

# Learning processes of students working with a computer simulation in mechanical engineering

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**LEARNING PROCESSES OF STUDENTS  
WORKING WITH A COMPUTER SIMULATION  
IN MECHANICAL ENGINEERING.**

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## Abstract

The general purpose of this study was to gain insight in the learning process of students working with a computer simulation as it is used in a practical educational setting. This learning process is described in terms of detailed learning processes. Additionally, information was gathered on issues at which students need help and on the tutorial actions that are given.

The domain involved in this study is a subdomain of mechanical engineering: control theory and the computer simulation used is PCMatlab ((c) Mathworks). Subjects in the experiment were 8 third-year students of mechanical engineering, working in pairs. Thinking-aloud protocols were used to gather data.

An analysis scheme of learning processes was developed. It consists of 12 categories: looking for and/or finding of information, planning, transformation of information, model exploration, predicting, manipulating, output interpreting, verifying, evaluating, generalizing, operations of PCMatlab and general off-task remarks. Although subjects were given an assignment which served as a general guidance for their actions it showed that:

1. Apparently, those processes relating to the problem solving process, e.g. planning and evaluating, were not utilized systematically and effectively enough.
2. Those processes characteristic of working with simulations, e.g. model exploration, predicting, manipulating and output interpreting were not fully employed.
3. Subjects tended to spend a major part of their actions on the operation of PCMatlab.
4. Subjects needed quite a lot of extra information, especially domain knowledge.

It can be concluded that students did not profit maximally from learning with this simulation program. The educational implications of the results will be discussed.

## 1. Introduction

Within the field of Computers in Education interest is increasing for computer simulations. A computer simulation is a program which incorporates a model of a process, phenomenon, system, an apparatus etc. The computer simulation can give a description of the state of the model and show its state changing, through time and/or as a result of intentional manipulations. The user is able to control input values of the model and examine the resulting changes in output. A second way of working with a computer simulation is 'modelling' (Ross, 1986). Here the user may not only vary the values of variables and parameters, but may also interfere with the properties of the model. The user may add, delete or modify the relations of variables and parameters in the model. In the present study 'modelling' is not our point for attention. We only refer to the first way of working with a computer simulation.

When used in an educational setting, learners working with a computer simulation are involved in a complex learning process. They can examine the model in a computer simulation in a very explorative, (inter)active way. Learning with computer simulations can be considered as an open learning environment. Learning in such an environment puts a high demand on learners especially because it requires "deep" learning processes (de Jong & Ferguson-Hessler, 1989). Therefore, information on the learning processes students apply is fairly crucial in assessing the impact of simulation based learning.

The general purpose of this study was to gain insight in the learning processes of students working with a computer simulation, with learning processes restricted to the cognitive (trans)actions of the learner. Additionally, information was gathered on issues at which students need help and on the tutorial actions that are given. An intentional choice was made to perform the study in a practical educational setting. Furthermore, it must be emphasized that the study is intended as an exploratory study.

This study was performed as a collaboration between psychologists of the Department of Philosophy and Social Sciences and engineers of the Department of Mechanical Engineering.

## 2. Theoretical background

Currently there is no comprehensive theory on learning with computer simulations. Such a theory must be developed on the basis of inter disciplinary cooperation between cognitive psychology, educational psychology and information theory. For the present study cognitive and educational psychology have made the contributions to the theoretical background.

Different, but related, approaches are taken. Learning with computer simulations is labelled by Hartley (1988) as a process of investigation, Kearsley (1985) considers it as active learning, Min (1987) regards it as discovery learning, Hille (1980) as a problem solving process, and Samson (1986) as a combination of knowledge acquisition and problem solving.

The viewpoint of Min (1987) which labels learning with computer simulations as discovery learning is quite feasible. The essential feature of discovery learning (Ausubel et al., 1978) is that the content of what is to be learned is not given, but must be discovered by the student before it can be meaningfully incorporated into the student's cognitive structure. This is extremely conceivable with computer simulations. So, discovery learning as well as working with computer simulation both allow for and encourage active experimentation and exploration. The learner can discover important concepts, principles, find solutions to problems etc.

To elaborate the viewpoints of Samson (1986) and Hille (1980) a general concept of problem solving is helpful. With regard to problem solving there has been an extensive number of studies. The classification of Mettes and Gerritsma (1986) is a suitable summary of the relevant learning processes in problem solving. They describe three general stages of the problem solving process:

1. Preparation: orientation and planning
2. Execution: transformation, determination of the solution and evaluation
3. Control: interpretation of results.

These stages resemble a recent classification of Reigeluth and Schwartz (1989). They distinguish three phases in the process of learning with simulations: acquisition, application and assessment. However, it must be stressed that they have a limited view on simulations and take only into account simulations that teach principles and procedures. According to them the learner must first acquire a basic knowledge of the content or behaviour of the simulation. Then the learner must master to apply this knowledge to the full range of relevant cases or situations. Generalization, automatization and utilization are required for this stage. The final stage is (self)assessment of what has been learned.

More specific studies on learning with computer simulations can be found in literature as well. DeNike (1976) reports that most of the studies have investigated the impact of computer simulations in terms of factual knowledge, motivation and attitudes. He states that the results of these studies have been conflicting and inconclusive. Smith (1987) reviewed 25 years of research and development in media/computer-based simulations with regard to feasibility, presentation mode(s) and benefits. He concludes that media/computer-based simulations have considerable potential but are not seriously evaluated. So, studies that really examine the specific learning processes are sparse.

Recent evaluative studies attempt to specify the effectiveness of computer simulations on more explicit learning processes. Rivers and Vockell (1987) have been doing research on scientific problem solving. The results of this study suggest that computerized simulation can help high school students substantially increase their problem solving abilities. This may occur because students using computers have more opportunities for

active, reinforced practice to help them develop a generalized skill in scientific problem solving. Though the identification of the learning processes was not a specific purpose of this study it inherently considers working with a computer simulation as a problem solving process. Thereby, according to Rivers and Vockell the generalization or transfer of the problem solving strategies to other situations is an important outcome of learning with computer simulations. Therefore, it can be inferred that generalization is also an important learning process to be performed by the learner.

Lavoie and Good (1988) have studied the prediction skills of students with a computer simulation. This study led to the identification of various program exploration and prediction behaviours of successful predictors. Successful predictors tend for example:

- *to predict how a given independent variable will relate to a given dependent variable during program exploration, test out the relationship and then judge the predictive success*
- *to plan future action during program exploration.*

Although some of these, as they call it "behavioural tendencies" are related to the learning processes, most of them are limited to prediction capabilities of the student. Furthermore, there is a difference in the level of detail. Next to the more extensive behavioural tendencies as mentioned above, Lavoie and Good give excessively detailed behavioural tendencies such as, procedures in which a learner can vary the independent variable(s) systematically or methods to identify the important dependent variable(s) and conditions. For example:

- *to return independent variable to a base line condition*
- *to look for the best and worst conditions for the dependent variables.*

The excessive distinction between tendencies is also given on the basis of different relationships between the independent and dependent variable(s). For example:

- *to wonder about, try to find, identify, and use bi-directional relationships (relationship between independent-dependent variable)*
- *to wonder about, try to find, identify, and use ratio relationships (relationship based on quantitative comparisons over a range of independent-dependent relationships).*

In sum, existing studies do not address the specific learning processes that we are looking for, but they can function as a basis for defining them. First, the learning process is mainly characterized as problem solving or discovery learning. Second, the general classification into three stages (preparation, execution and control) is to be found in specific literature on working with computer simulations as well as in general literature on problem solving.

### **3. Methods and techniques**

This section starts with information on the domain of control theory. Second, some general information on PCMatlab will be given and the computer simulation will be described in the context of the course in control theory. Following, the regular educational setting is reported because this study is realized in a practical situation. Finally, the subjects are characterized and the experimental setting is explained.

#### *Domain*

The domain involved in this study is a subdomain of mechanical engineering: control theory. The primary educational goal of the course in control theory is to teach students how to regulate models of systems. The systems are mechanical systems consisting of several masses, dampers and springs. Students are taught to regulate the systems by the mean of a control device, of which they can alter the control law (see figure 1). The

regulation influences the relations between the input and output signals of the system. Input- and output signals are for example displacement, velocity or acceleration. The purpose of the regulation is to obtain an optimal functioning of the system. This is expressed by:

- a. preferences of the students, or
- b. some prescribed or mechanical requirements, or
- c. the state of the system (e.g. stable or instable).

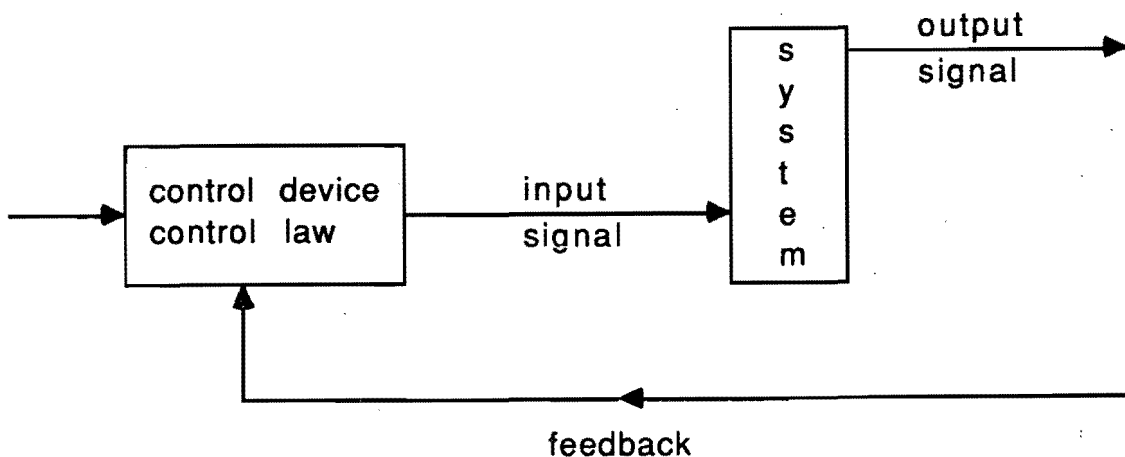


Figure 1: General model used in control theory.

#### Computer simulation

The computer simulation used is PCMatlab ((c) Mathworks). PCMatlab runs on IBM compatible machines, using a math coprocessor. Originally it is not developed for educational purposes but is intended for scientific and engineering numeric calculations and graphics. It can be considered as a type of spreadsheet for complex numeric calculations. These calculations would otherwise be almost impossible to do by hand or would take an enormous amount of time. On the other hand, it can also be considered as a simulation tool by which a simulation of a system can be constructed and operated. Apart from the control theory, it can, amongst others, be used for linear algebra, matrix calculations and digital signal processing. PCMatlab offers the student a range of standard functions and input of data is realized through the use of expressions. The program can produce both numeric and graphic (2- and 3-dimensional) output.

In the particular context of the control theory, specifications of the system and the control law can be given as input by series of differential equations. Once the mechanical system is given as input nothing will be changed in that part of the model. Thereafter the

only input that is given by the students is the control law or are the parameters of the control law. In other words, the mechanical part of the model is fixed and manipulation only takes place in a specific part of the model. This can result in the following types of output:

- a. graphics of variables which describe the relations between input signal and output signal
- b. numeric data which represent the feedback of the regulation.

In comparison with the traditional situation in teaching control theory, utilization of a computer simulation as PCMatlab makes it possible to present the students more complex mechanical systems.

#### *Educational setting*

The educational setting in which PCMatlab is used, is a computer lab, given parallel to the lectures. The lectures offer the theoretical background of the control theory and serve as a foundation for the computer lab. The computer lab consists of one session (3.5 hours) a week for a period of five weeks. Students work in fixed pairs and are free in their choice of the partner. Usually about 10 to 15 pairs are working in a classroom at the same time with two or three tutors available.

For each session the students are given an assignment. The assignment not only defines the system to control but also guides the students in the exploration of the model. Guidance is realized by prescribing the actions (e.g. manipulating, verifying) in domain specific terms and giving the requirements for the regulation. However, the guidance is not aimed specifically at the stimulation of exploratory behaviour.

The educational goals of the computer lab are:

1. To acquire knowledge of and practise the regulation of models of systems.
2. To acquire skills in the operation of PCMatlab.

Although the second goal is important, the first goal is considered as the primary goal of the computer lab. The subject is taught as a third year course at the Eindhoven University of Technology but students already have experience working with PCMatlab during a second year course.

#### *Subjects*

Subjects in the study were 8 third-year students of mechanical engineering, working in pairs. The 4 pairs of subjects were selected at random and participated on a voluntary basis. They received no credit points or financial compensation for their participation.

#### *Experimental setting*

The study tried to imitate the natural setting of a computer lab session as closely as possible. The original assignment was not altered and subjects were allowed to work in pairs. For experimental control, pairs of subjects worked together in separate rooms. The tutor was waiting in an other room and was called for whenever the subjects asked for assistance. This was done on purpose, in order to make sure that the verbalization did not influence the tutors actions. Moreover, subjects are now urged to try to solve their problems themselves first, before asking for the tutor.

Thinking-aloud protocols (Ericsson & Simon, 1984) were used to gather data. Furthermore, we had log-files (on-line registrations of subjects input and program output) and the notes subjects made. In order to register the tutor intentions, we asked the tutor to write down his idea of the subjects problem, and the reason why he reacted as he had done. In sum, the data gathered are:

1. thinking aloud protocols
2. tutor notes
3. subjects notes
4. on-line logfiles.

The thinking aloud protocols are the main data source for determining the learning processes. The last two sources were only used to sustain the analysis of the protocols and will not be reviewed in this paper. The tutor notes were used to examine the tutor-student interactions.

The protocols of the 4 pairs of subjects were transcribed and analyzed with the developed analysis scheme. This was done in cooperation with a domain expert to make sure that domain related reflections of the students would be properly interpreted and analyzed. The same method was used in de Jong and Ferguson-Hessler (1989) and showed a very satisfactory interrater reliability.

No discrimination has been made between the subjects within each pair because it was impossible to discriminate between the subject's line of thought. Therefore a pair of subjects was the unit of analysis. Miyaki (1986) considers thinking aloud in pairs a solution to the unnatural aspect of the traditional protocol. In a pair subjects are not forced to talk aloud in a situation in which they would normally be silent. Miyaki labels this new experimental method for gathering verbal reports "constructive interaction".

#### 4. Results

##### *Analysis scheme for learning processes*

In order to describe the learning processes the subjects use, we developed an analysis scheme that classifies the processes. This scheme is not only regarded as a tool, but can also be seen as a result from the experiment, because it gives, to our idea, a fairly complete listing of processes that can be used when interacting with a computer simulation. It certainly bears some generality to situations in which computer simulations are used for other domains and types of simulation models.

The analysis scheme (see Table 1) is developed from the information processing perspective and was constructed on the basis of research on problem solving, study processes and the specific studies on working with computer simulations.

The general stages of the problem solving process, preparation execution and control (Mettes and Gerritsma, 1986), served as a framework for the analysis scheme. On the one hand these stages can be found in the developed analysis scheme. For instance, the categories 3 through 7 characterize the execution stage. On the other hand a process can fulfil several purposes. For example, category 4: model exploration, can occur within the three different stages. It can be used for the preparation stage to make an orientation of the model. Eventually, category 4 can also be used for the control phase where evaluation of the results should be considered in relation to the model. So, the processes are not sequentially but can occur repeatedly, simultaneous or parallel, throughout the total learning process.

For a further differentiation of the execution stage, the study of Lavoie and Good (1988) contributed some of the processes like predicting and manipulating. Generalization was mentioned by Reigeluth and Schwartz (1989) and Rivers and Vockell (1987). The research of Ferguson-Hessler and de Jong (1989; in press) on study processes inspired some categories. A specific category was reserved for the operation of the program PCMatlab and a final category for general and off-task remarks.



The scheme was put to the test with the protocols, resulting in several modifications and alterations. The final analysis scheme consists of 38 processes ordered into 12 main categories. Some categories relate to the problem solving process e.g. planning and evaluating. Other categories appear to be more specific for working with computer simulations e.g. predicting and manipulating. In table 1 the 12 categories are described.

Table 1

*Analysis scheme for learning processes (main categories)*

Category	Definition
1. Looking for and/or finding of information	On the basis of a detected deficiency of information, looking and/or finding of information in memory or books etc.
2. Planning	To devise a scheme/outline for the exploration of the simulation.
3. Transformation	To transform information as in reading and making notes.
4. Model exploration	To examine the model relations carefully and making the relation within the model explicit. This can be done with or without a scale and on qualitative or quantitative basis.
5. Predicting	To predict the expected model relations as a result of manipulating. This can be done on qualitative or quantitative basis.
6. Manipulating	To handle, control or change the (values of the) variables or parameters.
7. Output interpreting	To give one's understanding of the meaning of the output on a conceptual level. This means that no explicit model relations are given. Interpreting can be done by comparing with other known graphs or data (output from previous assignments or graphs/data familiar from books/lectures).
8. Verifying	To control or check the accuracy or correctness beyond the syntax level.
9. Evaluating	To determine the value of results etc.
10. Generalizing	To draw, infer or induce general principles or inferences.
11. Operations of PCMatlab	Processes for the operation of PCMatlab (user-interface).
12. General	General and off-task remarks.

*Learning processes*

Because of the small sample size and the exploratory character of this study, data analysis is limited to frequencies as presented in Table 2. It can be seen that there is a high variation in, total numbers of processes applied, between protocols. Therefore Table 3 presents the relative frequencies.

Table 2

*Frequencies of the main categories of the analysis scheme for the protocols (1 - 4)*

Category <sup>1</sup>	Protocol					Σ	average
	1	2	3	4			
1	69	92	79	108	348	87	
2	46	38	15	33	132	33	
3	16	26	16	21	79	19.8	
4	19	2	5	18	44	11	
5	8	2	1	1	12	3	
6	4	3	5	4	16	4	
7	75	20	6	38	139	34.8	
8	24	10	29	28	91	22.8	
9	24	17	11	14	66	16.5	
10	1	0	0	1	2	0.5	
11	204	200	157	237	798	199.5	
12	8	22	2	21	53	13.3	
Σ	498	432	326	524	1780	445	

Table 3

*Relative frequencies of the main categories of the analysis scheme for the protocols (1 - 4)*

Category	Protocol				
	1	2	3	4	average
1	.14	.21	.24	.21	.20
2	.09	.09	.05	.06	.07
3	.03	.06	.05	.04	.05
4	.04	<.01	.02	.03	.02
5	.02	<.01	<.01	<.01	.01
6	.01	.01	.02	.01	.01
7	.15	.05	.02	.07	.07
8	.05	.02	.09	.05	.05
9	.05	.04	.03	.03	.03
10	<.01	<.01	.00	<.01	<.01
11	.40	.46	.48	.45	.45
12	.02	.05	.01	.04	.03

<sup>1</sup> The numbers of the categories correspond with the numbers in Table 1.

We will now present an overview of the results per category. Because of small sample size a statistical comparison between subjects is not possible, therefore average relative frequency in percentages<sup>2</sup> are discussed.

### 1. Looking for and/or finding of information

The subjects need for extra information was quite high (20%) especially for domain knowledge. The importance of domain knowledge in using a computer simulation has been emphasized by others. According to Hartley (1988) knowledge provides a guiding framework for the generation and testing of hypotheses about the model. The study of Lavoie and Good (1988) also showed that successful predictors working with a computer simulation generally had high initial knowledge on the subject matter.

### 2. Planning

Although Lavoie and Good (1988) present planning as one of the behavioural tendencies of successful predictors working with a computer simulation, it is not specific for computer simulations but applies to general problem solving conditions (Mettes & Gerritsma, 1986). Therefore, general planning qualities of students in the preparation phase of a problem solving situation are essential.

In our study planning was done in 7% of the actions and was not always done intentional. In some cases subjects attempted different approaches without a specific purpose in mind or subjects tended to use planning on short interval instead of overall strategic planning.

### 3. Transformation of information

In 5% of the actions subjects used this category. According to Lavoie and Good (1988) making notes is one of the important behavioural tendencies of successful predictors working with a computer simulation, because it facilitates identification of relationships by allowing comparisons to be made among several computer runs without having to rely on memory. In our study however, the subjects had to hand in a report for their evaluation. Therefore, the notes they made were mostly for this report and probably not as a reminder for themselves.

### 4. Model exploration

Lavoie and Good (1988) report this category as an important behavioural tendency of successful predictors working with a computer simulation. However, for the present domain, the emphasis on model exploration is not so important. Once the model of the system is given students only explore the possibilities of the control device. Most of the model explorations that were made by the subjects related to the output and had no relations within the part of the model that represents the mechanical system. But however, at some points in the assignment it is preferable to make these model relations explicit. Nevertheless, subjects sometimes failed to execute this category. In 2% of the actions subjects performed an exploration of the model.

White and Frederiksen (1987) differentiate between qualitative and quantitative models. Although the presented model in the assignment is described and operated in a quantitative way, the subjects only gave qualitative model relations.

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<sup>2</sup> Notice that the percentages mentioned are not equal to the amount of time spent on the process. It is a percentage of the total numbers of actions.

### 5. Predicting

This category was the main interest of the study by Lavoie and Good (1988) and they therefore presented subjects specific prediction problems. In our case the assignment did not particularly requested a prediction but to be able to manipulate some parameters in a valid way the students had to make certain predictions of the output. It is noticeable that subjects not only made few predictions (1%), but only predicted after some output was given. As with category 4, predictions were only given on qualitative basis.

### 6. Manipulating

In 1% of the actions subjects manipulated variables or parameters. Lavoie and Good (1988) describe several behavioural tendencies of successful predictors that fit in this category e.g.: to return independent variables to a base line condition in order to maintain a more consistent base of comparison for identifying effects. It is remarkable that in our study subjects seem to have trouble with the sheer fact that they were allowed to manipulate. The tutor had to draw the subjects attention to the fact that they could actually choose the values of the parameters according to their preferences. Knowing this, the subjects only manipulated as much as the assignment asked them to do. Maybe on the contrary of what is expected (Bork & Robson, 1972) subjects showed no own initiative at this point.

### 7. Output interpreting

Output interpreting (7%) was mostly done by comparing output with other known graphs or data such as output from previous assignments or graphs/data familiar from books/lectures. With regard to graphic output, Mokros and Tinker (1987) state that graphing allows us to use our powerful visual pattern recognition facilities to see trends and spot subtle differences in shape. McKenzie and Padilla (1984) explain that graphs are an important tool in enabling students to predict relationships between variables and to substantiate the nature of these relationships. Therefore, this category seems to be a very important one especially in relation to the categories 4 and 5: model relation and predicting. In our study however, subjects seem to have quite a lot of trouble with the interpreting of graphs and data. Subjects quite frequently requested help on the interpreting of output.

### 8. Verifying

Verifying is not a specific category for computer simulations but applies to general problem solving situations. 5% of the actions were utilized for this category. Most of the actions in this category refer to the input. In more than half of these actions it was done at initiative of the subjects.

### 9. Evaluating

Determining the value of results, by evaluating, also applies to general problem solving qualifications of the subjects. They performed evaluations in 3% of the actions. Partly this was done after interpreting the output but it was also done without making an interpretation. This means that subjects just stated that the output was correct and continued with the rest of the assignment. In more than half of the actions in this category subject evaluated the output. The solution strategy was hardly evaluated.

### 10. Generalizing

Because a computer simulation is mainly a representation of (a part of) reality some generalizing activities are expected or desirable. In the present domain it is possible to

transfer the results by relating to the original mechanical system or to other models. Maybe because the assignment did not invite the subjects to do this, they hardly generalized (less than 1%). According to Rivers and Vockell (1987) generalization of the problem solving strategies is an important outcome of working with computer simulations. It is plausible that the subjects performed no generalizations of the problem solving strategies because they also lacked to evaluate them.

#### 11. Operations of the PCMatlab program (user-interface)

Although the operation of PCMatlab is one of the educational goals of the computer lab, an average of 45% of the total amount of actions is quite a high percentage. As the program is originally not developed for educational purposes but for industrial usage, its user interface is not geared towards students. A lack of enough practical experience with PCMatlab handicapped most of the subjects. Some subjects were so engrossed in the operation of PCMatlab and the correction of syntax errors that the primary goal of the computer lab was overlooked.

#### 12. General

This category was reserved for off-task remarks as conversation on the weather, friends etc. It showed that subjects worked quite concentrated, only 3% of the total number of actions fell into this category.

#### *Questions for help and tutorial actions*

To study the issues at which students need help and on the tutorial actions that are given, we had at our disposal the protocols which also included the tutor-student interactions and the notes the tutor was asked to make.

It showed that students needed quite a lot of extra information, especially domain knowledge. In the tutor-student interactions almost 30% of the questions of the subjects were related to domain knowledge. Furthermore, subjects seem to have quite a lot of trouble with the interpreting of graphs and data. In 25% of the student-tutor interactions subjects asked help on the interpreting of output. Additionally, the subjects had difficulties with the manipulation of parameters. They declined to see that they could actually choose the values of the parameters according to their preferences. Other questions related to the operation of PCMatlab and the procedure.

As most of the questions involve domain knowledge, the subject expected the tutor to explain the missing knowledge. Usually, the tutor did not lecture but tried to stimulate the subjects to find the answers themselves. For instance, by asking questions, making relationships with the model or simply by referring to a quotation in the textbook.

With regard to the interpretation of the output, subjects mostly wanted feedback on results they had obtained. In some cases the subjects questioned the correctness of the output but in other cases they failed to understand the meaning of the graph or data. Generally, the tutor gave extensive feedback and suggestions for correction.

The questions referring to the manipulation of parameters related to the procedure to be followed. In general, procedural difficulties as well as difficulties in manipulating the parameters made subjects feel totally lost. They hoped for the tutor to tell them the following operation. The more general procedure difficulties were merely discussed in relation to domain knowledge. With the manipulation difficulties, the tutor had to emphasize that the subjects could choose the values of the parameters according to their preferences.

As for the operation of PCMatlab, subjects neglected to consult the manual and on-line help function. Repeatedly, the tutor had to hint the subjects to study these sources.

## 5. Conclusions and discussion

The primary purpose of this exploratory study was to gain insight into the learning process of students working with a computer simulation in a practical educational setting. Based on a collection of theoretical and experimental studies we found in literature, a list of specific learning processes for describing learning with computer simulations was developed. This list was used as an analysis scheme for analyzing thinking aloud protocols of students working with a computer simulation in the domain of mechanical engineering. On this basis the scheme was adapted and used to analyze the protocols from the same domain.

Our conclusions fall into four headings: an evaluation of the analysis scheme, a discussion of the learning behaviour of the students, an evaluation of the research method used, and suggestions for further research.

### *Evaluation of the analysis scheme*

As we stated in the introduction, studies identifying precise learning processes that take place when learning with a computer simulation are sparse. The analysis scheme presented here is a first attempt to create a comprehensive list. Of course, the data it is based upon, both theoretical and experimental, are not extensive. We therefore expect the scheme to develop when it will be used more frequently, as we are doing at the moment in a second study. Use of the scheme at other domains than mechanical engineering will also probably help to improve it. At present we can think of two directions of change:

#### a. Level of detail

The scheme as it is now, may need more detail for some of the learning processes. For example the category 'model exploration' is in itself a complicated process that needs more extensive study. The more general problem solving processes may also need adjustments for the specific situation of working with a computer simulation. For specific purposes, such as the development of Intelligent Tutoring Systems (Hijne & de Jong, 1989), a more detailed description is necessary.

#### b. Multiple views

Our scheme was developed with a general purpose in mind: describing the learning process. However, we think that categories have to be described in such a way, that by combining them, a scheme can be used for testing hypotheses of different kinds. As an example we can take the fact that so called regulation processes are now scattered around in the scheme mixed with so called processing activities (Vermunt & Rijswijk, 1988), whereas a research question aimed at this processes, might need a different combination of processes.

### *Learning processes of the subjects*

In the practical educational setting of this study subjects had quite a lot of difficulties in working with the computer simulation. It appears that they were not very familiar with problem solving and discovery learning in an open learning environment. Maybe traditional education is still too much based on reception learning. Also, the assignment given to the subjects was not explicitly aimed at provoking an exploratory attitude. In summary, we can conclude for the learning processes applied:

1. Apparently, those processes relating to the problem solving process, e.g. planning and evaluating, were not utilized systematically and effectively enough.
2. Those processes characteristic of working with simulations, e.g. model exploration, predicting, manipulating and output interpreting were not fully employed. In this respect, the assignment did not function as a guidance but as a restriction.
3. Subjects tended to spend a major part of their actions on the operation of PCMatlab. It is obvious that the user interface is not geared towards students. It is quite feasible that because of this there was not enough time and attention for the operation of the other, more specific, learning processes.
4. Subjects needed quite a lot of extra information, especially domain knowledge. Furthermore, help of the tutor was required with manipulation and output interpretation. The tutor presented a diverse range of tutorial actions e.g. explaining, giving feedback, asking questions and hinting.

In sum, subjects did not profit from this simulation maximally. Laurillard (1987) has already recognised that students are likely to exhibit irrational analysis and do not necessarily carry out a logical analysis of results when working with computer simulations. A question is whether students can be helped to acquire more benefit from a computer simulation. In Section 6 we will discuss some possibilities to provide more help and guidance to students working with a computer simulation.

#### *The method*

The method we used was thinking aloud in pairs. We have considerable experience in being an experimentator and analyzer of thinking aloud protocols, and it was striking that thinking aloud in pairs was a very natural way of gathering thinking aloud data compared to students thinking aloud at their own. Less experimentator encouragement was necessary. Miyaki (1986) criticism on the traditional thinking aloud protocols, where a subject is forced to talk aloud in a situation in which he would normally be silent, is hereby endorsed. The other data sources (students notes and on-line log files) were helpful in reconstructing the processes. For the analysis of tutor-student interactions more specific methods are necessary.

#### *Future research*

The conclusions drawn in the previous subsections lead us to the following intentions for future research:

- a. Further identification and differentiation of the relevant learning processes, resulting in an evolving analysis scheme of learning processes.
- b. A profound study on tutor-student interactions.
- c. Developing methods, such as guidance, to help students to benefit from computer simulations. This guidance must be designed in relation to the intended learning processes. Eventually, it can result in directives for the design of guidance on specific learning processes.

The collaboration between the Department of Philosophy and Social Sciences and the Department of Mechanical Engineering creates the environment for further research on these aspects.

## 6. Educational implications

### *Operation of PCMatlab*

Although the operation of the PCMatlab program is not the main interest of this study and will not be the interest of future research, the results show that it needs some consideration. To meet the main educational goal of the computer lab it is important to reduce the PCMatlab operations to a reasonable level and to increase the PCMatlab experience of the students. First, this can be achieved by adjusting the manual to the students needs. Second, the computer lab can be extended or utilized for other (sub)domains. Third, a reconsideration of the structure of the computer lab is necessary. Currently, the two educational goals of the computer lab are intertwined. Maybe more general attention should be given to the operation of PCMatlab or it should initially be practised with a less complex domain. Finally, the suggestions on guidance discussed hereafter are also appropriate. The Department of Mechanical Engineering is considering these possibilities and in our following study some of these are already taken into account.

### *Guidance*

On the basis of the results of this study it can be concluded that students did not profit maximally from learning with this simulation program. Guidance (on-line or off-line) might help in improving this situation. Several studies discuss the design of guidance.

Smith (1987) presents several guidelines for developers of classroom simulations. One of them is that training time may be shortened by providing students with specific guidance (prompts) for "correct" responses. Kearsley (1985) explains that well-constructed simulations can guide or coach the learner to minimize inefficiency.

Steinberg (1984) gives several guidelines for designing simulations. One implication is that the students have to be provided with sufficient guidance or advice, dependent on the purpose of the simulation, to direct their exploration and attain the stated goals. According to her guidance has two aspects:

1. instructions about the technical aspects, the mechanics of executing the simulation
2. guidance on how to learn from it.

Furthermore, guidance may be provided on-line or off-line by printed materials, classroom discussions, or any combination thereof. On-line guidance might be operated by: suggestions about what to do, questions about findings, hints, corrective feedback or debriefing.

Off-line guidance includes:

- printed materials: e.g. questions to interpret the data (ask for relation decision-goal).
- classroom-demonstration and discussion presented before the students do the simulation individually. In this respect Hartley (1988) states that students have a need for explanation on (unsuccessful) decisions and a need for direct discussions afterwards with teaching staff.

In our view, Steinbergs functional separation of on-line and off-line guidance is not obvious. Some of the functions can be fulfilled both by on-line and off-line assistance.

The only controlled experiment on guidance with computer simulations we know of was performed by Rivers and Vockell (1987). They used two conditions in their study of stimulation of scientific problem solving by computer simulations: guided discovery and unguided discovery. The guided discovery condition contained brief paragraphs of general strategies to use as the student solved the problems presented in the simulation. For example:



- It is a good idea to change only one variable at a time.
- Use this program to test your hypotheses.
- Look for patterns or relationships as you systematically change the variables.

The guidance was supplied at a controlled pace as part of the computer program and students could not by-pass its presentation. Students were permitted to re-examine previous screens upon request. An accompanying student manual provided study questions and problems to solve. One of the conclusions of the study was that students using the guided version developed the skills in critical thinking and scientific thought processes more effectively than those using the unguided version.

In summary, we can conclude that guidance for computer simulations seems a promising way to follow. Special attention should be given in regard to the learning processes the guidance is relating to and to the reference between the design and purpose of the guidance. A dilemma is to what extent the guidance should be accomplished. Do students still have enough control in a guided computer simulation and is it still an open learning environment? In studies that follow we will explore these questions.

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