather superficial and inquired about simple effects in the simulation. We, therefore, decided to support students in the design of assignments that involved more complex relations and effects in the simulated domain.

5.2.3 Study 2: Supporting ‘Learning by designing assignments’

In study 2, we developed a Design Sheet, a paper and pencil tool meant to support students in their inquiry and design process (see Chapter 3). With this tool, students were guided in performing experiments and drawing conclusions. In this way, students gathered data for the design of their assignment and were thus provided with a resource on which they could base their assignment (White & Gunstone, 1992). To support students in the actual design of their assignment (that is, the question, answers and feedback), they were recommended to find a relation between input and output variables, or to start their questions with 'What happens if…', as such questions are more likely to be based on deeper thinking than simple recall (King, 1994; Webb & Palinscar, 1996). In evaluating their assignment, students could run their assignment as part of the software and check whether the assignment behaved the way they intended.

To investigate the supportive effect of the Design Sheet on the design of assignments, we performed a comparison study (see Chapter 3). This study also represented our first attempt to measure learning effects of designing assignments. The experimental condition (N= 23) was made up of a group of students who used the Design Sheet while designing assignments. Students in the control condition (N=19) designed assignments without the support tool.

We found significant differences concerning the assignments designed. Students using the Design Sheet designed, on average, relatively more assignments about relations in the domain. Students in the control condition designed, on average, relatively more assignments in which they asked for reading a number from the graph, determining the phase difference in the circuit, or for a definition. We discovered that the Design Sheet supported our students in making notes about the experiments they performed, in drawing conclusions, and in designing assignments about those conclusions. We concluded that the Design Sheet can function as a powerful tool in guiding the inquiry process and in focusing students' attention on specific knowledge aspects (e.g., relations) in the design of assignments.

To measure the learning effect of designing assignments we developed a knowledge test for measuring intuitive knowledge about relations, a definitional knowledge test, and a test for measuring knowledge of representations (see appendix A for some sample items). These types of tests had been used in other studies for measuring learning gains with simulations (van der Meij & de Jong, 2006; Gijlers, 2005; Swaak & de Jong, 1996; Swaak & de Jong, 2001). Using our tests, we found no differences between the two conditions. The reason for this might have been that the knowledge test was too abstract for the students from secondary vocational schools. Another reason might have been that thinking about the dynamics of relations in electrical circuits is a difficult process and that it took more time for our students to develop knowledge about those relations (Booth Sweeney & Sterman, 2000).

5.2.4 Study 3: Improve and test the design approach LOOK EXPERIMENT DESIGN

In study 3, we decided to extend the inquiry process, so that students would not only study relations in the simulated domain, but would also gain a deeper understanding of the concepts represented in the simulation. In this revised approach, students were supported in Looking around in the simulation, in performing Experiments and in Designing assignments about the data obtained. Several instructional supports were developed to guide students in these inquiry processes (see Appendix C for some examples). We called this design approach LOOK EXPERIMENT DESIGN (see Chapter 4).

In a comparative study we compared the learning approach 'learning by designing assignments' with the traditional way of learning. Students in the experimental condition (N= 21) used the LOOK EXPERIMENT DESIGN approach to design assignments for a computer simulation. Students in the control condition (N=28) received instruction in the traditional, expository way. Both conditions had three weekly lessons of two hours on the same subject in the domain of electricity. In this study we focused on learning differences between these two ways of learning. A knowledge test was administered after the series of three lessons to measure knowledge of calculation procedures and insight into the domain. This test resembled the more regular tests used at secondary vocational schools.

Two intact classes participated in this study. These classes came from different educational tracks within technical vocational training and differed in experience with computer simulations about electrical circuits: Class 1 had more experience in working with simulations than Class 2. For their regular 'practical lessons' the teacher had already split up each of the classes in two groups. The experiment was run twice, such that one group from each class participated in the experimental condition and one group in the control condition.

Overall, we found no differences in learning effects between the two conditions. However, when we looked at the classes separately, we found a significant difference. In Class 1, we found that students in the experimental condition performed significantly better on the knowledge items measuring insight in the simulated domain. This difference was not replicated in Class 2, which might have been caused by the fact that Class 2 had less experience in working with simulations about electrical circuits. For items measuring knowledge of calculation procedures, we found no differences between the conditions.

5.3 Conclusions

The first part of our research question was concerned with the *support* needed to design assignments for computer simulations. Our first study showed that in designing assignments without any form of support, students mainly asked for performance of a calculation or description of simple simulation effects. We found that a support tool such as a Design Sheet (second study) supported students in investigating more complex relations in a domain and in designing assignments about the investigated relations. Our third study showed that the more progressive LED-sheet supported students in making a broader analysis of the domain. Several instructional measures guided their investigations of relations, concepts and formulae, and supported the students in designing assignments about their findings. In conclusion, in the course of these studies we have been able to develop a tool that supports students in investigating the simulated domain and in designing several types of assignments about those investigations.

The second part of the research question was concerned with the *learning effect* of designing assignments. In our first study, we had already discovered that designing assignments could stimulate retrieval of prior knowledge: in designing assignments about calculations, students mentioned retrieval of knowledge about calculation procedures. Designing assignments about (simple) experiments in the simulation also seemed promising. Students, for example, realised the dynamic character of the relation U=I*R (diminishing R causes I to rise) or of an electronic device (a rising voltage causes the diode to conduct current). Our second study was a first attempt to measure learning by designing assignments. We developed a knowledge test for measuring intuitive knowledge of relations, definitional knowledge and knowledge of representations. Using this test, we found no difference for learning by designing assignments between the two conditions. The total score on the test was rather moderate, which might have been caused by the abstract items. For our third study, we developed a knowledge test containing items that resembled the regular and less abstract exam items. This test contained items measuring insight in the simulated domain and knowledge of calculation procedures (see Chapter 4 for some sample items). We found that, in one specific class, students who learned by designing assignments performed significantly better on test items measuring insight in the domain than students who learned from traditional instruction; in a second class no difference was found. We found no differences between the conditions in both classes on a test measuring knowledge of calculation procedures.

5.4 Learning by designing

In the first chapter of this thesis, we presented several types of learning by designing. We described how students can learn by designing artefacts, by building models, or by designing instruction. In the following subsection we deal with the question: When students are engaged in designing assignments what kind of knowledge do they need to fulfil this task? With the implementation of learning by design in mind, the second subsection presents suggestions for the supportive role of the teacher in the design cycle LOOK EXPERIMENT DESIGN.

5.4.1 Designing instruction by students

In designing instruction, a designer might employ three types of knowledge: Knowledge about the content to be taught, knowledge about teaching, and knowledge about the design task itself (Greeno, Korpi, Jackson III, & Michalchik, 1990).

With respect to *the knowledge about the content to be taught*, in our first study we observed that students used their prior domain knowledge to a large extent in designing the assignment. Student designers, however, do not have an extended knowledge base about the content to be taught – after all, they are still learning about the domain. In the first study, some students said they could not design more instruction: they felt a lack of content knowledge. Therefore, for students to become designers of assignments, it is important to extend their content knowledge prior to or along the way of designing assignments. In our studies, students were supported in finding relations in the domain (second study) and in gaining a deeper understanding of the simulated concepts (third study). In this way, students extended their knowledge base and were provided with a resource on which they could base their assignments.

Knowledge about teaching concerns among other things knowledge about the users of the instruction and knowledge about the type of questions one should ask in the assignments. Knowledge about the (fictive) users of the instruction guided the students in the design of their assignments. In their instruction, the student designers tried to explain subjects that were commonly considered to be difficult topics. This 'inside' knowledge about common mistakes means that students, in designing instruction, can pinpoint the topics that need more attention.

It is important for designers of assignments in a discovery learning environment to be aware of the '*discovery aspect'* the instruction should have (Limbach, 2001). In inquiry learning the learner is expected to be more active than in a traditional learning environment and the instruction should guide the learner in this process. This awareness of the discovery aspect was realized in several ways in our studies. First, in the introductory phase of each experiment, the students were told to design instruction about 'the effect of changing a variable in the learning environment'. This was clarified with an example. Second, during the design process, students received hints for formulating their questions by means of examples and question starters. Third, students in the third study were engaged in discovery learning themselves more than in the previous studies. In this way they could experience themselves the difference from traditional instruction. In the course of the studies, we saw that students became more able to design instruction for an inquiry learning environment. In conclusion, an awareness of the type of instruction appropriate for the learning environment is important for designing instruction.

Knowledge about the design task includes knowledge about what should be designed and knowing how the design task should be performed. In discussing this type of knowledge, we restrict ourselves to the technical knowledge needed for the authoring process. To support students in the authoring process, they received instruction so that they were able to fill in the assignments in the SIMQUEST authoring environment (Carver, Lehrer, Connell, & Erickson, 1994; Zahn, Schwan, & Barquero, 2002). The advantage of authoring assignments was that students could actually run their assignment in the learning environment, which was meant to inspire them. For the implementation of designing assignments in an educational setting, however, the authoring process also has some clear disadvantages. First, someone must explain the authoring process to students. Although the teachers were very willing to cooperate in the studies, it might be too time consuming for them to become experienced enough to give the authoring instructions themselves. Second, in our studies, students first wrote their ideas and the actual assignment on their work sheet. Authoring assignments, therefore, was merely reduced to ‘filling in the assignment in the authoring environment’. We therefore wondered whether ‘authoring assignments’ would be a necessary component of designing assignments. The alternative was to have students design their assignments on paper. This option seemed to have the additional advantage that students could use all kinds of representations in their assignments (assignments authored in the computer were confined to text). In the third study, the option to have students write their assignments on paper was explored. Students received a work sheet that guided them in both the inquiry process and the actual design of the assignment. We observed that students made notes on their inquiry process, drew different types of representations and used the notes for the design of their assignments. In addition, as was expected, students used different types of representations (text, formula, diagrams) in the feedback for their assignments. The conclusion is that, for designing assignments in educational settings, writing the assignments on paper is a suitable implementation.

A point of concern, however, might be the evaluation of the assignment designed. Does it make a difference whether the student evaluates the assignments on paper or in the simulation? In general, in designing instruction the core feature is finding issues that need to be addressed and coming up with plans for addressing them (Harel, 1991). Such a view of design differs from the engineering approach where one designs and produces artefacts or working models (Kolodner et al., 2003; Penner, Lehrer, & Schauble, 1998). In both approaches, students are engaged in learning. The difference, however, is in the feedback provided by the product. Products designed under the ‘engineering approach’ give the student immediate feedback about the appropriateness of the product. For example, in designing an elbow, the student can test the functioning of the elbow using the design artefact (Penner et al., 1998). The design of an assignment or another form of instruction, does not provide that feedback. For example, one can run the assignment in the simulation, despite the errors in the instructional text. The evaluation of the product, therefore, should be performed by peer students (Kafai & Ching, 2001), clients (Liu, 2003) or the students themselves (this thesis). In our first and second study, students could actually run their own assignment and in this way judge whether the assignment answered their intentions. In the last study, students could evaluate their assignment by rereading the written assignment. In conclusion, in receiving feedback on the correctness of the assignments designed, there is no difference between ‘writing the assignment on paper’ or ‘authoring the assignment in the simulation’: in both situations the students themselves have to check the assignment for correctness.

5.4.2 Teacher support in Look Experiment Design

In general, it is considered that designing is an ‘ill-structured’ problem and that it is important to structure the design process (Goel & Pirolli, 1992). In the process of designing instruction, the designer selects information and incorporates it in the design, evaluates the design, and makes changes in the design (Greeno et al., 1990). From the beginning of our research, we searched for ways to structure the design process, finally leading to the design structure expressed in the LOOK EXPERIMENT DESIGN approach (see Chapter 4).

In the previous subsection, we mentioned that after students designed their assignment, they evaluated their own assignments. An alternative for this self-evaluation of assignments is the evaluation of assignments by peer students. Recent research on the effects of peer assessment show positive effects on learning (Bos, Terlouw, & Pilot, 2006) for students from secondary schools. It might, therefore, be interesting to implement this peer assessment in the evaluation of the designed instruction. However, in our third study, we observed that our students had problems reflecting about the correctness of conclusions, predictions etc. It is likely that students would have problems evaluating the correctness of the assignments designed by their peers. Therefore, we consider another alternative for evaluating the assignments and suggest giving the teacher a role in this evaluation process. For example, after the students finish their designs, the teacher might lead the class into a discussion about the assignments designed. In this discussion, students can share their assignments. This sharing of assignments allows the teacher to become aware of common misconceptions and common difficulties. In addition, this sharing of assignments might display the students' creativity and give them an awareness of the different (types of) questions that can be asked about a subject.

In the LOOK EXPERIMENT DESIGN approach, the teacher might be involved in the evaluation of the assignment, but also become involved in supporting students in their inquiry and design processes. Puntambekar and Kolodner (2005) stress the importance of distributed scaffolding, which implies that support not only comes from a support tool in the learning environment or a work sheet but can also be provided by the teacher. In the inquiry phases Look and Experiment, the teacher might support the student in e.g., making observations, interpreting the representations, or looking at the important relations in the domain. The teacher might also challenge students to perform more and deeper investigations, e.g., search for similarities and differences between the filters simulated. In our third study, students had difficulty making predictions and reflecting on them. The teacher can support them in this process, for example, by talking about his own reasoning processes. In the design phase Design, the teacher can challenge students to formulate different types of questions and he can give additional explanations when needed. Several studies, however, show that it takes time for a teacher to gain expertise in managing the inquiry and design processes in the classroom (Hendrikse, van der Meij, & de Jong, 2006; Holbrook & Kolodner, 2000; Puntambekar & Kolodner, 2005). For actual implementation of learning by designing assignments in school settings, it is therefore necessary to investigate how the teacher can be supported in managing the inquiry and design processes in a class.

5.5 Inquiry learning

In asking the student to become a designer of assignments for peer students in a scientific inquiry learning environment, the two learning approaches of ‘inquiry learning’ and ‘learning by designing’ were combined. Up until now, we have viewed the whole research theme as a design problem – after all, we started the first chapter of this thesis with an introduction about learning by design and applied this approach in a scientific discovery computer simulation. However, is it possible to change this point of view and approach the research theme as a problem in the field of inquiry learning and investigate whether the design of assignments can play a role in this environment?

Important learning processes in inquiry learning include orientation, hypothesis generation, experimentation, drawing a conclusion, and making an evaluation (de Jong, 2006a). Students often experience problems with inquiry learning (de Jong, 2006b; de Jong & van Joolingen, 1998) and need to be supported in these processes (Mayer, 2004). With the development of the work sheets and the instructional supports, we wanted to guide our students in these inquiry processes. Students were supported in orienting themselves to the simulated domain and in performing experiments. In drawing conclusions, students looked back at an experiment and received support in drawing a conclusion about it. In *making an evaluation* students even go further: students take a step back, look at the data gathered and try to reflect on the knowledge discovered (de Jong, 2006b). In the actual development of their assignment, we asked students to look back at the investigations they had performed in the simulation and use the data for the design of their assignments. Results of our studies showed that students indeed used data from a single experiment or a series of experiments in their assignments. Designing assignments for a simulation, therefore, can support students in making an evaluation of the knowledge acquired and become a means for verbalizing this newly acquired knowledge. In this way, designing assignments can provide students with a more concrete target to aim at in an otherwise rather open inquiry environment. Other type of targets could also play this focal role, for example, the design of a concept map (Gijlers, 2005) or a runnable model of the simulated domain (Löhner et al., 2003; Penner, 2001).

5.6 The educational setting

In the first chapter of this thesis, we indicated the need for attractive learning material for secondary vocational schools. In the following subsections, we discuss possible usage of discovery simulations in these schools and present suggestions for the development of new discovery simulations.

5.6.1 Simulations in secondary education

In looking back at the third study in particular, it was obvious that the students were very enthusiastic about working with the simulation. The teachers were also very enthusiastic in cooperating in the studies and in working with the simulation. Currently, the learning environment continues to be used in the regular curriculum of the school. It seems, therefore, that simulations can play a role in making instruction more attractive. In our research, simulations were used as an environment in which students could design instruction for their peers. However, simulations might be used in several ways. First, simulations can be used during instruction. The teacher uses the simulation interfaces to show and explain a domain to the students. Second, simulations can be used as a kind of 'practical'. A teacher can add assignments to the simulation, and during a class lesson, the students are invited to do those assignments while using the simulation. Third, simulations can be used for the retrieval of prior knowledge. The student can use the simulation at home or in a school lab as a kind of 'homework': the student uses the simulation to freshen up knowledge about a certain subject.

5.6.2 Development of new simulations for secondary education

Generally, the students of our secondary vocational school share the characteristic of being 'do-ers' and are interested in the practical application of their knowledge. In regular lessons, teachers link the theoretical instruction with examples of practical applications of the theory. In a learning environment such as a computer simulation, the simulated domain and reality can be connected in several ways. Based on our experiences, we list some suggestions for this 'reality-link' in future inquiry learning environments.

First, we used situations from the daily school practice of students in the simulation. During their practicals, students often work with electrical circuits. They have to build them themselves and measure current and voltage. In our first study *digital photos* were added to the simulation (see figure 1 in Chapter 1). Both teacher and students expressed recognition for the equipment used during practicals. These digital photos not only made the learning environment more attractive, but also helped relate the simulation to experiences in practical lessons.

Second, we used '*realistic values for the variables*'. During their schooling, our students have to get a feeling for realistic values of variables such as resistance, capacity, inductance, and frequency. However, for our second study we considered the use of 'easy' values for the variables - values that are easy to use in calculation procedures. We found students to be confused about those non-realistic values, so that they started searching for 'the real values'. Therefore, in our third study, realistic values of variables were used. This implied, for example, that students could investigate the effect of a wide range of frequencies on the current (e.g., a range from 10 – 10000 rad/s). In general, students seemed more confident with the realistic values used in the third study, than with the 'easy to use values' used in the second study.

Third, we considered the '*reality of the simulation's subject'*. In our first and third study, realistic circuits were simulated. In the second study, the subject of the simulation was a circuit printed in the textbook; this circuit did not exist in reality. An important phenomenon in this simulation was the concept of 'phase difference' (see Chapter 3 for a description of the simulation). This same phenomenon could also be observed in the simulation used in the third study. It is our impression that, for this phenomenon and maybe also for other abstract phenomena, students grasped more of this phenomenon in the realistic simulation. It seemed that the phase difference remained a theoretical idea in the 'theoretical simulation', whereas in the 'realistic simulation' the students could observe phase differences between input and output signals.

The three studies described in this thesis investigated the design of instruction as a way of learning. More specifically, students' learning by designing assignments for peer students in a computer simulation has been investigated. In the course of three studies, the LOOK EXPERIMENT DESIGN approach was developed. In this approach, students were supported in both inquiry and design processes, so that they were able to perform investigations and gather data for the design of their assignments. Results of the third study showed that, in some cases, students can gain more insight in the simulated domain when using the LOOK EXPERIMENT DESIGN approach compared to traditional instruction. For the actual implementation of learning by designing assignments in classrooms, large scale experiments are necessary to confirm this learning effect and additional attention should be paid to the support teachers may give for learning by designing assignments in inquiry environments.

Nederlandse samenvatting

6

Inleiding

We hebben allemaal wel eens het plezier gevoeld toen we zelf iets gemaakt hadden. Wellicht was het een huis gemaakt van LEGO-blokken met een dak, wat ramen en een deur die echt open en dicht kon. Misschien was het een vogelhuis gemaakt van wat losse planken, of een beeld van klei gemaakt op school. Het gaf plezier omdat we er zelf in geslaagd waren iets te maken, een gevoel van trots omdat we erin geslaagd waren uitdrukking te geven aan gedachten en gevoelens en dat maakte dat het ‘ding’ ook echt van ons was. Als we nu terugkijken op het werkstuk, dan beseffen we dat we, tijdens het maken, ook iets geleerd hebben. Over de klei leerden we bijvoorbeeld dat er verschillende soorten en kleuren klei zijn. We zien nu ook dat het tijd kostte om iets zoals een LEGO-huis te maken; we moesten ontdekken hoe LEGO-blokken aan elkaar bevestigd kunnen worden en ook hoe een raam of een stevig dak gemaakt wordt. Het bouwen van een vogelhuis ging evenmin vanzelf: er moest een schets van het huisje gemaakt worden en een idee over hoe de verschillende onderdelen in elkaar gezet moesten worden. En we leerden de pijnlijke les de spijker te raken in plaats van de duim.

In het onderwijs wordt ‘Leren door zelf iets te ontwerpen’ op verschillende manieren gebruikt. In een studie uitgevoerd door Hmelo, Holton en Kolodner (2000) werd leerlingen gevraagd om kunstlongen te ontwerpen. Door het ontwerpen van deze *artefacten* leerden leerlingen over het menselijke ademhalingssysteem. De Vries (2004) voerde een onderzoek op school uit waarin leerlingen een *begrippenkaart* ontwierpen over een biologisch systeem (een bijenkolonie). Een begrippenkaart wordt vaak gebruikt om leerlingen de begrippen die ze kennen onderling te laten relateren. In het verlengde hiervan ligt het maken van een *model* van een fysisch fenomeen. In een onderzoek van Manlove en anderen (Manlove et al., 2006) werd leerlingen gevraagd om een model te ontwerpen van een vat dat leegstroomt. De leerlingen konden hun model invoeren en testen in een computersimulatie. Het ontwerpen van dit soort modellen kan leerlingen helpen om fysische fenomenen beter te begrijpen. Tot slot willen we nog het leren door ontwerpen van *instructie* noemen. Zo liet Kafai (1995) leerlingen computerspellen ontwerpen om medeleerlingen te leren over wiskundige breuken. De gedachte achter het leren door ontwerpen van instructie is dat leerlingen zo gaan nadenken over wat zij en anderen moeten leren, en hoe ze deze kennis het beste kunnen overbrengen zodat het begrijpelijk en interessant is (Harel, 1991).

Het onderzoek dat beschreven is in dit proefschrift gaat over *leren door het ontwerpen van instructie* voor medeleerlingen. Leerlingen werd gevraagd om, bij een simulatie over elektrische schakelingen, opdrachten te ontwerpen voor hun medeleerlingen. De leerlingen die deelnamen aan ons onderzoek waren leerlingen van het middelbaar beroepsonderwijs.

We verwachtten dat het ontwerpen van opdrachten voor een simulatie een instructieve ontwerptaak voor de leerlingen zou zijn. Een opdracht, zoals ze die moesten ontwerpen, bestond uit een vraag, een correct antwoord met een aantal alternatieve antwoorden, en een uitleg op de antwoorden. Als een leerling een opdracht moet ontwerpen, dan is hij/zij dus bezig met 'het stellen van vragen', 'het vinden van antwoorden' en 'het geven van uitleg'. Diverse onderzoeken hebben aangetoond dat dit leerzame activiteiten zijn. Door het stellen van vragen gaan leerlingen zich richten op de inhoud en nadenken over wat ze belangrijke onderwerpen vinden om vragen over te stellen (Palincsar & Brown, 1984). Door dit vervolgens uit te leggen, kunnen leerlingen leren om bestaande en nieuwe kennis te integreren (Chi et al., 1994) wat kan leiden tot betere leerprestaties (Ainsworth & Loizou, 2003; Bielaczyc et al., 1995; Wong, Lawson, & Keeves, 2002).

Het ontwerpen van opdrachten blijkt echter een complexe taak te zijn waarbij zelfs expertontwerpers ondersteuning nodig hebben (Limbach, 2001). We verwachtten daarom ook dat leerlingen ondersteuning nodig zouden hebben bij het ontwerpen van opdrachten voor een computersimulatie.

De onderzoeksvraag

In het onderzoek dat beschreven is in dit proefschrift hebben we onderzocht hoe we leerlingen kunnen ondersteunen in het ontwerpen van opdrachten voor simulaties. De centrale onderzoeksvraag kan als volgt geformuleerd worden:

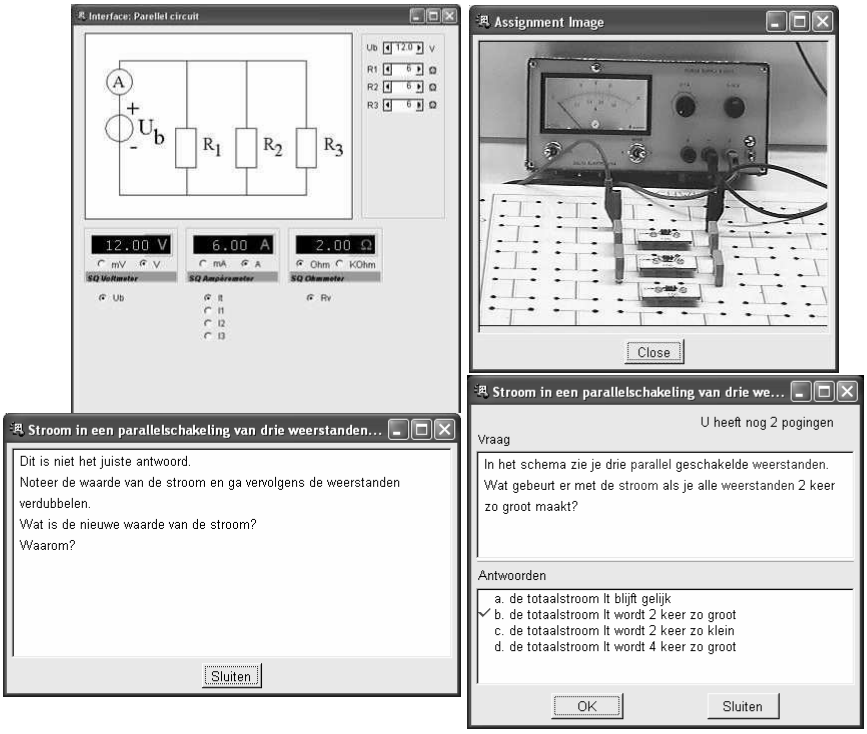
> *Hoe kunnen we leerlingen ondersteunen in het ontwerpen van opdrachten voor een simulatie zodat ze in staat zijn opdrachten te ontwerpen voor medeleerlingen en bovendien leren over het domein dat centraal staat in de computersimulaties?*

Om een antwoord te vinden op deze onderzoeksvraag, hebben we een drietal studies uitgevoerd. Voordat we deze studies bespreken, geven we een korte inleiding over de simulatieomgeving die gebruikt is en over de leerlingen die meegewerkt hebben aan ons onderzoek.

Simulatie

De simulaties die gebruikt werden in ons onderzoek zijn ontwikkeld met SIMQUEST. SIMQUEST is een computerprogramma voor het ontwikkelen *en* uitvoeren van simulaties. Figuur 1 toont een SIMQUEST simulatie van een elektrisch parallelcircuit. In de simulatie-interface kan de leerling invoervariabelen veranderen (in de figuur de spanning en de weerstanden) en het effect op de uitvoervariabelen observeren (in de figuur de stroom en de totale weerstand). Door op deze manier het gesimuleerde domein te bestuderen kan de leerling meer ontdekken over belangrijke relaties en begrippen in het domein. Om de leerling te ondersteunen in het ontdekkend leerproces kunnen opdrachten toegevoegd worden aan de simulaties. De opdrachten geven de leerling een kortetermijndoel, zoals het vinden van een relatie tussen twee variabelen. Zo wordt er in figuur 1 gevraagd om te onderzoeken wat er met de stroom gebeurt als de weerstanden verdubbeld worden. De leerling kan de simulatie gebruiken om een antwoord te vinden en vervolgens een antwoord selecteren uit de lijst van antwoordalternatieven. De leerling krijgt feedback op het antwoord dat gekozen is. Het blijkt dat het aanbieden van opdrachten bij een simulatie een positief effect heeft op het leereffect van werken met simulaties (Swaak & de Jong, 2001).

In het onderzoek beschreven in dit proefschrift hebben leerlingen opdrachten voor medeleerlingen ontworpen voor simulaties van: serie en parallelschakelingen (studie 1); schakelingen met weerstanden, condensatoren en spoelen op wisselspanning (studie 2); en hoog- en laagdoorlaatfilters (studie 3). De eerste en de derde simulatie zijn toegankelijk via de website www.simquest.nl.



Ub 12.0 V
R1 6 Ω
R2 6 Ω
R3 6 Ω

12.00 V ○ mV ● V
6.00 A ○ mA ● A
2.00 Ω ● Ohm ○ KOhm

● Ub
● It
○ I1
○ I2
○ I3
● Rv

Dit is niet het juiste antwoord.
Noteer de waarde van de stroom en ga vervolgens de weerstanden verdubbelen.
Wat is de nieuwe waarde van de stroom?
Waarom?

U heeft nog 2 pogingen

Vraag

In het schema zie je drie parallel geschakelde weerstanden. Wat gebeurt er met de stroom als je alle weerstanden 2 keer zo groot maakt?

Antwoorden

- a. de totaalstroom It blijft gelijk
- ✓ b. de totaalstroom It wordt 2 keer zo groot
- c. de totaalstroom It wordt 2 keer zo klein
- d. de totaalstroom It wordt 4 keer zo groot

Figuur 1. Een schermafbeelding van een simulatie ontwikkeld met SIMQUEST. Linksboven is de simulatie interface en, met de klok mee, een afbeelding van een circuit, de opdracht en de uitleg op een antwoord.

Deelnemers aan het onderzoek

Recente ontwikkelingen in de technologie maken het mogelijk dat leren steeds meer gerelateerd is aan virtuele omgevingen, simulaties, e.d. ‘Virtual reality’ maakt vaak al deel uit van het leven van studenten door bv. games en chat. De leerlingen die participeerden in ons onderzoek kwamen van het middelbaar technisch beroepsonderwijs. Leerlingen van dit type onderwijs delen de kenmerken dat ze visueel georiënteerd zijn en dat ze doeners zijn. Het zijn vaak leerlingen die leren door te doen en problemen hebben met abstracte, theoretische modellen en methoden. Een computersimulatie lijkt een omgeving te zijn die aansluit bij de recente technologische ontwikkelingen en bij de visuele oriëntatie van deze leerlingen. Het ontwerpen van opdrachten in een simulatie zou daarom een goede leeractiviteit kunnen zijn voor leerlingen die leren door te doen.

Overzicht van de drie studies

Alvorens in te gaan op de drie studies die beschreven zijn in dit proefschrift, geven we een kort overzicht van het onderzoek.

Om inzicht te krijgen in hoe de leerlingen de ontwerptaak aanpakken, hebben we eerst een exploratieve studie uitgevoerd. In deze studie observeerden we leerlingen terwijl ze opdrachten ontwierpen voor de simulatie. We verwachtten zo meer inzicht te krijgen in de beslissingen die studenten namen in het ontwerpproces. Ook verwachtten we meer zicht te krijgen op hoe we studenten zouden kunnen ondersteunen bij het ontwerpen van opdrachten. Die studie, beschreven in hoofdstuk 2 van dit proefschrift, leverde veelbelovende resultaten aangaande het leerproces van ontwerpen van opdrachten. De resultaten zijn gebruikt om een werkblad te ontwikkelen dat leerlingen begeleidde in het ontwerpen van opdrachten en in het leren van deze ontwerptaak.

In hoofdstuk 3 is de studie beschreven die is uitgevoerd om dit werkblad te evalueren. Resultaten van die studie lieten zien dat het werkblad de leerlingen hielp bij het ontwerpen van opdrachten, maar dat er nog geen meetbaar leereffect was. De gegevens van de eerste twee studies zijn gebruikt om het werkblad te verbeteren. Dit leidde tot de ontwikkeling van LOOK EXPERIMENT DESIGN (LED), een aanpak voor het leren door ontwerpen van opdrachten.

In de derde studie hebben we het ‘leren door ontwerpen van opdrachten met de LED-methode’ vergeleken met leren op de traditionele manier. Zowel de methode LOOK EXPERIMENT DESIGN en de laatste studie zijn beschreven in Hoofdstuk 4.

Studie 1

De eerste studie was een exploratieve studie met als doel meer inzicht te krijgen in de overwegingen en beslissingen van studenten tijdens het ontwerpen van opdrachten voor een simulatie. In deze studie, waaraan 19 leerlingen deelnamen, kregen de leerlingen eerst een uitleg over SIMQUEST en over hoe opdrachten ingevoerd moesten worden in de simulatie. Na deze klassikale instructie was er een 1-op-1-sessie, waarin de leerling opdrachten ontwierp voor een simulatie en daarbij geobserveerd werd door een experimentator. In deze sessie werd de leerling gevraagd om hardop te denken tijdens het ontwerpen van opdrachten voor de simulatie over serie- en parallelschakelingen.

In het merendeel van hun opdrachten vroegen de leerlingen om een berekening uit te voeren. Zo vroegen ze bijvoorbeeld om de totale weerstand in een circuit met drie weerstanden te berekenen. In de uitleg van hun antwoord schreven ze vaak de hele berekening uit. Dit laat zien dat het ontwerpen van opdrachten samen kan gaan met het ophalen van rekenprocedures. In veel andere opdrachten verwezen de leerlingen naar de simulatie. Ze vroegen bijvoorbeeld naar het effect van het omzetten van een knop zodat een lamp kortgesloten zou worden. In hun opdrachten schreven leerlingen over hun ontdekkingen. Met het ontwerpen van opdrachten over de simulatie zijn leerlingen in feite bezig met het doen van ontdekkingen in de simulatie (ontdekkend leren) en met het uitwerken van hun vondsten in de opdrachten. Omdat de beschreven relaties en effecten nog oppervlakkig waren, besloten we om voor het tweede onderzoek de leerlingen te ondersteunen in het ontdekken van complexere relaties en effecten. Hiertoe hebben we een speciaal werkblad ontwikkeld dat leerlingen begeleidde in het uitvoeren en beschrijven van experimenten in de simulatie. Daardoor konden leerlingen gegevens verzamelen om vervolgens over deze data een opdracht te ontwerpen.

Studie 2

De tweede studie was een vergelijkingstudie. Deze studie had als doel te onderzoeken of het werkblad leerlingen daadwerkelijk ondersteunde in het leren en ontwerpen van opdrachten over relaties in de simulatie. In deze studie hebben we de ontworpen opdrachten en de scores op een kennistoets van twee groepen leerlingen met elkaar vergeleken. De experimentele conditie (23 leerlingen) werd gevormd door een groep leerlingen die opdrachten ontwierp met behulp van het werkblad. De controle conditie (19 leerlingen) werd gevormd door een groep leerlingen die opdrachten ontwierp bij dezelfde simulatie maar zonder gebruik te maken van het werkblad.

De resultaten van dit onderzoek lieten zien dat de ontworpen opdrachten van de twee groepen van elkaar verschilden. Leerlingen uit de experimentele groep ontwierpen relatief meer opdrachten over relaties, terwijl de andere leerlingen relatief meer opdrachten ontwierpen over het aflezen van grafieken. Dit laat zien dat het werkblad kan helpen om leerlingen te laten nadenken over de relaties die ze ontdekt hebben door het uitvoeren van experimenten. Voor dit onderzoek hadden we een toets ontwikkeld voor het meten van intuïtieve kennis van relaties, definitionele kennis en kennis van representaties (zie Appendix A). De kennistoets die de leerlingen hadden gemaakt na afloop van het ontwerpen van opdrachten liet echter geen verschillen tussen de twee condities zien. Dit type toetsen is met succes gebruikt op VWO-scholen, maar bleek te abstract voor onze leerlingen (de gemiddelde score was 50% correct).

De resultaten van de eerste twee studies zijn gebruikt om een verbeterde ontwerpaanpak te ontwikkelen. In deze aanpak hebben we ons meer gericht op het ondersteunen van het onderzoeksproces, zodat leerlingen kennis kunnen opdoen en er vervolgens opdrachten over ontwerpen. Deze methode hebben we LOOK EXPERIMENT DESIGN genoemd, oftewel: Kijken, Experimenteren en Ontwerpen. In deze methode werden leerlingen ondersteund in het Kijken naar (observeren van) wat er gebeurt als je iets verandert, in het uitvoeren van Experimenten en in het Ontwerpen van opdrachten over de verkregen data.

Studie 3

De derde studie, beschreven in hoofdstuk 4, was een vergelijkingsstudie. In deze studie vergeleken we de aanpak 'leren door ontwerpen van opdrachten' met de traditionele manier van lesgeven. Leerlingen uit de experimentele conditie (21 leerlingen) gebruikten de methode LOOK EXPERIMENT DESIGN om opdrachten te maken voor een simulatie over hoog- en laagdoorlaatfilters (zie Appendix B voor een aantal schermafbeeldingen). Leerlingen uit de controle conditie (28 leerlingen) kregen op de gewone manier les: de docent gaf klassikale instructie en leerlingen maakten de sommen uit het boek. Na drie wekelijkse lessen van twee uur kregen leerlingen uit beide condities een toets om kennis van rekenprocedures en inzicht in de circuits te meten.

Aan deze studie hebben twee klassen meegedaan. Deze klassen kwamen van verschillende richtingen binnen het mbo. Klas 1 had meer ervaring in het werken met simulaties over elektrische circuits dan Klas 2. Ten behoeve van de practicumlessen had de docent de klas opgesplitst in twee groepen. Van elke klas was de ene groep onderdeel van de experimentele conditie en de andere groep onderdeel van de controle conditie.

Als we de resultaten van beide klassen samennemen, dan vinden we geen verschillen tussen beide condities op de toetsen. Als we beide klassen apart beschouwen, vinden in Klas 2 geen verschil tussen de beide condities op inzicht- en rekenvragen. In Klas 1 vonden we dat de experimentele conditie significant beter scoorde op de inzicht vragen dan de controle conditie. In deze klas presteerden beide condities evengoed op de rekenvragen. Het zou kunnen zijn dat de ervaring in het gebruiken van andere simulaties, de leerlingen uit de experimentele conditie van Klas 1 geholpen heeft in het leren van de simulatie.

Conclusie

Het eerste deel van de onderzoeksvraag ging over het ontwikkelen van ondersteuning voor het ontwerpen van opdrachten. De eerste studie liet zien dat leerlingen zonder enige vorm van ondersteuning al in staat zijn om opdrachten te ontwerpen voor een simulatie, maar dat die opdrachten vaak nog oppervlakkig zijn of over het uitvoeren van berekeningen gaan.

In de tweede studie merkten we dat het werkblad leerlingen ondersteunde in het onderzoeken van de meer complexe relaties in de simulatie en in het ontwerpen van opdrachten over deze onderzochte relaties.

De derde studie toonde aan dat het verbeterde werkblad leerlingen ondersteunde in het maken van een uitgebreide analyse van het domein en in het ontwerpen van opdrachten over de onderzochte relaties, formules en begrippen. Samengevat zijn we er in geslaagd om in de loop van de onderzoeken een methode te ontwikkelen die leerlingen ondersteunt in het onderzoeken van het gesimuleerde domein en in het ontwerpen van opdrachten over deze ontdekkingen.

Het tweede deel van de onderzoeksvraag ging over het leereffect van het ontwerpen van opdrachten. Al in de eerste studie merkten we op dat het ontwerpen van opdrachten kon samengaan met het ophalen van voorkennis: in het ontwerpen van opdrachten over berekeningen zeiden leerlingen dat ze rekenprocedures weer moesten 'ophalen'. Het ontwerpen van opdrachten over eenvoudige experimenten in de simulatie leek ook veelbelovend. Leerlingen realiseerden zich bijvoorbeeld het dynamische karakter van de relatie U=I*R (het verlagen van de weerstand R zorgt ervoor dat de stroom I vergroot wordt), of van een elektrische component (een stijgende spanning zorgt ervoor dat de diode een stroom gaat geleiden).

Toen we in het tweede onderzoek leereffecten van ontwerpen van opdrachten wilden meten, bleek dat de gangbare toetsen voor mbo'ers te abstract waren.

Voor het derde onderzoek hebben we daarom een toets ontwikkeld die meer leek op een normale toets voor mbo-leerlingen. De test bevatte items om rekenvaardigheden te meten en items die inzicht in het domein maten. Resultaten van dit onderzoek lieten zien dat in een klas leerlingen die leerden door het ontwerpen van opdrachten beter presteerden op de inzichtvragen dan leerlingen die traditioneel onderwijs volgden. In een tweede klas werd dit significante verschil niet gevonden. In beide klassen vonden we geen verschillen op de rekenvragen. Samengevat kunnen we stellen dat het ontwerpen van opdrachten voor een simulatie met de LOOK EXPERIMENT DESIGN aanpak, mogelijkheden biedt voor leerlingen om meer inzicht te krijgen in het gesimuleerde domein. Eerdere ervaring in het werken met simulaties zou daarbij een essentiële voorwaarde kunnen zijn.

De drie studies beschreven in dit proefschrift onderzochten het 'leren door ontwerpen van instructie' als een manier van leren. Specifieker gesteld is het 'leren door ontwerpen van opdrachten' voor medeleerlingen bij een computersimulatie onderzocht. In de loop van de drie studies is de LOOK EXPERIMENT DESIGN aanpak ontwikkeld. In deze aanpak werden leerlingen ondersteund in zowel het onderzoeksproces als het ontwerpproces, zodat ze in staat waren experimenten uit te voeren in de simulatie, gegevens te verzamelen en opdrachten te ontwerpen over de gevonden data. Resultaten van de laatste studie lieten zien dat, in bepaalde situaties, leerlingen die opdrachten ontwierpen voor een simulatie met de LOOK EXPERIMENT DESIGN aanpak, meer inzicht kregen in een onderwerp dan leerlingen die traditioneel onderwijs volgden over hetzelfde onderwerp. Voor implementatie van leren door ontwerpen van opdrachten op school is meer onderzoek nodig om dit leereffect te bevestigen.

References

7

Ainsworth, S., & Labeke, N. (2004). Multiple forms of dynamic representation. *Learning & Instruction, 14*, 241-255.

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1997). Information technology and multiple representations: new opportunities - new problems. *Journal of Information Technology for Teacher Education, 6*, 93 - 104.

Ainsworth, S. E., & Loizou, A. T. (2003). The effects of self-explanation when learning with text or diagrams. *Cognitive Science, 27*, 669-681.

Aleven, V. A. W. M. M., & Koedinger, K. R. (2002). An effective metacognitive strategy: learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science, 26*, 147-179.

Bielaczyc, K., Pirolli, P. L., & Brown, A. L. (1995). Training in self-explanation and self-regulation strategies: investigating the effect of knowledge acquisition activities on problem solving. *Cognition and Instruction, 13*, 221-252.

Booth Sweeney, L., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review, 16*, 249-286.

Bos, A., Terlouw, C., & Pilot, A. (2006). Het leereffect of de peerassessor van conventioneel en gecomputeriseerd peer assessment in voortgezet beta-onderwijs, *Onderwijs Research Dagen*. Amsterdam, The Netherlands.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How People Learn: Brain, Mind, Experience and School*. Washington, D.C: National Academy Press.

de Bruijn, E., van de Berg, J., & Onstenk, J. (2004). De pedagogisch-didactische vormgeving van het middelbaar beroepsonderwijs. In E. de Bruijn (Ed.), *Beroepsonderwijs in ontwikkeling. Onderwijskundig Lexicon Editie III. Actuele thema's in het onderwijs* (pp. 58-87).

de Bruijn, E., Overmaat, M., Glaudé, M., Heemskerk, I., Leeman, Y., Roeleveld, J., & van de Venne, L. (2005). Krachtige leeromgevingen in het middelbaar beroepsonderwijs: Vormgeving en effecten (Results of powerful learning environments in vocational education). *Pedagogische Studiën, 82*, 77-95.

Carver, S. M., Lehrer, R., Connell, T., & Erickson, J. (1994). Learning by hypermedia design: Issues of assessment and implementation. *Educational Psychologist, 27*, 385-404.

Chi, M. T. H., de Leeuw, N., Chiu, M.-H., & Lavancer, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439-477.

Chin, C., Brown, D. E., & Bruce, B. C. (2002). Student generated questions: a meaningful aspect of learning in science. *International Journal of Science Education, 24*, 521-549.

Coleman, E. B., Brown, A. L., & Rivkin, I. D. (1997). The effect of instructional explanations on learning from scientific texts. *The Journal of the Learning Sciences, 6*, 347-365.

Collins, A., Brown, J. S., & Newmann, S. E. (1989). Cognitive apprenticeship: teaching the craft of reading, writing and mathematics. In L. B. Resnick & R.

Glaser (Eds.), *Knowing, Learning, and Instruction: Essays in Honour of Robert Glaser* (pp. 453-494.). Hillsdale N.J: Lawrence Erlbaum.

de Corte, E. (1990). Towards powerful learning environments for the acquisition of problem solving skills. *European Journal of Psychology of Education, 5*, 5-19.

Cox, R. (1999). Representation construction, externalised cognition and individual differences. *Learning & Instruction, 9*, 791-820.

Crismond, D. (2001). Learning and using science ideas when doing investigate-and-redesign tasks: a study of naive, novice and expert designers doing constrained and scaffolded design work. *Journal of Research in Science Teaching, 38*, 791-820.

Davey, B., & McBride, S. (1986). Generating self-questions after reading: A comprehension assist for elementary students. *Journal of Educational Research, 80*, 43-46.

Dutch department of Education. (2005). *Kerncijfers 2000-2004. Onderwijs, Cultuur en Wetenschap*. [Main Numbers 2000- 2004. Education, Culture and Science]. Zoetermeer: Ministerie van Onderwijs Cultuur en Wetenschap.

Edelson, D. (2001). Learning-for-use: a framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38*, 355-385.

Ferguson-Hessler, M. G. M., & de Jong, T. (1990). Studying physics text; differences in study processes between good and poor performers. *Cognition and Instruction, 7*, 41-54.

Fretz, E. B., Wu, H. K., Zhang, B. H., Davis, E. A., & Krajcik, J. S., Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education, 32*, 567-589.

Gijlers, A. H. (2005). *Confrontation and co-construction. Exploring and supporting collaborative scientific discovery learning with computer simulations.* University of Twente, Enschede, The Netherlands.

Goel, V., & Pirolli, P. L. (1992). The structure of design problem spaces. *Cognitive Science, 16*, 395-429.

Graesser, A. C., & Person, N. K. (1994). Question asking during tutoring. *American Educational Research Journal, 31*, 104-137.

Greeno, J. G., Korpi, M. K., Jackson III, D. N., & Michalchik, V. S. (1990). *Processes and knowledge in designing instruction* (Technical / Research report). California: Stanford University.

Harel, I. (1991). *Children designers*. Norwood, New Jersey: Ablex Publishing Corporation.

Hendrikse, P., van der Meij, H., & de Jong, T. (2006). *Onderzoekend leren met computersimulaties in de wiskunde klas.* Paper presented at the Onderwijs Research Dagen, Amsterdam, The Netherlands.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of the Learning Sciences, 9*, 247-298.

Holbrook, J., & Kolodner, J. L. (2000). Scaffolding the development of an inquiry based (science) classroom. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 221-227): Erlbaum, Mahwah, NJ.

Janssen, F. J. J. M. (1999). *Ontwerpend leren in biologie onderwijs. Uitgewerkt en beproefd voor immunologie in het voortgezet onderwijs (Learning biology by designing. Exemplified adn tested for the topic of immunology in secondary education).* University of Utrecht, Utrecht, The Netherlands.

Jonassen, D. H. (2000). *Computers as mindtools for schools. Engaging in critical thinking*. Upper Saddle River, N.J.: Merrill Prentice-Hall.

Jonassen, D. H., & Carr, D. S. (2000). Mindtools: affording multiple knowledge representations for learning. In S. P. Lajoie (Ed.), *Computers as cognitive tools, no more walls, Vol. II* (pp. 165-196). Mahwah, NJ.: Lawrence Erlbaum Associates.

de Jong, T. (2005). The guided discovery principle in multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 215-229). Cambridge, UK: Cambridge University Press.

de Jong, T. (2006a). Computer simulations: Technological advances in inquiry learning. *Science, 312*, 532-533.

de Jong, T. (2006b). Scaffolds for computer simulation based scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Dealing with complexity in learning environments.* (pp. 107-128). London: Elsevier Science Publishers.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*, 179-201.

de Jong, T., van Joolingen, W. R., Swaak, J., Veermans, K., Limbach, R., King, S., & Gureghian, D. (1998). Self-directed learning in simulation-based discovery environments. *Journal of Computer Assisted Learning, 14*, 235-246.

de Jong, T., Limbach, R., Gellevij, M., Kuyper, M., Pieters, J., & van Joolingen, W. R. (1999). Cognitive tools to support the instructional design or simulations-based discovery learning environments: the SimQuest authoring system. In T. Plomp, J. van den Akker, N. Nieveen & K. Gustafson (Eds.), *Perspectives on Developmental Research in Education and Training* (pp. 215-224). Dordrecht,The Netherlands: Kluwer Academic Publishers.

de Jong, T., & Pieters, J. M. (in press). The design of powerful learning environments. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology (2nd ed.).* Mahwah: Lawrence Erbaum Associates.

van Joolingen, W. R., & de Jong, T. (2003). SimQuest: Authoring educational simulations. In T. Murray, S. Blessing & S. Ainsworth (Eds.), *Authoring Tools for Advanced Technology Educational Software: Toward Cost-Effective Production of Adaptive, Interactive, and Intelligent Educational Software.* (pp. 1-31). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Kafai, Y. (1995). Minds in Play. Computer game design as a context for children's learning. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Kafai, Y. (1996a). Learning design by making games. Children's development of design strategies in the creation of a complex computational artifact. In Y. Kafai & M. Resnick (Eds.), *Constructionism in practice. Designing, thinking and learning in a digital world.* (pp. 71-96). Hillsdale, NJ.: Lawrence Erlbaum Associates.

Kafai, Y. (1996b). Software by kids for kids. *Communications of the ACM, 39*, 38-39.

Kafai, Y., & Ching, C. C. (2001). Affordances of collaborative software design planning for elementary students' science talk. *The Journal of the Learning Sciences, 10*, 323-363.

Kafai, Y., Ching, C. C., & Marshall, S. (1997). Children as designers of educational multimedia software. *Computers & Education, 29*, 117-126.

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching, 36*, 1065-1084.

King, A. (1994). Guiding knowledge construction in the classroom: Effects of teaching children how to question, how to explain. *American Educational Research Journal, 31*, 338-368.

Klahr, D., & Dunbar, K. (1988). Dual space during scientific reasoning. *Cognitive Science, 12*, 1-48.

Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology, 25*, 111-146.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice. *Journal of the Learning Sciences, 12*, 495-547.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Ryan, M. (2001). *Learning by design ^{TM}: promoting deep science learning through a design approach.* Paper presented at the Design Conference 2001. Design: Connect, Create, Collaborate, The University of Georgia, Athens.

Land, S. M., & Zembal-Saul, C. (2003). Scaffolding reflection and articulation of scientific explanations in a data-rich, project-based learning environment: an investigation of progress portfolio. *Educational Technology: Research & Development, 51*, 65-84.

Lee, M. O. C., & Thompson, A. (1997). Guided instruction in LOGO programming and the development of cognitive monitoring strategies among college students. *Journal of Educational Computing Research, 16*, 125-144.

Lehrer, R., Erickson, J., & Connell, T. (1994). Learning by designing hypermedia documents. *Computers in the Schools, 10*, 227-254.

Limbach, R. (2001). *Supporting instructional designers. Towards an information system for the design of instructional discovery learning environments.* University of Twente, Enschede, The Netherlands.

Limbach, R., de Jong, T., Pieters, J., & Rowland, G. (1999). Supporting instructional design with an information system. In T. Plomp, J. van den Akker, N. Nieveen & K. Gustafson (Eds.), *Perspectives on developmental research in education and training*. Enschede, The Netherlands: Kluwer Academic Publishers.

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science Education, 87*, 517-538.

Liu, M. (1998). The effect of hypermedia authoring on elementary school students' creative thinking. *Journal of Educational Computing Research, 19*, 27-51.

Liu, M. (2003). Enhancing learners' cognitive skills through multimedia design. *Interactive Learning Environments, 11*, 23-39.

Löhner, S. (2005). *Computer based modeling tasks. The role of external representation.* University of Amsterdam, Amsterdam, The Netherlands.

Löhner, S., Van Joolingen, W. R., & Savelsbergh, E. R. (2003). The effect of representation on constructing computer models of complex phenomena. *Instructional Science, 31*, 395- 418.

Makkink, H. K. (1994). *Met hoofd, hart en handen. De geschiedenis van het Middelbaar Technisch Onderwijs in Nederland.* Amsterdam, The Netherlands: Buijten & Schipperheijn.

Manlove, S., Lazonder, A. W., & de Jong, T. (2006). Regulative support for collaborative scientific inquiry learning. *Journal of Computer Assisted Learning, 22*, 87-98.

Martin, J.-P. (2002). Lernen durch lehren. *Zeitschrift für pädagogische Führung und Fortbildung in Bayern., 29*, 3-9.

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning? *American Psychologist, 59*, 14-19.

van der Meij, J., & de Jong, T. (2006). Learning with multiple representations: supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning & Instruction, 16*, 199-212.

Moreno, R., & Mayer, R. E. (2005). Role of guidance, reflection, and interactivitiy in an agent-based multimedia game. *Journal of Educational Psychology, 97*, 117-128.

National Science Foundation. (2000). An introduction to inquiry. In *Foundations. Inquiry: Thoughts, views and strategies for the K-5 classroom* (Vol. 2, pp. 1-5).

Njoo, M., & De Jong, T. (1993). Exploratory learning with a computer simulation for control theory: learning processes and instructional support. *Journal of Research in Science Teaching, 30*, 821-844.

Novak, J. D. (1990). Concept mapping: a useful tool for science education. *Journal of Research in Science Teaching, 27*, 937-949.

Novak, J. D. (1998). *Learning, Creating, and Using Knowledge. Concepts Maps™ as Facilitative Tools in Schools and Corporations*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Olsher, G., & Dreyfus, A. (1999). Biotechnologies as a context for enhancing junior high-school students' ability to ask meaningful questions about abstract biological processes. *International Journal of Science Education, 21*, 137-153.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension fostering and comprehension monitoring activities. *Cognition and Instruction, 2*, 117-175.

Papert, S. (1980). *Mindstorms: children, computers, and powerful ideas*. Brighton: Harvester Press.

Penner, D. E. (2001). Cognition, computers, and synthetic science: building knowledge and meaning through modelling. *Review of Research in Education, 25*, 1-37.

Penner, D. E., Lehrer, R., & Schauble, L. (1998). From physical models to biomechanics: A design-based modeling approach. *Journal of the Learning Sciences, 7*, 429-449.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching, 42*, 185-217.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). Scaffolding the design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*, 337-386.

Reimann, P., & Neubert, C. (2000). The role of self-explanation in learning to use a spreadsheet through examples. *Journal of Computer Assisted Learning, 16*, 316-325.

Reiser, B. J. (2004). Scaffolding complex learning: the mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*, 273-304.

Riley, D. (1990). Learning about systems by making models. *Computers & Education, 15*, 255-263.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: a review of intervention studies. *Review of Educational Research, 66*, 181-221.

Roth, W.-M. (2001). Learning science through technological design. *Journal of Research in Science Teaching, 38*, 768-790.

Russel, T., & Harlen, W. (1990). *Practical tasks. Assessing science in the classroom*. London: Paul Chapman Publishing.

Schauble, L., Glaser, R., Duschl, R. A., Schulze, S., & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *The Journal of the Learning Sciences, 4*, 131-166.

Seezink, A., & Van der Sanden, J. M. M. (2005). Lerend werken in de docenten werkplaats: Praktijktheorieën van docenten over competentie-gericht voorbereidend middelbaar beroepsonderwijs [Learning and working within a "teachers' workplace": Teachers' practical theories about competence-oriented prevocational secondary education]. *Pedagogische Studiën, 82*, 275-292.

Shepardson, D. P., & Pizzini, E. L. (1991). Questioning levels of junior high school science textbooks and their implications for learning textual information. *Science Education, 75*, 673-682.

Shipstone, D. (1985). ELectricity in simple circuits. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's ideas in science*. Milton Keynes: Open University Press.

Shuel, T. J. (1988). The role of the student in learning from instruction. *Contemporary Educational Psychology, 13*, 276-295.

Skinner, J. (1994). Learning by Teaching. *Zielsprache English, 2/94*, 38-39.

Slaats, A., Lodewijks, H. G. L. C., & van der Sanden, J. M. M. (1999). Learning styles in secondary vocational education: disciplinary differences. *Learning & Instruction, 9*, 475-492.

Slotta, J. (2004). The web-based inquiry science environment (WISE): Scaffolding knowledge integration in the science classroom. In M. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 203-233). Mahwah (NJ): Lawrence Erlbaum Associates.

Smith, P. L., & Ragan, T. J. (1999). *Instructional design. Second edition*. New York: John Wiley & Sons.

Soloway, E., Guzdial, M., & Hay, K. (1994). Learner-centered design. *Interactions, 1*, 36-48.

Swaak, J., & de Jong, T. (1996). Measuring intuitive knowledge in science: the development of the intuitive knowledge test. *Studies in Educational Evaluation*, 341-362.

Swaak, J., & de Jong, T. (2001). Discovery simulations and the assessment of intuitive knowledge. *Journal of Computer Assisted Learning, 17*, 284-294.

Veermans, K. H. (2003). *Intelligent Support for Discovery Learning.* University of Twente, Enschede, The Netherlands.

Veermans, K. H., van Joolingen, W. R., & de Jong, T. (2006). Using heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education, 28*, 341-361.

Vreman-de Olde, C., & de Jong, T. (2003). Leren door het ontwerpen van opdrachten over elektrische schakelingen (Learning by designing assignments about electrical circuits). *Tijdschrift voor Didactiek der beta-wetenschappen, 20*, 105-120.

Vreman-de Olde, C., & de Jong, T. (2004). Student generated assignments about electrical circuits in a computer simulation. *International Journal of Science Education, 26*, 859-873.

Vreman-de Olde, C., & de Jong, T. (2006). Scaffolding learners in designing investigation assignments for a computer simulation. *Journal of Computer Assisted Learning, 22*, 63-73.

de Vries, B. (2004). *Opportunities for reflection. E-mail and the web in the primary classroom.* University of Twente, Enschede, The Netherlands.

Webb, N. M. (1989). Peer interaction and learning in small groups. *International Journal of Education Research, 13*, 21-39.

Webb, N. M., & Palinscar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Cafree (Eds.), *Handbook of Educational Psychology* (pp. 841-873). New York: Simon & Schuster MacMillan.

White, R., & Gunstone, R. (1992). *Probing Understanding*. London: The Falmer Press.

Wong, R. M. F., Lawson, M. J., & Keeves, J. (2002). The effects of self-explanation training on students' problem solving in high-school mathematics. *Learning & Instruction, 12*, 233-262.

Zahn, C., Schwan, S., & Barquero, B. (2002). Authoring hypervideo's: Design for learning and learning by design. In R. Bromme & E. Stahl (Eds.), *Writing Hypertext and learning. Conceptual and empirical approaches. Advances in learning and instruction.* (pp. 153-176). London: UK: Pergamon, Elsevier Science.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: experimental research. *Journal of Computer Assisted Learning, 20*, 269-282.

Appendix A

In this appendix, we show and explain some items of the knowledge test used in study 2. In this test, we measured knowledge of relations, understanding of formulae, and understanding of representations.

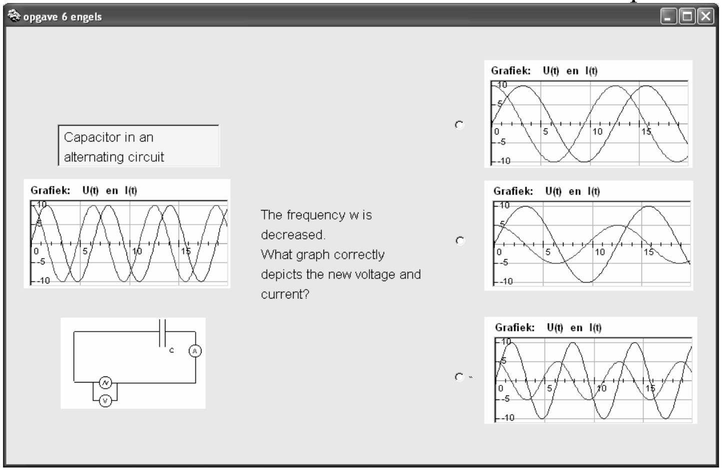
APPENDIX A

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. One of the nine multiple choice items (six items contained four and three items had five alternatives) is shown below. Students received one point for each correct answer.

If you want to increase the maximum current in a RCL-circuit, you can:

a. decrease C and L;
b. increase C and L;
c. decrease R, increase Umax;
d. increase R, decrease Umax;
e. none of the given options

The WHAT-IF test was a computerized test that consisted of 25 items. This type of test was created to measure intuitive knowledge about the causal relations between variables in the domain. In this computerized test, each test item (Figure 1) contained three parts: an initial condition, an activity, and three predictions. The initial condition and the predictions were possible states in the simulation. The initial conditions (voltage and current) were displayed in graphs. The action was presented in text. The predictions (voltage and current) were also displayed in graphs. In the instructions, the students were asked to choose the graph that correctly depicted how voltage and current changed as a result of the action. Whenever a student selected an answer, the item disappeared from the screen and the next item popped-up. The students could not go back to previously answered items. For each correct answer students received one point.



Capacitor in an alternating circuit

The frequency w is decreased.
What graph correctly depicts the new voltage and current?

○
○
○

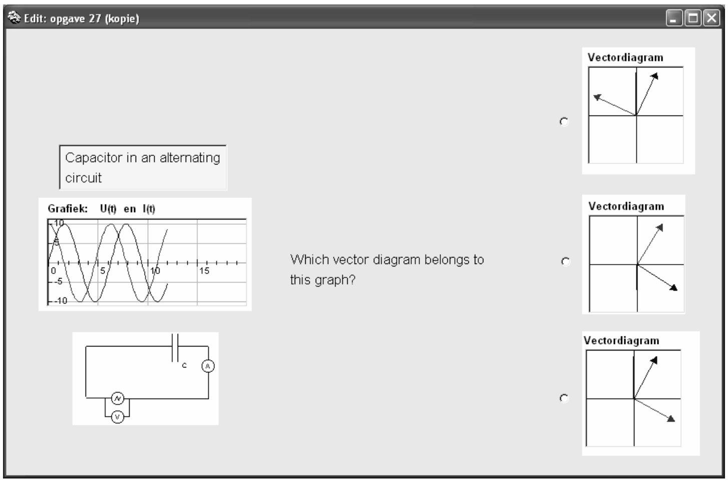
Figure 1 Screenshot of a sample item in the intuitive knowledge test.

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 (see example), the frequency, or the current through a resistor. An example of a definitional knowledge item is given below. Again, students received one point for each correct answer.

In a circuit with a capacitor, the formula for the capacitive reactance is:

- a. 1/(wC);
- b. wC;
- c. w/C;
- d. 1/C.

Understanding of representations was measured by the representational test comprising 5 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 (see Figure 2) In the instructions, the students were asked to choose the vector diagram that corresponded to the graphical representation. Students received one point for each correct answer.



Capacitor in an alternating circuit

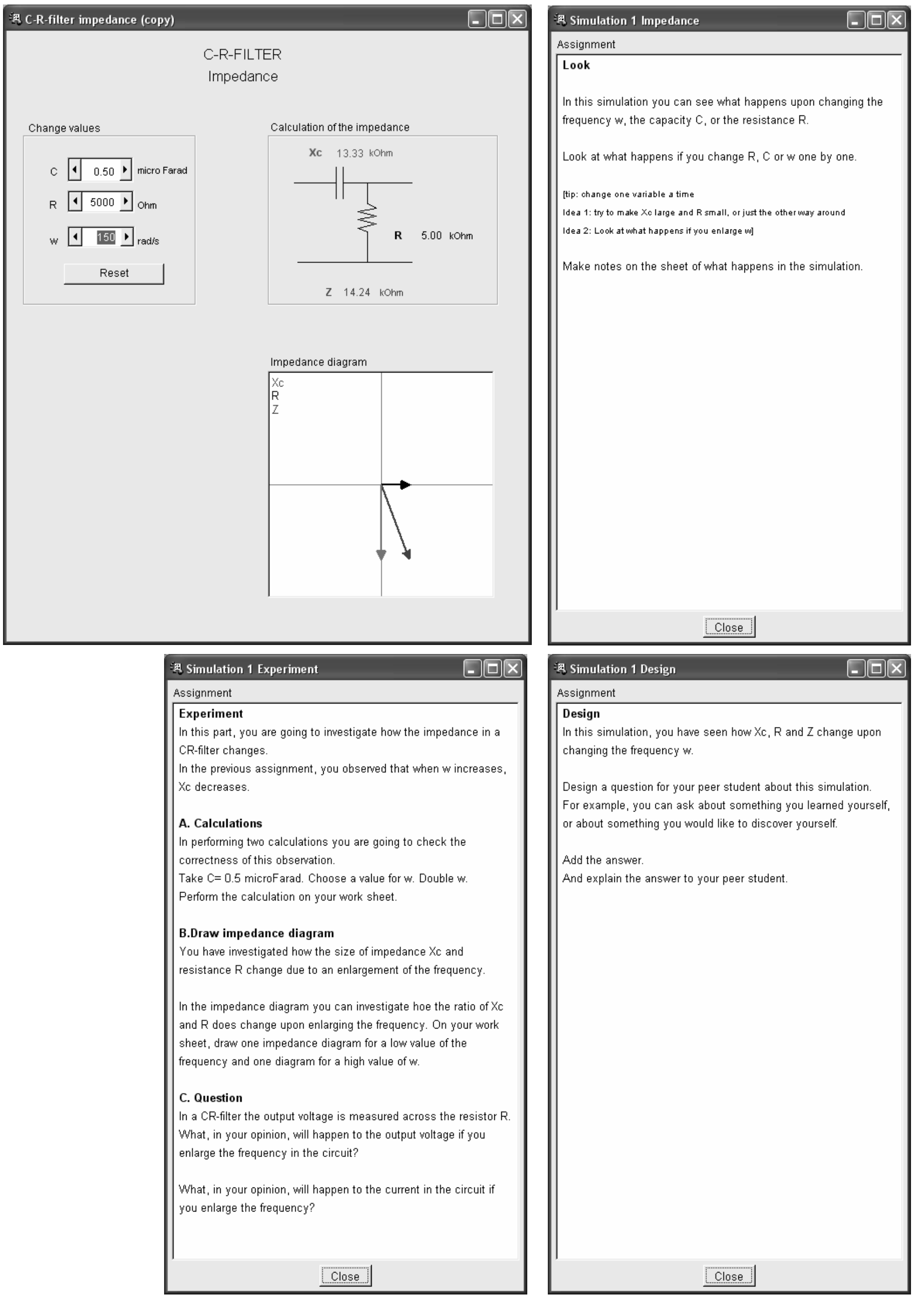
Which vector diagram belongs to this graph?

○ ○ ○

Figure 2. Screenshot of a sample item in the representation test

Appendix B

In this appendix, three simulation interfaces together with the integrated support developed for the simulation 'High pass and Low pass filters' are presented. Next to each screenshot of an interface, the first phase of the LED-approach, namely LOOK, is presented. Underneath these screen shots, the two other phases, namely EXPERIMENT and DESIGN, are presented. The simulation and the LED-approach are explained in Chapter 4.



C 0.50 micro Farad
R 5000 Ohm
w 150 rad/s

Xc 13.33 kOhm
R 5.00 kOhm
Z 14.24 kOhm

Look

In this simulation you can see what happens upon changing the frequency w, the capacity C, or the resistance R.

Look at what happens if you change R, C or w one by one.

[tip: change one variable a time
Idea 1: try to make Xc large and R small, or just the other way around
Idea 2: Look at what happens if you enlarge w]

Make notes on the sheet of what happens in the simulation.

Experiment

In this part, you are going to investigate how the impedance in a CR-filter changes.
In the previous assignment, you observed that when w increases, Xc decreases.

A. Calculations

In performing two calculations you are going to check the correctness of this observation.
Take C= 0.5 microFarad. Choose a value for w. Double w.
Perform the calculation on your work sheet.

B.Draw impedance diagram

You have investigated how the size of impedance Xc and resistance R change due to an enlargement of the frequency.

In the impedance diagram you can investigate hoe the ratio of Xc and R does change upon enlarging the frequency. On your work sheet, draw one impedance diagram for a low value of the frequency and one diagram for a high value of w.

C. Question

In a CR-filter the output voltage is measured across the resistor R. What, in your opinion, will happen to the output voltage if you enlarge the frequency in the circuit?

What, in your opinion, will happen to the current in the circuit if you enlarge the frequency?

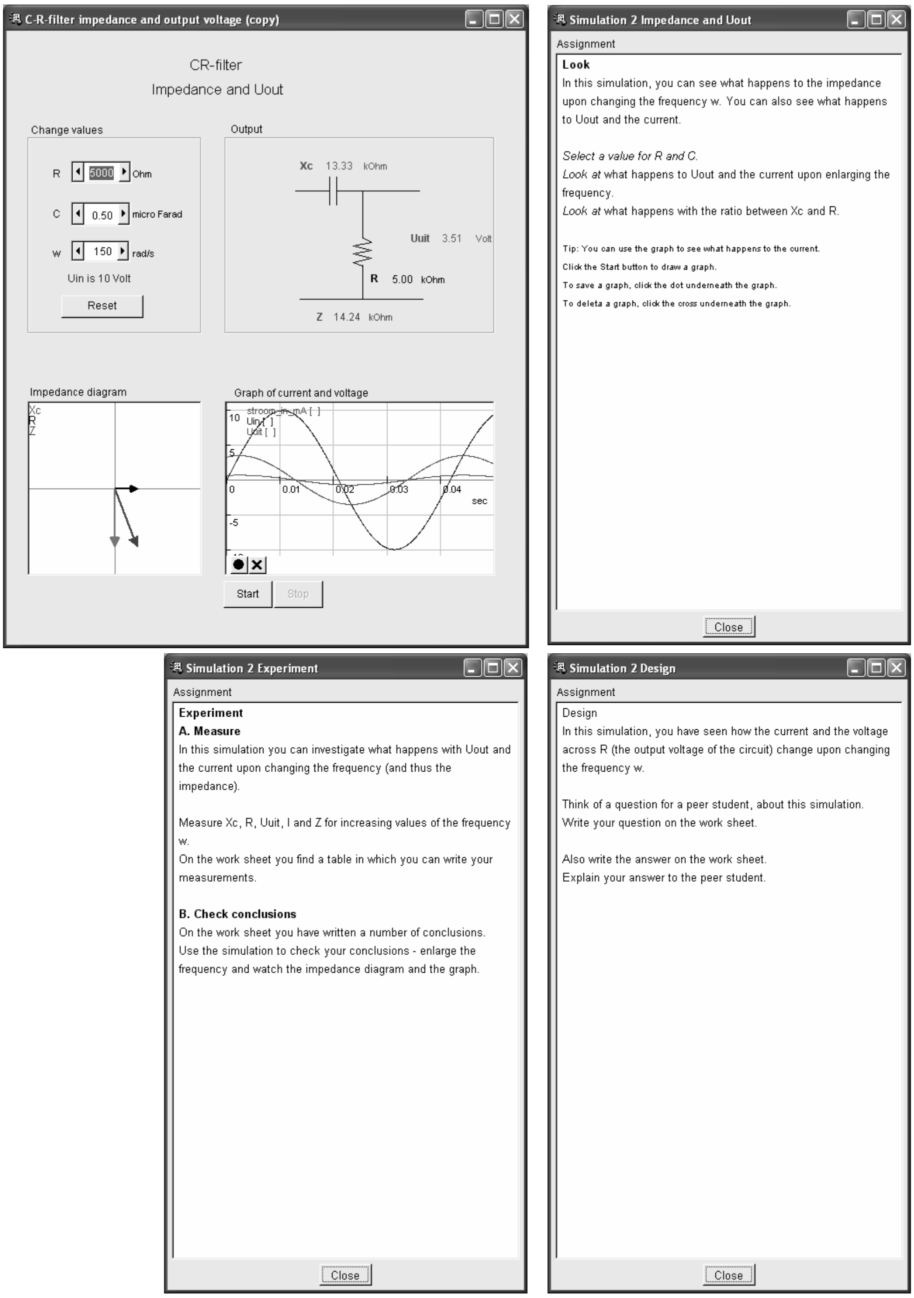
Design

In this simulation, you have seen how Xc, R and Z change upon changing the frequency w.

Design a question for your peer student about this simulation.
For example, you can ask about something you learned yourself, or about something you would like to discover yourself.

Add the answer.
And explain the answer to your peer student.

Figure 1 Screenshot of the interface belonging to the SimQuest simulation about electrical filters. Shown is the first out of three interfaces for the CR-filter and the integrated support



R 5000 Ohm

C 0.50 micro Farad

w 150 rad/s

Uin is 10 Volt

Xc 13.33 kOhm

Uuit 3.51 Volt

R 5.00 kOhm

Z 14.24 kOhm

Look

In this simulation, you can see what happens to the impedance upon changing the frequency w. You can also see what happens to Uout and the current.

Select a value for R and C.
Look at what happens to Uout and the current upon enlarging the frequency.
Look at what happens with the ratio between Xc and R.

Tip: You can use the graph to see what happens to the current.
Click the Start button to draw a graph.
To save a graph, click the dot underneath the graph.
To deleta a graph, click the cross underneath the graph.

Experiment

A. Measure

In this simulation you can investigate what happens with Uout and the current upon changing the frequency (and thus the impedance).

Measure Xc, R, Uuit, I and Z for increasing values of the frequency w.
On the work sheet you find a table in which you can write your measurements.

B. Check conclusions

On the work sheet you have written a number of conclusions.
Use the simulation to check your conclusions - enlarge the frequency and watch the impedance diagram and the graph.

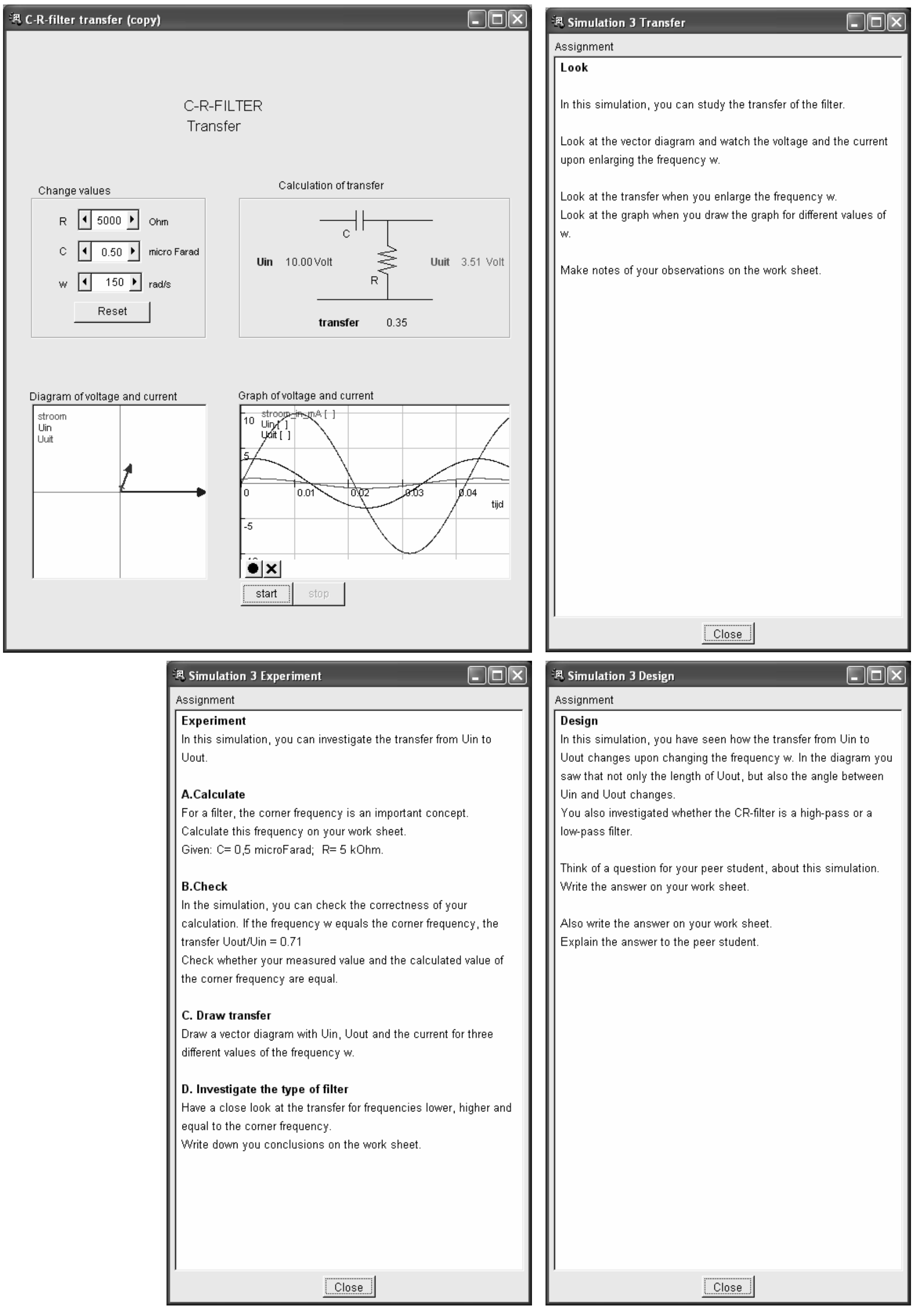
Design

In this simulation, you have seen how the current and the voltage across R (the output voltage of the circuit) change upon changing the frequency w.

Think of a question for a peer student, about this simulation.
Write your question on the work sheet.

Also write the answer on the work sheet.
Explain your answer to the peer student.

Figure 2 Screenshot of the interface belonging to the SimQuest simulation about electrical filters. Shown is the second out of three interfaces for the CR-filter and the integrated support.



R 5000 Ohm

C 0.50 micro Farad

w 150 rad/s

Uin 10.00 Volt

Uuit 3.51 Volt

transfer 0.35

Look

In this simulation, you can study the transfer of the filter.

Look at the vector diagram and watch the voltage and the current upon enlarging the frequency w.

Look at the transfer when you enlarge the frequency w.
Look at the graph when you draw the graph for different values of w.

Make notes of your observations on the work sheet.

Experiment
In this simulation, you can investigate the transfer from Uin to Uout.

A.Calculate
For a filter, the corner frequency is an important concept.
Calculate this frequency on your work sheet.
Given: C= 0,5 microFarad; R= 5 kOhm.

B.Check
In the simulation, you can check the correctness of your calculation. If the frequency w equals the corner frequency, the transfer Uout/Uin = 0.71
Check whether your measured value and the calculated value of the corner frequency are equal.

C. Draw transfer
Draw a vector diagram with Uin, Uout and the current for three different values of the frequency w.

D. Investigate the type of filter
Have a close look at the transfer for frequencies lower, higher and equal to the corner frequency.
Write down you conclusions on the work sheet.

Design
In this simulation, you have seen how the transfer from Uin to Uout changes upon changing the frequency w. In the diagram you saw that not only the length of Uout, but also the angle between Uin and Uout changes.
You also investigated whether the CR-filter is a high-pass or a low-pass filter.

Think of a question for your peer student, about this simulation.
Write the answer on your work sheet.

Also write the answer on your work sheet.
Explain the answer to the peer student.

Figure 3 Screenshot of the interface belonging to the SimQuest simulation about electrical filters. Shown is the third out of three interfaces for the CR-filter and the integrated support.

Appendix C

In this appendix, examples of instructional supports as developed for the work sheet used in our third study are shown. An overview and description of the instructional supports is presented in Table 1 in Chapter 4. A qualitative discussion about the effectiveness of the supports in presented in section 4.6.3.

Observation starters

In this simulation, you can see what happens to the impedance upon changing the frequency, the capacity C, or the resistance R.

If R increases then,…..

If C increases then,….

If ω increases then,…..

Empty space for making notes
[idea: try to make Xc larger and R small, or just the other way around.
Draw and/or describe how you can do this]

Prediction starter

When the frequency becomes higher, I think the output voltage will ……..

When de frequency becomes higher, I think the current in the circuit will…..

Partly filled in table and conclusion starter

U_{in} = 10 Volt
C =
R =
Calculate the current I, I= U_{in}/Z.

ω (in rad/s)	Xc (in kOhm)	R (in kOhm)	U_{out} (in V)	Z (in kOhm)	I (in mA)
50					
100					
500					
1000					
5000					
Conclusion: If ω increases, then	Xc becomes	R becomes	U_{out} becomes	Z becomes	I becomes

If the frequency is increased, the total impedance in the CR-filter becomes larger/smaller* and therefore the current becomes larger/smaller*
* cross off the wrong alternative

Representation (1) Calculations and conclusion starter

Two calculations

The formula for Xc = $\frac{1}{w.C}$.

ω = …….. rad/s Xc = ……..
ω= …… rad/s Xc =……..

Conclusion 1 : if ω doubles, Xc will …………….

Conclusion 2 : if ω doubles, R will ………

Representation (2) Diagrams and conclusion starter

Draw impedance diagram

diagram for low value of ω   diagram for high value of ω

Conclusion: When the frequency becomes higher, the total impedance becomes smaller/larger*.

* cross off the wrong alternative

Dankwoord

Dit proefschrift is het resultaat van een onderzoeksproject dat is uitgevoerd bij de afdeling Instructietechnologie van de faculteit Gedragswetenschappen. Ik wil graag eenieder bedanken die heeft bijgedragen aan de totstandkoming van dit proefschrift. Een aantal van hen wil ik hier met naam noemen.

Allereerst wil ik mijn promotor en begeleider Ton de Jong bedanken voor de gelegenheid om dit onderzoeksproject uit te voeren. Ik bedank hem voor zijn adviezen, commentaar en geduld bij het voorbereiden, uitvoeren en beschrijven van het onderzoek. Ton, ik heb er veel van geleerd.

De drie experimenten die in dit proefschrift worden beschreven zijn uitgevoerd bij het ROC van Twente in Hengelo. Ik bedank Jan Nijmeijer en zijn leerlingen voor de bereidheid om mee te werken aan de drie experimenten. Zijn inbreng in de vormgeving van de simulaties, zijn belangstelling voor het onderzoek en al het regelwerk dat vooraf ging aan de experimenten waren erg nuttig en waardevol. Ook bedank ik Peter Westerveld en zijn leerlingen voor de enthousiaste medewerking aan het derde experiment.

De simulaties die gebruikt werden in dit onderzoeksproject zijn ontwikkeld in SIMQUEST. Ik wil Paul Weustink bedanken voor zijn enthousiaste hulp bij het maken van de modellen voor de SIMQUESTsimulaties over wisselspanning. Jakob Sikken bedank ik voor het maken van de simulaties over diodes en parallelle spanningsbronnen en Jan van der Meij bedank ik voor al zijn praktische hulp met SIMQUEST.

Als promovendi van Instructietechnologie kwamen we regelmatig bij elkaar om over ons onderzoek en aanverwante onderwerpen te discussiëren. Ik heb het erg boeiend gevonden om op deze open manier te kunnen praten en mee te denken over de vraagstukken waar we in ons werk tegen aan lopen. Ik bedank iedereen die eraan heeft bijgedragen.

Een aantal collega's die me bijzonder nabij zijn geweest wil ik niet onbenoemd laten. Hans van der Meij wil ik bedanken voor zijn luisterend oor en wijze woorden in tijden dat het leven niet zo makkelijk voor me was. Petra Hendrikse wil ik bedanken voor haar gezelschap bij de wandelingen door het park en de Zwitserse bergen. Sylvia van Borkulo, mijn kamergenote, bedank ik voor haar gezelschap en haar uitleg over de gulden snede (Sylvia, zoals je ziet heb ik er gebruik van gemaakt).

De engelse tekst in dit proefschrift werd gecorrigeerd door Emily Fox, waarvoor ik haar graag wil bedanken. Ik wil Henriëtte van de Wetering bedanken voor het corrigeren van de nederlandse samenvatting.

Als ik vragen had over statistiek kon ik altijd terecht bij Hannie Gijlers. Hannie, hartelijk dank voor je uitleg en hulp.

Tot slot wil ik mijn familie noemen. Ik ben blij dat mijn ouders me de gelegenheid hebben gegeven om te gaan studeren. Ik bedank hen voor hun belangstelling voor mijn werk en voor het oppassen op de kinderen. Bert, ik bedank je voor je steun, inspiratie en verfrissende kijk op het werk. Timon en Macy, jullie hebben vaak voor een welkome afleiding gezorgd tijdens het onderzoek. Ik ben blij jullie moeder te zijn!

Het wachtwoord voor mijn computer was gebaseerd op een lied uit de bijbel ‘De Heer is mijn herder’. Dit hoopvolle lied gaf me vaak nieuwe energie.

Cornelise Vreman-de Olde
Hengelo, augustus 2006