Support for Simulation-Based Learning: The Effect of Assignments in Learning about Transmission Lines

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Abstract

This article discusses a study on discovery learning with a computer simulation environment in the physics domain of transmission lines. In the learning environment, which is called *TeEl*, based on the numerical solution of the telegraph equations, the transmission of changes in voltage and current are simulated and visualised. The instructional goal concerns the basic nature of the concepts 'transmission', 'superposition', and 'reflection'. In the experiment we conducted with *TeEl*, the emphasis was on the role of assignments in the discovery learning process. The intended instructional role of assignments is to guide the learner through the domain and in this way to support the planning process. Moreover, by presenting the adequate assignments, learners can be pointed to phenomena they perhaps would not have discovered on their own. In the experiment the effect of providing assignments was evaluated by comparing the learning behaviour and results of learners over two experimental conditions. The first condition presented a simulation environment that was surrounded by explanations and built up through different levels of model progression, and also had a large number of on-line assignments available from which subjects could choose. In the second condition the same environment was presented, but now assignments were replaced by short introductory texts pointing the subjects to relevant phenomena. Learners' use of the environment was logged and their learning result was assessed using a number of different assessment procedures. Results showed that assignments helped students in mastering the domain as reflected in a test of their intuitive knowledge.

1. Introduction

Scientific discovery is a knowledge acquisition process that has a complicated nature and puts a high responsibility for the learning process in the hands of the learner. Studies into discovery learning processes have identified a large number of relevant processes. Njoo and de Jong (1993), for example, analysed (by means of thinking aloud protocols) the discovery processes of students of mechanical engineering working with a computer simulation. Their main distinction is between *transformative processes* (processes that directly yield knowledge) and *regulative processes* (processes that are necessary to manage the discovery process). For transformative processes they make a further distinction into: *Analysis* which is the process of identifying and relating variables in the model and indicating general properties of the model; *Hypotheses generation* which is the formulation of a relation between one or more variables (input and

output) and parameters in the simulation model. A hypothesis is stated with the intention to test it; *Testing*, which refers to those activities that are necessary for furnishing data on which the learner expects to be able to accept or refute an hypothesis, or to create an hypothesis. Testing includes the processes 'designing an experiment', 'making predictions', and 'data interpretation'; And, finally, *evaluation*, in which results are put into a more general context. Regulative processes are divided into: *Planning*, which can take place at the level of the complete discovery process, or at the level of one of the transformative processes indicated above; *Verifying*, which is checking the correctness of actions and results at a conceptual level; And, finally, *monitoring*, in which the learner observes and keeps track of his/her own study process.

Quite a few studies have been conducted that compared learning results from discovery and expository learning. These studies, without many exceptions, showed that pure discovery is not a fruitful way of learning, because learners may fail to find the rule that they had to discover. These studies were conducted in the area of 'concept discovery', but a similar phenomenon has been observed in recent studies on 'scientific discovery'. Quite a few studies could not find advantages of learning with pure discovery environments (in the form of computer simulations) compared to other instructional methods (e.g., Carlsen & Andre, 1992; Chambers et al., 1994; de Jong, de Hoog, & de Vries, 1993; Rivers & Vockell, 1987).

There are two reasons for not finding the expected advantages of discovery environments over, for example, expository instruction. The first one is that students lack the necessary skills for discovery learning and thus are not able to engage in a successful learning process. This indeed seems to be the case. In De Jong and Van Joolingen (1996) many studies are cited in which it was found that learners show deficiencies in the discovery learning process. De Jong and van Joolingen (1996) also describe a large number of environments that include supportive measures in combination with a discovery environment (a simulation). These supportive measures are meant to help students overcome or surpass the problem they encounter in discovery learning, in analogy to guided discovery in the classical concept discovery studies (see Mayer, 1987).

One of the problems that learners experience is in the planning of their actions. Planning support may, as Charney et al. (1990) have postulated, be especially helpful for low prior knowledge subjects. Planning support takes away decisions from learners and in this way helps them in managing the learning process. This support for planning can be given in different ways. Showalter (1970) recommended to use *questions* as a way to guide the learner through the discovery process. His questions focused the learners attention to specific aspects of the simulation. White (1984) helped learners to set goals in a simulation of Newtonian mechanics by introducing *games*. Games, as White uses them, ask learners to reach a specific state of the simulation. In an experiment White found that learners who learned with a simulation that contained games, outperformed learners who worked with the pure simulation on a test of qualitative problems (asking questions of the form "What would happen if ..?" or "How could one achieve ...?" (p. 81)). Also, in the ThinkerTools environment (White, 1993) games are used in a similar context as in White (1984). A second way to help the planning process is to divide the domain into separate pieces that follow each other in complexity. This idea of *model progression* was used in for example the QUEST project (White & Frederiksen, 1991).

The second potential reason for a lack of results of discovery learning is the use of assessment methods that do not do justice to the discovery process. Traditional methods of assessment (definitional tests) ignore the fact that in scientific discovery learning the learning goal is more in the area of intuitive, qualitative, knowledge instead of formalised knowledge (Berry & Broadbent, 1984; Laurillard, 1992; Lindström, Marton, Ottosson, & Laurillard, 1993; White, 1993).

In the present study we have performed an evaluation of a discovery environment built around a simulation in the physics domain of transmission lines. In the experiment we concentrated on the effect of providing support for the planning process in the form of assignments (having a similar status as the games from White's studies). The discovery environment used in the present study was based on the SMISLE system (De Jong et al., 1994; De Jong & Van Joolingen, 1995). In SMISLE environments *assignments* are one of the measures used for directing the learner. In the experiment two simulation environments were compared with regard to learning process and learning outcome, one included a large set of on-line available assignments, in the other assignments were replaced by short introductory texts that pointed learners to relevant points from the model. The main way for the evaluation of learning results in the present study was carried out by using a new and different assessment procedure, the WHAT-IF test, that aimed at a specific type of (intuitive) quality of knowledge (Swaak & de Jong, 1996). Moreover, we registered learners' use of the environment and assessed the cognitive load that learners experienced while working with the environment.

The basic hypothesis of the study is that learners who use assignments will experience less cognitive load and display better planning behaviour and thus will gain better knowledge compared to learners who do not use assignments.

2. Method

2.1 Domain

In TeEl, transmission processes, especially the transmission of changes in voltage and current on a double line, are addressed. The simple geometry of a linear double line is adequate for a major part of technical devices and arrangements and the involved phenomena of transmission, reflection, and superposition are of basic importance for a conceptual understanding of related processes. Traditionally, the solutions of the underlying system of coupled differential equations is found by applying sophisticated mathematical tools (Fourier analysis, complex calculus). As a consequence this has raised rather high learning barriers for understanding, especially for newcomers to this field. Due to the computational power of modern computers, the solution of such equations can be found directly in time domain, using adequate numerical techniques. Furthermore, it is possible to offer to the learner the possibility to interact with the system in a detailed way. All relevant parameters can be changed and immediate feedback is received in respect to the system's dynamics.

The basic phenomena under study are transmission, superposition, and reflection. These phenomena relate to mechanical systems – a gas or water pipe – as well as to electrical ones. In a gas pipe, a change in pressure along the axis of the pipe – a pressure gradient – will cause a current to develop in time. In electrical systems, a voltage drop will change the flow of electrons – the current. If in a gas pipe there exists a

change in current along the axis – a current gradient – the pressure will either build up or decrease. The same holds for electrical systems with respect to a current gradient and a change in voltage. These two effects – voltage gradient and change in current – are mutually influencing each other, leading to a system of coupled differential equations for their mathematical description. In the TeEl simulation this interaction process is broken up into basic elements which can be changed individually and then observed in detail as the dynamic system behaviour evolves. A clear understanding of these fundamental processes should serve as an intermediate step towards the understanding of more abstract mathematical methods, needed for a more general and more powerful description of related processes and systems. The algorithm, controlling the proper run of the simulation is based on a discretized form of the Telegraph Equations, which are numerically integrated in time domain. This work has been transferred from former developments within the CoLoS project (Härtel, 1994).

2.2 Description of the simulation environment

Simulation environments as they are developed in the SMISLE context carry a number of features. The central part of such an environment is the *simulation*. In addition to the simulation four instructional support measures can be present. The first one of these is *model progression*. The basic idea of offering model progression in a simulation environment is to gradually unfold the properties of the domain to the learner, by offering a sequence of models. This means that different models are offered that gradually increase in complexity. The second type of support is *assignments*. Assignments direct the learner in what to find out of the simulation model. Within SMISLE a number of different assignments can be present. These are labelled: *Investigation*, *Optimisation*, *Fault diagnosis*, *Specification (prediction)*, *Explicitation*, and *Normal operation*. The third type of support are *explanations*. Explanations give the learner a direct view on domain properties. Finally, learners can have access to a *hypothesis scratchpad*. A hypothesis scratchpads is a software tool designed to support the learner in stating hypotheses about the simulation. An elaborate description and justification for each of these measures is given in De Jong et al. (1994) and De Jong & Van Joolingen (1995). Here, we will detail the realisation of these measures within the TeEl application.

The simulation

Figure 1 demonstrates one of the simulation windows, as seen by the students¹. As indicated in the upper part of the window a voltage source and a load are connected via a double line. All relevant parameters as V , $R_{(intern)}$, L , C , and $R_{(load)}$ can be set. In the two output windows below the voltage and current for each segment are shown. The values can in these output windows can be directly manipulated in order to create a starting position.

¹ All interfaces were in German. In this paper we have included translations from German into English.

Figure 1. Simulation window for transmission processes on a double line

Model progression

Four model progression levels have been developed. At the beginning (see Figure 2 for the input part) a simple mechanical device, a gas or water pipe, is presented, where some of the basic phenomena (transmission and superposition) can be studied.

Figure 2. Gas pipe with absorbers as introductory model for transmission processes

At the second model progression level a circular system with an energy source and a load are introduced to study reflection processes (see Figure 3 for the input part).

Figure 3. Circular mechanical device to study reflection processes

At the third model progression level electrical systems are introduced where the internal resistance of the voltage source is introduced and where its influence on the resulting steady state conditions can be studied (Figure 4 shows the input part)).

Figure 4. Voltage source with internal resistor connected with a load by a double line

At the fourth, and final, model progression level the variation of the speed of transmission can be measured depending on the values of L and C (see Figure 5 shows the input and output parts).

Figure 5. Time measurement for determining the transmission velocity

Explanations

A set of 30 explanations has been developed, covering all introduced variables, interpretations of mathematical descriptions, and the basic processes involved. As a general rule the explanations contain text and graphic as an example shows in Figure 6.

Figure 6. Example of an explanation as offered to the student upon request

The explanations, developed for the TeEl application, are structured according to three basic ideas: the use of mechanical devices and terms as introduction, a newly developed approach for explaining transmission processes, and a close and smooth transition from qualitative arguments to the description of physics laws and definitions in mathematical form.

The use of a mechanical system at the beginning is based on the assumption that the mechanical world is easier for newcomers than electrical devices and terms. Having studied all basic phenomena within a mechanical system the transfer to the electrical world should be facilitated.

The explanations are further based on an approach to explain the transmission process in a linear system. In this approach a narrow zone – a pulse – with a non-equilibrium value for voltage and a pulse with a non-equilibrium drift current are seen as the basic elements and as starting point for further explanations of transmission, superposition, and reflection. If either one of these two possible deviations from equilibrium, a voltage or a current pulse, does exist somewhere on a line, it will cause a symmetric transmission process to both sides. If the two pulses occur at the same place and if the ratio of the amplitudes of these pulses is set to a specific value (the wave resistance or impedance of the line) it follows that their effects to one side will cancel while it adds up in the opposite direction. The combination of these two effects is a simple transmission. This basic concept already contains the principle of linear superposition, while reflections follow quite naturally when the ratio between voltage and current is changed by inhomogeneties on the line. In order to formulate the related laws in mathematical form, the terms gradient of voltage and gradient of current have to be introduced. The derivation of the so-called Telegraph equations (without losses) follows within a few steps, leading to the well known expression for the relation between velocity of transmission as function of inductance and capacitance.

Assignments

For each model progression level a set of assignments was developed, with most of them having the format of investigation or specification assignments. An example of an assignment for the first model progression level is:

What voltage will be found at element #10 if both pulses will meet after the 3. time step?
Select the correct answer from the given selection.

Students could then select an answer from a number of alternatives and received feedback on the answer.

The sequence of assignments is structured in accordance with the didactical approach described in the previous section. The proposed activities in the assignments are planned in such a way that the learner will get in contact with all involved concepts and events. In the first model progression the concept of transmission and linear superposition is covered. In the second level activities are proposed to find out about reflection at the load for R taking extreme values. For the third model progression, where electrical devices and terms are used, reflection is treated again in greater detail, including reflection at the energy source and its internal resistor. Furthermore, the term "wave resistance" is introduced and activities are proposed to find out about the importance of Z (impedance) for a termination of a line with no reflection. For the fourth model progression level, the dependence of v , the velocity of transmission, as a function of L and C is introduced. Activities are proposed to verify the derived functional relation: $v^2 = 1/LC$.

2.3 Design

In the study we compared two versions of basically the same environment. The first one (Condition I) is a simulation combined with model progression, explanations, and assignments. The second one (Condition II) was basically the same environment except that assignments were now replaced by short introductory texts that pointed learners to important aspects of the models to be learned. An example of such an introductory text is the following:

Today again two chapters (model progressions) with two simulations are offered to be worked at. The simulation of the first chapter allows to study reflection at the load. The main questions are: how can a line be terminated to prevent reflection and what influence is caused by the terms inductance L and capacitance C . Furthermore you are asked to study the kind of reflection that occurs at the load and at the internal resistance of the energy source. You should be able to explain the sign of the reflected voltage/ current step as depending on R . Finally, the focus is set to the internal resistance of the energy source, which has an important influence on voltage and current of the double line. To explore this influence, knowledge about the so-called simple electric circuit are important which can partly be applied to this problem.
(Translated from German)

2.4 Subjects

The topic treated here is part of the curriculum of physics courses at upper secondary level and introductory courses at university level, usually found under the title "Oscillations and Waves". In relation to electrical phenomena and transmission lines it is covered at the end of the second year of electrical engineering. However, in each case this topic is treated in a rather mathematical and non-qualitative manner. No interference with the approach applied in TeEl should occur. The majority of the subjects (age about 20/22) came from a technical high school where they had nearly finished their

first year in either mechanical or electrical engineering. A minority part of the subjects (age about 17/18) came from a Gymnasium where they had followed special courses in physics. Due to practical reasons it was not possible to balance these two groups over the two conditions. The number of subjects in Condition I was 17 (technical high school), in Condition II there were 12 subjects (7 from technical high school, 5 from Gymnasium).

2.5 Tests

For assessing the learners' knowledge three different tests were used. The first one was a WHAT-IF test in which subjects had to indicate their understanding by predicting the result of the next step, following a given situation. The second was a test for subjects' knowledge of the structure of the domain, and the third test was a so-called transfer test.

Knowledge test

For measuring intuitive understanding of the subject matter we used a test that we called the WHAT-IF test. The information in the WHAT-IF task is represented in the form of conditions, actions, and predictions. The conditions and predictions are the states in which the system can be. The conditions are displayed in a drawing of the system that was, if necessary for the learners' understanding, accompanied with some text. The action, or the change of a variable within the system, is presented in text. The predicted state is displayed in text or in a drawing of the system. The WHAT-IF task requires the learner to decide which of the three predicted states follows from a given condition given the action that is displayed. In other studies (e.g., De Jong et al., 1995) we used this test as a so-called speed test, urging students to answer the items as fast as possible. Due to practical circumstances this was not possible in the current study. The speed character of the test emphasises even more the intuitive character of the knowledge measured. The items of the task are kept as simple as the domain permits, and the items have a three-answer format. Subjects were explained that if they did not know the answer they could leave the item open. Pre-test and post-test were parallel versions of the same test that consisted of 38 items. An example item is depicted in Figure 7

Structural knowledge

For assessing the structure of knowledge acquired a *concept-mapping task* was used. The concept-mapping task required the learner to sort the concepts (variables) of the domain into clusters of concepts in a way that represents their view of the domain. It was emphasised that there is no correct or incorrect solution. We used a computerised task in which concepts of the domain are presented on the computer screen. The subject can point with the mouse to a concept. When the subject clicks the mouse the concept will be selected and can be dragged to the part of the screen where the subject wishes to create the relevant cluster. Then the subjects can select another concept and add it to the already existent cluster or create a new cluster. For the TeEl application the terms, offered to the learner, were related to the microscopic level, the macroscopic level, and the elements of the visible devices, and observable processes. Figure 8 displays the interface of the concept mapping test.

Question: A voltage/current step is approaching the load of a line. The picture on the right shows the moment after reflection. Which of the three statements about the resistance of the load is the correct one?

Figure 7. Test item for WHAT-IF test (Translated from German)

Figure 8. Interface of the concept mapping test, with all the concepts presented.

Transfer test

In order to check depth and possible limits of the understanding gained during the learning experience a so-called 'transfer-test' was added as a post-test. The main idea behind these transfer items was the use of negative values for the applied voltage instead of positive ones. Such negative voltage was never explicitly mentioned in the offered material, even though such values could have been applied by the students while exploring the system. The transfer test consisted of 8 items and these had the same format as the items of the WHAT-IF task.

2.6 Measuring the interaction behaviour

We registered all actions learners made while interacting with the simulation. This provided us with data on the use of the simulation and the supportive measures that were

present. These data were used to make a comparison between groups, but also to relate specific interaction patterns with outcomes of the post-tests.

A second type of measurement that we introduced is a measurement of subjectively experienced *subject matter difficulty* and *workload*. At regular moments in the text a small electronic questionnaire appeared that subjects had to fill in before they continued working with the environment. By pulling sliders subjects could indicate their perceived difficulty of the subject matter, their perceived difficulty of the interaction with the environment (this concerns the man-machine interaction aspects), and their view on the helpfulness of the instructional measures (the functionality of the tools) that they had used. The questionnaire was set to pop up every 20 minutes, but display was always postponed until an event occurred that marked the end of a coherent subject's action, such as closing an explanation or completing an assignment. This was done in order not to let this measurement interfere with the discovery behaviour.

2.7 Procedure

Sequence of activities

The general structure of the experiment is displayed in Figure 9.

Figure 9. *Sequence of activities during the experiment*

Experimental sessions were divided into two parts of about 3 hours each. This was necessary, because it was found during pre-runs that otherwise students were put under too much load. In Part I, model progression levels 1 and 2 were treated, in Part II, model progression levels 3 and 4. At the beginning of each part an introduction was offered. This was necessary to introduce the students to the topic, and its special kind of treatment which was new to them.

During the introduction of Part I the content of model progression levels 1 and 2 was presented to the group of participants, similar to the explanations as found in the application and the use and functionality of the interface was demonstrated. After working on the pre-test/part I the students received a written document. This document explained the procedure of the sessions and the general idea behind simulation-based discovery learning. The different support measures as applicable to the experimental condition were explained. The interface of the simulation environment with all its relevant options was described. Finally, learners were told that everything they would do in the environment was logged and the meaning of the cognitive load/subject matter difficulty questionnaire was explained. Learners could read through this written introduction and ask questions to the experiment leader. They could consult the written introduction during the whole course of the experiment. After having read the document

each individual student got a short introduction in the use of the interface and the use of the tool for measuring the cognitive load. The time for either exploring the environment or to work on the assignments was not fixed but left to the decision of the students. The time used by the students varied between 100 and 150 minutes. During this time they could ask question about the use of the environment, but received no help in respect to the content. The students were asked not to discuss their problems with neighbours but to work on their own. The first session was closed by administering the post-test, which was a parallel version of the pre-test.

Part II started again with an introduction were the content of model progression 3 and 4 was presented to the group, using as material the same explanations as found in the application. After administering the pre-test/part II the students worked on there own for a time between 50 and 120 min. Again they could refer to the written document or ask question about the handling of the interface. No information about the content was given and no discussion was allowed between neighbours. The session finished by administering the post-test/part II (parallel version of the pre-test + transfer items) and the structural knowledge test. The post test contained some extra items, so-called transfer items, to check depth and possible limits of the acquired knowledge.

The procedure was essentially the same for the two experimental groups. The only exception being that for experimental condition II, instead of assignments integrated with the environment, an additional text was presented in which all the important facts to be studied were listed. These students were explicitly told to study this text carefully as support for their discovery activities.

3. Results

3.1 The knowledge test

Knowledge of subjects was measured by the so-called WHAT-IF test. In this test subjects had to decide upon the result of an action that was introduced in a situation. The answer format was multiple choice with three answer alternatives, and students were advised to leave the answer open when they did not know it.

Table 1 displays the number of items correctly answered (out of the total of 38 items in the test) at the WHAT-IF pre-test and post-test for both experimental groups.

Table 1. *Number correct on the WHAT-IF pre-test and WHAT-IF post-test ($n = 38$ items) for the two experimental conditions*

condition	WHAT-IF pre-test	WHAT-IF post-test
I (assignments)	13 ($sd = 4$)	24 ($sd = 5$)
II (no assignments)	11 ($sd = 7$)	18 ($sd = 9$)

Scores on the WHAT-IF pre-test did not differ significantly between the two groups, thus indicating that, though students partially had a different background, the prior knowledge of these two groups of students was comparable. Non-parametric Sign Tests showed that across the 29 students of the two experimental conditions the number of correct items of the WHAT-IF pre-test differed from the number correct on the WHAT-IF post-test (z -score = 4.62, $p < .001$). A Mann-Whitney test revealed differences between

the experimental conditions on the gain in number correct WHAT-IF items (z-score = -2.00, $p < .05$).

3.2 Structural knowledge

For assessing the subjects performance on the structural knowledge test we used concept maps created by two experts (physics teachers) as criteria. Subjects' concept maps were transformed into 'similarity matrices' in which similarity of concepts was given a '1' if two concepts appeared in the same group and a '0' if two concepts belonged to different groups. The same procedure was followed for the two expert concept maps. For each subject the proximity between the subject's matrix and the two expert matrices were calculated using a formula introduced by de Jong and Ferguson-Hessler (1986). This proximity measure equals '1' when the expert's grouping is identical to the subject's grouping, and may reach a small negative value with very dissimilar groupings. The proximity between the two expert groupings was rather low and had a value of .23. Table 2 gives the average proximity measures with both experts over the two experimental conditions. The table shows that there are no average differences between the two experts as criteria.

Table 2. Average proximity measures of subject's sorting and two experts

Condition	Expert 1	Expert 2
I (assignments)	.28 (<i>sd</i> = .08)	.37 (<i>sd</i> = .08)
II (no assignments)	.28 (<i>sd</i> = .07)	.37 (<i>sd</i> = .05)

3.3 Transfer test

The transfer items have only been included in the post-test of part II. For the transfer test we found that the students of both experimental conditions had very low scores, and answered on the average only 2 out of 8 transfer items correctly.

3.4 Interaction behaviour

We registered all the actions learners made while interacting with the simulation. This provided us with data on the use of the simulation and the supportive measures that were present. In the subsequent analyses the complete interaction data of each of the 29 subjects were summed across the two experimental sessions.

Time on task

In the experimental procedure a minimum time of 120 minutes, taken across the two sessions, was set for interacting with the simulation. Table 3 displays the average time in minutes learners spent with the simulation environment for the two experimental conditions.

Table 3. Average total time spent in the two experimental conditions

Condition	time in minutes
I (assignments)	335 (<i>sd</i> = 68)
II (no assignments)	262 (<i>sd</i> = 103)
Overall average	305 (<i>sd</i> = 91)

A Mann-Whitney test revealed no differences between the experimental conditions on the time spent in minutes at the $\alpha < .05$ level (z-score = -1.86, $p < .10$).

Number of runs

Students were rather active in the simulation. Table 4 shows the average number of runs (a run is related to the action of the learner to launch the simulation in the simulation window) over the conditions. We might expect a higher number of runs in Condition II, since this condition contains no assignments to work with. Table 4 shows, however, that the number of runs is higher in Condition I. A Mann-Whitney test revealed differences between the experimental conditions on the average number of runs (z-score = -1.99 $p < .05$).

Table 4. *Average number of runs over the two conditions*

Condition	Number of runs
I (assignments)	175.3 (<i>sd</i> = 69.7)
II (no assignments)	125.5 (<i>sd</i> = 52.7)
Overall average	154.7 (<i>sd</i> = 67.0)

Number of assignments and explanations used

Subject made extensive use of assignments and explanations. Almost always all explanations were consulted and also assignments were very popular. In condition II there was an almost maximum use of explanations for all students, in Condition I students used on the average less explanations, but they also had assignments available which they used very frequently.

3.5 Cognitive load

Subjects' appreciation of the environment was measured by means of the pop-up electronic questionnaire. For condition I, subjects' appreciation of three aspects of the environment were gathered: subject matter difficulty (is the subject matter seen as easy or difficult), system usage (is working with the system easy or difficult), and usability of tools (do tools, here the assignments, make the learning task easier or more difficult). For condition II, no ratings were gathered on the usability of assignments, since the students in this condition had no assignments available to them. Subjects scores could range from 5 to 100, where 100 was the 'negative' side, meaning that the subject matter was extremely difficult, the environment was extremely difficult to work with, and tools made the task much more difficult.

In condition I the cognitive load questionnaire was filled in on the average 9.35 times, with a range of 3 to 20 times. In condition II the average was 21.7 times and the range was 11 to 36 times. Due to technical/procedural issues the frequency of the popping-up of the questionnaire was not the same for all students, and for a number of students it was much higher than the planned frequency of every 20 minutes. As a consequence some subjects clicked away the questionnaire without filling it in, resulting in ratings of 0. These instances were not used when calculating mean scores. For reasons we mentioned, results that we report here should be considered preliminary and interpreted with caution.

The scores at the cognitive load measures over the two conditions are given in Table 5.

Table 5. *Average scores on the three measures of 'cognitive load'*

Condition	Difficulty	System use	Tools
I (assignments)	41.4 (<i>sd</i> = 11.6)	28.3 (<i>sd</i> = 13.8)	32.6 (<i>sd</i> = 14.3)
II (no assignments)	54.1 (<i>sd</i> = 19.8)	30.9 (<i>sd</i> = 17.9)	-
Overall average	46.6 (<i>sd</i> = 16.5)	29.4 (<i>sd</i> = 15.4)	-

A Mann-Whitney test revealed no differences between the experimental conditions on the difficulty rating at the $\alpha < .05$ level (z -score = -1.71, $p < .10$), and no differences between the conditions were found on the appreciation of the system (z -score = -.25, $p > .10$).

Table 6 shows that the correlation between system use and tools is of a moderate level, thus indicating that the two measures assess different aspects of cognitive load. The correlation between difficulty and system use is high, suggesting much overlap between these two aspects of cognitive load for the students in condition I (see Table 6). When we calculate this correlation across the two conditions it drops to a non significant correlation of .22 ($p > .10$).

Table 6. *Correlations between the 'cognitive load measures' in Condition I*

	System use	Tools
Difficulty	.87 ($p < .01$)	.26 ($p > .10$)
System use		.59 ($p < .05$)

3.6 Interaction of behaviour and learning results

There is little to say on the relations between use of instructional measures (assignments, explanations, model progression) and scores on the knowledge tests. All the learners used the support measures available to them to the maximum extent and hardly any variation between subjects existed. The calculated correlations are displayed in Table 7 and Table 8.

Table 7. *Correlations between post-test score and number of explanations and assignments used: the correlation with explanations is calculated across condition I and II, the one with assignments just within condition I*

post-test score	number of explanations used	number of assignments used
WHAT-IF post-test scores	.15 ($p > .10$)	.07 ($p > .10$)

Table 8. *Correlations between knowledge scores (post-test) and number of runs used and time spent*

post-test score	number of runs	time spent
WHAT-IF post-test scores	.05 ($p > .10$)	.23 ($p > .10$)

The figures in these tables show that none of the correlations reaches a level of significance below .05. Taken over the two conditions, we can therefore not conclude

that a higher number of runs and a longer time spent in the environment are associated with higher scores.

We further computed the correlations between the cognitive load measure and the WHAT-IF pre- and post-test scores. This is displayed in Table 9.

Table 9. *Correlations between pre- and post-test scores and measures of cognitive load: the correlations with difficulty and system use are calculated across condition I and II, the correlation with 'tools' is only calculated within condition I*

test	difficulty	system use	tools
WHAT-IF pre-test scores	-.44 ($p < .05$)	.04 ($p > .10$)	-.17 ($p > .10$)
WHAT-IF post-test scores	-.42 ($p < .05$)	-.05 ($p > .10$)	-.05 ($p > .10$)

We can infer from the table that the perceived difficulty of the subject material correlated with the pre- and post-test scores, while system appreciation did not. This suggests again that different aspects of cognitive load can be captured with the used measure and that the students are capable of producing sensible ratings.

Finally, we computed the correlations between the cognitive load measure and the WHAT-IF post-test score while we controlled for the pre-test scores. This control was introduced since pre-knowledge influenced the perceived difficulty. The partial correlations are displayed in Table 10.

Table 10. *Partial correlations between post-test scores and measures of cognitive load: the correlations with difficulty and system use are calculated across condition I and II, the correlation with 'tools' is only calculated within condition I*

test	difficulty	system use	tools
WHAT-IF post-test scores	-.26 ($p > .10$)	-.09 ($p > .10$)	-.02 ($p > .10$)

From this table we can read that when controlled for pre-test score the correlation between the difficulty rating and the post-test score disappeared.

4. Discussion

The most salient, and promising, conclusion from this study is that adding assignments to the environment worked. Learners in the condition that contained assignments showed a larger gain in scores on the WHAT-IF post-test compared to the WHAT-IF pre-test, the learners who instead had text pointing to specific parts of the model. Adding assignments did not work for structural knowledge or 'transfer' knowledge.

Log data showed that assignments were used intensively. Informal observations during the experiment showed that students, who were offered to work on the assignments, showed a rather concentrated and intensive learning behaviour during the time they were working. For the control group, who did not receive any assignments, the learning activity was quite obviously different. They asked more often for help and made the impression of being less motivated than the group that received assignments. They had to be specifically motivated to go on and not to give up too early.

An accompanying result is that adding assignments did not significantly increase time spent with the simulation. Also cognitive load was not increased by adding assignments.

For complex (learning) environments, cognitive load might be an important factor. In this study we measured cognitive load by means of an electronic questionnaire that popped up once in a while. Three different aspects of cognitive load were measured: subject matter difficulty, use of the environment, and usability of the instructional measures. The students' appreciation of working with the two environments did not differ while there seemed to be a difference in perceived difficulty of the material, which in turn might be due to differences in helpfulness of instructional measures. As we did not collect ratings on the helpfulness of the tools in one of the two experimental conditions, we do not have data to strengthen this idea. In any case, there was no indication for a higher cognitive load as a result of adding instructional measures to the environment, but some evidence for an opposite effect was present. Caution, however, with these data is needed, since a number of times subjects did not fill in the questionnaire.

An interesting observation concerned the dependence of the students on assignments. The number of proposed assignments is drastically reduced from 17 for the first model progression to 3 for the last level. In spite of this reduction, which was intended to stimulate exploring activities on the side of the students, such an activity was hardly seen. Practically all participants stopped their work when the last assignment was finished. This effect might be considered as a negative side-effect of assignments, and needs further study.

An overall conclusion from this study is that learning in a pure exploratory environment can take place, however, with difficulties and the risk to get lost and de-motivated. Assignments are a promising means to guide students, to keep up their motivation, and to increase certain aspect of the learning results.

5. References

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Acknowledgement: The current study was performed within the SMISLE project, partially sponsored by the European Commission in the DELTA program as project D2007. The SMISLE project is currently continued in the SERVIVE project also partially sponsored by the European Commission (project ET 1020).