Learning and instruction with computer simulations

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Computer simulations are used in many contexts, such as what-if analyses, experimentation and instruction. The topic of the present volume is the use of computer simulations in instruction. Instructional use of computer simulations has four characteristics:

- Presence of a formalized, manipulable model;
- Presence of learning goals (such as conceptual or operational knowledge);
- Elicitation of specific learning processes (such as hypothesis generation and testing);
- Presence of learner activity (learners may perform manipulations with the model).

These four characteristics together confine our view on instruction and learning with computer simulations. The related topic of modelling shares the above mentioned characteristics with simulation, but has an additional one:

- Possibility of interfering with the properties of the underlying model.

Applying simulations in instruction is important for a number of reasons, the most important of which is probably that learners will be engaged in active exploration and learning - an approach which is advocated in modern instructional/learning theories. Creating hypothetical realities or changing time scales in simulations might sustain this learning approach. Additional reasons for using simulations are a motivational aspect and the possibility of creating situations that are unacceptable in reality for reasons of danger, costs or time.

Learning through exploration puts high cognitive demands on learners. This may result in inefficient and ineffective learning behaviour, where students flounder and do not use the opportunities the simulation environment offers. Therefore, it seems that support is needed if learning from simulations is to be effective. This support can be given by a human teacher but also by a computer learning environment.

The present volume presents the results of an inventory of elements of such a computer learning environment. This inventory was conducted within a DELTA project called SIMULATE. In the project a learning environment that provides intelligent support to learners and that has a simulation as its nucleus is termed an Intelligent Simulation Learning Environment (ISLE).

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1. Introduction

This introductory article provides a framework (organizer) for the rest of the present volume. It starts by defining the *subject* to be discussed: the use of computer simulations in an instructional context and the need for providing learner support along with a simulation. Then the *context* of this work is given by a brief outline of the SIMULATE project, the project of which the articles presented in this volume are one of the products. It proceeds by presenting a *conceptual framework* in which the contents of the present volume is organized and a short preview of the results of the inventory. Finally, it will give, as a guide to the reader, the *global structure* of the articles that follow.

2. Computer simulations in an instructional context

Nowadays, prevalent theories state that in the learning process the learner is actively involved in constructing and reconstructing his/her knowledge base (Anderson, 1983; Rumelhart & Norman, 1981; Rumelhart, 1980). This finds its reflection in the teaching process. Contrary to traditional ways of teaching in which the learner was viewed as an 'empty box' into which knowledge could be poured, new approaches stress the active role of the learner and the importance of his/her prior knowledge. This change in teaching attitude includes a change in learning goals from reproduction of knowledge to deep understanding of a domain and to transferrable knowledge. However, the activity level of the learner is accompanied by an increasing complexity in the inference processes involved, and thus poses additional problems for the learner. Michalski (1987) describes a number of these learning strategies and the related inferences demanded of learners.

Some forms of Computer Assisted Instruction (CAI) are well suited to this teaching and learning approach. The use of hypertext-like systems is an example. Here, learners are encouraged to explore a domain under study or to construct representations of a domain. An example of this is Learning Tool (Kozma, 1987). A second example of CAI that supports active learner behaviour, is simulation based learning (Hall & Layman, 1987; Miller, 1984; Rivers & Vockell; 1987, Woodward, Carnine, & Gersten, 1988). Here, learners also actively explore a domain, but now by changing input values for a model of the domain. The advantages of simulation based learning are recognized by authors of courseware as was shown in a recent Dutch survey (de Jong, 1990). This study showed that of the courseware used in higher education in the Netherlands about 50% was indicated as being simulation based. Other references indicate the increasing use of computer simulations in a number of domains such as economics (Robinson, 1985). A closely related field is the field of *microworlds* (see e.g. Peterson, Jungck, Sharpe, & Finzer, 1989). A microworld can be seen as a computer environment in which learners may exhibit exploratory behaviour within a set of well defined microworld boundaries. Originally, these boundaries were not domain determined. The best example of these are LOGO (see e.g. Papert, 1987), and Boxer (diSessa & Abelson, 1986; though Boxer is more suited for modelling specific domains). The concept of microworlds, however, is nowadays also used for models of domains, thus creating a vague boundary between microworlds and simulations.

2.1. *Characterizing instructional use of simulations*

Computer simulations are used in many contexts, such as what-if analyses, experimentation and instruction (see McLeod, 1989). Even within the context of instruction, however, the interpretation of the concept simulation and its use may differ widely (de Jong, 1990; Gredler, 1986; Reigeluth & Schwartz, 1989). It will therefore be useful to give a definition of *instructional use of computer simulations*.

In our view, instructional use of computer simulations has four characteristics:

a. *Presence of formalized, manipulable underlying models*
By computer-based simulation is meant that a phenomenon, a process, a system or an apparatus (or whatever it is that is being simulated) is *formalized* into a model and implemented as a computer program. This model may have a qualitative character, or a quantitative one (or both). For a quantitative simulation, independent variables, dependent variables and parameters are combined into a numerical model. For qualitative simulations the model will not be purely numerical, but the components of the model and the relations between them will be represented symbolically or structurally. The underlying models may range from simple to very complex. It is essential that the output of the program is calculated or inferred from the implemented model in response to input from the learner.
For some simulations not only the underlying model but also the procedures of input to and output from the model can be regarded as essential aspects of the 'real world' that has been modelled (an example of this is a Flight Simulator).

Some courseware programs (notably in the field of medicine) present the learner with a number of steps from a certain operation or procedure. The learner is asked questions at each step. The 'model' and all the values in it are fixed; no calculations on the basis of the model take place. For this reason, we will not regard these kind of programs as simulations. Gredler (1986) denotes these kind of programs as 'drill and practice'. We also exclude what are sometimes called 'computer-assisted simulations' (Coote, Crookall, & Saunders, 1985). Here, the simulation is performed outside the computer, and the computer is only used to process data, if necessary. This kind of use of simulations is frequently seen in instructional settings that also require a social context.

b. *Presence of learning goals*
Second, the simulation has to be used to reach a certain *learning goal.* These goals can be of different types:

- Acquisition of knowledge about the underlying model, i.e. *conceptual knowledge.*
- Attainment of specific *procedures,* i.e. *operational knowledge.* These might be cognitive

skills (e.g. problem solving in a specific domain) or skills with a psychomotor component (e.g. learning to fly).

- Development of *knowledge acquisition knowledge*, i.e. knowledge of the process that takes place while learning with the simulation (e.g. experimentation and subprocesses).

We distinguish *instructional* goals from *learner* goals, the first originating from an instructor/-teacher, the second one belonging to the learner. In a normal teaching situation the teacher will try to minimize the distance between instructional goals and learner goals. When, in the discussion, we don't want to distinguish between instructional and learner goals, we will use the term learning goals.

The *use* of the simulation merely as a tool or calculating device (as is frequently the case in instruction) is therefore not accounted for as the 'use of simulations in an instructional context'. Also, *learning* to use the simulation as a tool or calculating device is not a part of our scope. The instructional goal characteristic also excludes *games* that are merely meant for gaining pleasure, even though quite often they are based on 'world models'.

c. *Elicitation of specific learning processes*
Third, and this is a cardinal characteristic, the simulation must be used to invoke specific *learning processes* characteristic of exploratory learning (such as hypotheses generation). The path to the learning goal leads through these learning processes. The learner can generate his/her own hypotheses and test them subsequently. This constructive approach is generally accepted as an efficient way to acquire knowledge, both conceptual and operational. Other learning processes, such as planning and monitoring, play a supportive role in the learning process. However, as we indicated above, they can also become the object of instruction.

Of course, this characteristic of learning with computer simulations is not distinctive. Other instructional means exist that might be used to provoke these learning processes. We think, however, that computer simulations are especially suited to it. It is therefore remarkable that this characteristic of simulations is hardly ever mentioned in standard books for designing courseware (e.g. Hannafin & Peck, 1988).

This characteristic excludes those situations in which the learner (for example because of a lack of necessary conceptual background) is forced into random manipulation.

d. *Presence of learner activity*
Fourth, there must be some level of *learner activity*. This means that the learner must actually *manipulate* something in the simulation, e.g. by setting input variables and parameters, choosing output variables, attaching measuring devices etc.

This characteristic excludes those situations in which the simulation is used merely as a *demonstration device*.

These four characteristics *together* describe the instruction/learning situation that will be discussed in this volume. These characteristics were discussed here very briefly, but will receive full discussion in van Berkum et al. (this volume).

A closely related type of instruction/learning is *modelling*. Such an environment shares the above mentioned characteristics of learning with a computer simulation, but has one additional characteristic:

e. *Possibility of interfering with the properties of the underlying model*

Another way in which the learner may manipulate a simulation is called 'modelling'. Here the learner may not only vary the values of variables and parameters, but may also interfere with the properties of the model (Ross, 1986; Goodyear, 1987; Ogborn, 1985). The learner may add, delete or modify the variables and parameters in the model, or the relations between them. In modelling, the learner task may be to make the simulation work in such a way that for a specified set of inputs the model gives outputs that resemble those of the simulated reality. This last method of model building is more closely related to the way simulations are utilized in scientific research.

Our interest is in *simulation* and *not* directly in modelling. This, however, does not mean that we will not discuss this related topic whenever necessary. Moreover, we can see that the boundary between simulation and modelling is getting blurred. This holds for qualitative simulations, but also for quantitative simulations in which the learner is offered a number of elements that s/he can use to create a simulation. The simulation language EXTEND, for example, offers libraries of elements, e.g. for building electronic devices, that the learner might pick up and configure. If the learner, for example, includes a resistor in an electronic device, s/he does not really change the fundamentals of the model. It is not clear whether this can be denoted as simulation or modelling. The same argument holds for systems such as ELAB (Böcker et al., 1989) and IMTS (Towne, Munro, Pizzini, Surmon, & Wogulis, 1988). Perhaps, the best approach is to take into account the learning goal. If the learning goal is to learn a specific circuit, then adding elements is modelling. However, if the instructional goal is knowledge of the basics of electronics, then the insertion of an element is simulating.

2.2. *Why use simulations in instruction?*

The previous sections stressed the relevance of computer simulations for instruction because of the *learning processes* they might evoke in learners. In fact we think that this is one of the most important characteristics of simulations, since learning goals are attained through these processes. Many authors stress the *affective* or *motivational* appeal of computer simulations (e.g. Ratchford, 1988). Hebenstreit (1987) states that a computerized simulation creates a 'world' in between reality and some abstract model of it; this intermediate layer may help the learner to bridge the gap between reality and the model. Dekkers and Donatti (1981) list a (large) number of claims made for the use of simulations in instruction: improvement of motivation, enhancement of cognitive learning of factual information, better understanding of processes, improvement of critical thinking skills, improvement of transfer of learning to other situations, development of favourable attitudes to social issues such as the conservation of the environment, development of a more positive attitude towards learning and the instructional process, development of communication and social skills, improvement of classroom climate, enhancement of teacher flexibility, and providing teachers with a greater sense of their own worth.

Additional reasons for using simulations in instruction relate to economic and/or other objections or difficulties in learning in a real life situation. The following more 'practical' reasons may be given for using simulation as an instructional device:

a. Training on the job can be expensive or time-consuming;
b. Training on the job can be dangerous to man, environment and/or material.
c. In simulations, one can introduce disasters so that the trainee can learn to react to them.
d. Sometimes, training on the job can be highly stress provoking.

Also, simulations offer opportunities that are helpful in the process of learning and understanding:

a. In simulations, the time-scale can be changed: real processes can be slowed down or speeded up to have an acceptable time of instruction;
b. In simulations, a hypothetical reality can be created, e.g. a simplification of reality;

2.3. *The need for support alongside simulations*

Simulation thus seems to have many advantages for use as an instructional device. However, it is also clear that learning by means of simulations puts a high cognitive demand on the learner. As was shown earlier in this section, simulations may incorporate models ranging from the very simple to the very complex. Also, the associated input/output procedures may be very complex. Learning these models and procedures by simply exploring alternatives may be very unfruitful. Learners may become involved in making changes randomly instead of purposefully manipulating variable and parameter values, and there is a chance that especially weak learners may derive little benefit from the simulation (see for example Lavoie & Good, 1988; Bork & Robson, 1972) has shown similar results. However, students can also be too much passive, not using the opportunities that the simulation environment offers (Njoo & de Jong, 1991a,b,c). De Jong and Njoo (1990) offer a short overview of problems that learners might encounter in exploratory learning. It seems clear that support is needed if learning from simulations is to be effective. Sometimes this support is provided by human tutors, but it could also be given by a computer learning environment. This is the research topic of the SIMULATE project.

3. Authoring for computerised instructional environments for simulations: an overview of the SIMULATE project.

One of the research and development programmes of the EC aims specifically at the use of advanced technology in and for education. This programme is termed DELTA (Development of European Learning through Technological Advance). The current phase of the programme is called the exploratory phase and as such it has a preparatory character.

One of the main projects within DELTA is SAFE (Standard Authoring Facilities) and one of the subprojects within SAFE is SIMULATE, which is short for SIMulation Authoring Tools Environment. The topic of SIMULATE is *authoring of simulations embedded in intelligent instructional environments*.

This topic has two elements: the *components* that constitute such a learning environment and the *tools and techniques* to create and integrate these components into a learning environment. SIMULATE is the authoring workbench that will contain all the means (tools and methodologies) necessary to create an Intelligent Simulation Learning Environment (ISLE) that can then be presented to a learner. The acronym SIMULATE is used for the project as well as for the resulting authoring workbench.

The present volume is about the first element, it present the results of an inventory of the components of an ISLE. A parallel document describes the tools (Tait, 1990). One could say that in the present volume *demands* are listed, whereas in Tait (1990) the *possibilities* are described. Each document has the character of an inventory.

One of the ongoing activities in the project combines these two elements into what we have called the *formalisation activity* (de Jong & Tait, 1991, see also de Jong, Tait, & van Joolingen, 1991). In this activity we strive to develop a more structured language for describing the information that is here described in natural language. This structured ('formal') language will help to reduce the gap between natural language and programming languages. Another important aspect of the formalisation activity is that it tries to identify basic conceptual entities that will find their software counterparts in 'Basic Building Blocks'. In this respect, the project adopts an object oriented approach (see De Jong, Tait, & Van Joolingen, 1991).

The SIMULATE project aims to support authors of ISLEs in three ways:

1. a *software workbench*, that offers the author libraries of 'Basic Building Blocks', from different sources, that the author may *select*, *specialise*, and *instantiate* (see de Jong, Tait, & van Joolingen, 1991). These building blocks are put into a *knowledge base* that together with an *ISLE shell* will create a runnable system (van Berkum & Hijne, 1991).
2. a set of *recommendations* that will help the author to select pedagogically correct actions (Njoo et al., 1991)
3. a *development methodology* that will guide the author in the process of developing an ISLE using the software workbench and the recommendations (De Hoog, de Jong, & de Vries, 1991).

In the present phase of the DELTA programme the SIMULATE project performs the groundwork for developing this support.

4. Instructional environments and simulations

There has been a recent spate of learning environments that present the learner with a simulation together with some kind of support. Examples are: QUEST (troubleshooting of simple electronic circuits; White & Frederiksen, 1987a,b; 1990), STEAMER (operating a steam propulsion plant, Hollan, Hutchins, & Weizman, 1984), MACH-III (maintenance and trouble shooting of a complex radar device; Kurland & Tenney, 1988), IMTS (troubleshooting in complex devices; Towne, Munro, Pizzini, Surmon, Coller, & Wogulis, 1990) and Smithtown (microeconomics; Shute, Glaser, & Raghavan, 1989; Shute & Glaser, 1990). See also van Berkum and de Jong (this volume).

Despite these recent developments and despite the fact that numerous simulations are used in instruction, there is still very little research on how to support learners in exploratory learning (see e.g. Lesgold, 1990).

ISLEs (Intelligent Simulation Learning Environments), as we envisage them in the SIMULATE project, contain a simulation together with advanced help, hints, explanations and tutoring facilities etc. Such an environment may offer the learner a 'guided tour' through the simulation, tailored to his/her specific instructional needs.

An elaborated functional architecture of an ISLE can be found in Hijne and van Berkum (1991). An ISLE basically has four components, similar to the four modules found in the ITS literature (see e.g. Duchastel, 1988): *domain module, learner module, teaching module,* and *learner interface module.* The four resulting components are therefore:

1. *Domain*
   The basis of a simulation is some type of model of the domain. These models may differ on a variety of dimensions, e.g. the number of parameters, number and type of relations, static vs. dynamic, qualitative vs. quantitative relations (Gredler, 1986; Welham, 1986).
   A representation of the domain is strongly related to the model and its characteristics; this domain representation can be used not only to form the simulation but also to function as a basis for the support given by the ISLE.
2. *Learners*
   Learners will display a number of cognitive and non-cognitive characteristics that have significance for interacting with (tutorial embedded) simulations. These characteristics range from domain knowledge, through learning processes used, to, for example, self-control. An intelligent simulation learning environment will need to adapt instruction to individual differences in these characteristics of the learner, to his/her misconceptions, and to the knowledge base of the learner as it develops during the learning process. Knowledge of these learner aspects provides the basis for learner modelling in an intelligent learning environment.
3. *Tutors*
   An intelligent tutoring system needs knowledge about tutoring and help facilities. In the field of simulations several general tutoring approaches can be taken, e.g. a Socratic dialogue (Jungck & Calley, 1985), or progressive model implementation (White & Frederiksen, 1987a,b; 1990).
4. *Learner interface*
   Learner interfaces have a double function. They have to be designed in such a way that the output of the system is understandable to the user, and that the user may easily transform the actions s/he has in mind into inputs for the system (Norman & Draper, 1986). Screen output for simulations may range from tables to full graphical output. Some of the man-machine interface aspects have a more general character that has to be specified to working with simulations (e.g. direct manipulations), whereas others are more specific for simulations (e.g. the fidelity of the interface, meaning the relation of the interface to reality). In the present inventory we will mainly focus on those interface aspects that are specific to learning with simulations (see also Symons, 1985). Also, knowledge about how and when to present help (to be distinguished from support, see Carroll & McKendree 1987), and knowledge about what type of help is required to suit particular local needs, have to be present.

5. A conceptual framework

The contents of the present volume is sketched within a *conceptual framework*, which combines the *design components* of an ISLE (as described in Section 4) with the characteristics of instructional use of simulations as presented in Section 2.1. These characteristics are indicated as *themes* in the following discussion.

The main body of the present volume is the discussion of each of the four design components of an ISLE: *domains*, *learners*, *tutors*, and *learner interfaces*. In discussing a design component reference will be made to the relation of the component to all four themes: *simulation models*, *learning goals*, *learning processes*, and *learner activity*.

Table 1 provides a diagram that depicts this conceptual framework. The four columns under 'design components' each represent one of the contributions to this volume. The characteristics from Section 2.1 are termed 'themes' and can be found along the vertical axis. A separate contribution to this volume will give an outline of these themes. Each will receive extensive discussion in one of the design component related contributions (see Section 7 for a structured overview).

The themes provide the basis for horizontal lines through the diagram. For each of the design components (domain, learner characteristics, instructional strategy and learner interface) some *examples* for each of the four themes are presented in the cells of the matrix. For example, one of the subjects to be discussed under the theme *models*, for the design component *learner characteristics*, is the subject of mental models. A relevant *instructional strategy* is for example: progressive implementation (especially when the models are complex models). For the design component *learner interface* subjects such as visualizers (how to externally represent elements from the model), and transparency will be treated.

The other cells of the diagram all provide examples of the subjects to be discussed at the conjunction of a design component and a theme. Of course the list of examples given here is far from exhaustive and inevitably some subjects will cover more than one theme within a design component.

The next section gives a short summary of what

	DESIGN COMPONENTS			
THEMES	*domain*	*learner characteristics*	*instructional strategy*	*learner interface*
models	Domain/simulation models	Mental models Misconceptions	Progressive implementation	Visualisers Multiple views Transparency
learning goals	Scenarios Experimental frame	Prior knowledge Related skill levels	Immediate feed-back for skill learning	Goal decomposition tools
learning processes	Complexity of domain	Scientific skills Self regulation Self confidence	Hints Suggestions Explanations	Learner instruments
learner activity	Handles on the model	Knowledge of exploratory learning environments	Giving constraints on input	Input transparency

Table 1 *A conceptual framework for a componential description of computer simulations in an instructional environment.*

will be presented in the subsequent articles in this volume.

6. A preview and summary of the results of the inventory

As was mentioned in Section 3, the present volume is based on work that provides a background of information on all aspects of learning and instruction with computer simulations. It contains the results of an inventory and survey of existing material. In trying to achieve a more structured overview of the field, the document presents quite a few classifications and introduces quite a lot of new and adapted terminology. The present section gives a preview of the most important issues in this volume, and briefly defines some of the terms used.

The key topic in our work is *learning with computer simulations*. We assume that learning with computer simulations allows for attaining certain *learning goals* with *models of domains* by inviting the learner to perform *specific learning processes* and to perform certain *learner activities*. However, we make a second assumption that, depending on characteristics of the learner (e.g. his/her experience with exploratory environments in general), accompanying *support* for the simulation is needed. We think this support can be provided by a computer environment that we have called an ISLE (Intelligent Simulation Learning Environment).

One can say that instructional design starts with a *situation* and tries to define *instruction* in order to give an answer to that situation. The situation consists of two main components: (a) the *domain* with its associated learning goals and the learning processes and activities needed to achieve these, and (b) the *learners* involved.

Domain models show a variety of characteristics. The main distinction is between quantitative and qualitative models. Dependent and independent variables in quantitative models are either discrete or continuous. If one of the independent variables is time we call a model dynamic, otherwise it is a static model. Next to variables, parameters play an important role in models. They can be either internal or external, static or dynamic, and deterministic or stochastic. Qualitative models can be 'real' qualitative models where the model relations are stated in terms of propositions, or they can be qualitative translations of quantitative models. Another important aspect of models is whether they have a procedure/operation associated with the underlying model. Procedures guide the interaction process with the underlying model.

We will distinguish two main types of *learning goals*, which have a clear relation with characteristics of the model. First, we have *conceptual knowledge* as a learning goal. This learning goal reflects the characteristics of the underlying model as sketched above. Second, we have the learning goal of *operational knowledge*, which is related to the procedure associated with the underlying model. These learning goals have two attributes: the level of domain dependency (do we want learners to have their knowledge closely linked to a specific domain or to have it in domain independent form), and the level of 'compiledness', in other words how automated do we want the knowledge to be. These attributes do of course have an impact on design of the instruction and on the kind of models to offer the learner. How exactly this should be done is still a matter of research. A third learning goal has a somewhat different position from the first two and is related to the process of knowledge acquisition. In other words it is aimed at how to learn in an exploratory learning environment. A very preliminary conclusion can be that exploratory learning environments are less efficient (than direct instruction) for learning facts, and for learning knowledge in declarative form in general.

Crucial to learning with computer simulations is that learning takes place through a *process of scientific discovery* or *exploration*. We have attempted to unravel what is involved in exploratory learning. This has resulted in a multi-level approach with learning processes described at different levels. At the highest level we distinguish the processes of 'orientation', 'hypothesis generation', 'testing' and 'evaluation'. Some of the processes at the second level are 'model exploration', 'prediction', and 'interpretation'. Also supporting processes such as 'planning', 'control' and 'monitoring' are important in exploratory learning. However, what exactly constitutes exploratory learning is to a great extent unknown (see also Lesgold, 1990).

Learner activity is closely related to learning processes and enumerates all the 'manipulations' the learner may apply to the simulation, such as defining experimental settings, taking decisions in the interaction process, collecting data, choosing data presentation, and exercising metacontrol over the simulation. This whole range of learner activities is only possible of course when the simulation model allows for it. Learner activity is distinguished from *learner control*. Learner control is the overall control a learner has over the instructional situation (such as choosing a particular part of the material to study or asking for a test or exercise), whereas learner activity only concerns the learner's control over the simulation as such.

An important actor in the instructional situation is the *learner* who brings all kinds of learner characteristics to the situation. Goodyear et al. (this volume) illustrate that there is a large number of learner characteristics that have a possible relation to learning with computer simulations. Examples of relevant characteristics are: prior knowledge, cognitive style, and learning approach. An analysis of these characteristics, together with an overview of potential problems in exploratory learning, suggests that it may be wise not to give learners a pure simulation, with maximal freedom, but to have this freedom reduced by adding explicit *guidance* (or non-directive support) to the simulation.

Adding guidance to a simulation reduces the freedom the learner has and thus reduces the chance of some desired (exploratory) learning processes showing up. One of the critical tasks of the author of simulation based instruction is to find the optimum balance between instruction and freedom and, perhaps even more important, to find those instructional measures that *elicit* exploratory learning processes. Here we touch upon an important distinction that we have made between *directive* and *non-directive* support. Directive support limits the freedom of the learner, for example by interrupting the student's interaction with the simulation and presenting him/her with a tutorial, or by pushing the learner in a certain direction. Non-directive support does not reduce the learner's freedom, but supports him/her in carrying out the actions that s/he had in mind, for example by providing the learner with what we have called *learner instruments*, tools for *notation* and *inspection* (such as scratch pads to note down hypotheses). We discuss directive support (guidance) primarily in the article on instructional environments (Van Berkum & de Jong, this volume), and non-directive support in the article on interfaces (De Hoog et al., this volume).

In analyzing the instructional component (Van Berkum & de Jong, this volume) we find that when one looks at instructional strategies or principles used in existing 'exploratory environments', these environments adopt a fairly eclectic approach, with most of their principles, however, borrowed from *cognitive theory*.

Summarizing the results we can say that there seem to be two basic approaches. The first one sees simulations (or exploration) as only one of a number of possible instructional approaches. Domain information contained in the simulation may also be presented in another form. In this approach, exploration is alternated with other, more explanatory, forms of instruction or is embedded as just one phase of instruction in an instructional strategy. The second approach places exploration at the pivot, and tries, by a number of measures, to smooth the study process of studying with the simulation. These instructional measures may range from presenting a certain sequence of (increasingly complex) domain models, providing explanations of various kinds, or entering into a Socratic dialogue.

What becomes clear from surveying a number of instructional strategies and measures is that most of these strategies and measures do not provide a clear relation to characteristics of the domain/model involved or to characteristics of learners.

In examining the *learner interface* for simulations (De Hoog et al., this volume) a distinction is made in showing the learner the model in an *overt* or *covert* way. The covert way is clearly more related to our traditional view of simulations, because here the learner has to induce the properties of the model from the input/output relations. In reviewing all the possibilities here, the distinction between physical, artificial, and hypothetical systems is adopted. Furthermore, the interface may sustain the study process by providing the learner with *learner instruments*. These are facilities such as goal decomposition editors, hypotheses scratch pads, etc. Finally, the learner interface must be appropriate for learner activity (the manipulations of the simulation as such) to occur.

7. Global organization of this volume; a guide to the reader

The conceptual organisation of this volume was given in Section 5 and a preview of the results in Section 6. The present section outlines a global, structural overview of the document.

The reader may study the document in two different ways. First s/he can follow the articles in succeeding order. Van Berkum et al. present a summary of each of the four themes of learning with computer simulations. The articles that follow each have one of the design components as their topic and relate this design component to all four themes. Moreover, the themes that were outlined in van Berkum et al., each receive full discussion in one of the articles on design components that follow.

Van Joolingen and de Jong start by giving an extensive overview of the design component *domains*. This design component is closely related to the theme *models for simulations*. This theme will therefore receive a full treatment through a presentation of *types of models* on which simulations can be based. This article also presents a discussion of characterizations of simulations found in the literature. Specific attention is also given to the theme *learner activity*.

Goodyear, Njoo, Hijne and van Berkum discuss *learner characteristics* relevant to learning with computer simulations. They relate this design component to all four themes mentioned, but more specifically the theme *learning processes* is discussed.

Van Berkum and de Jong give an overview of relevant *instructional strategies* and *actions*. The theme *instructional goals* is of special relevance here.

De Hoog, de Jong and de Vries, finally, examine *learner interface* aspects.

A second way to study the document is to follow the themes through the articles. Again Van Berkum et al. present an overview of the themes. The fol-

THEMES	DESIGN COMPONENTS			
	domain	*learner characteristics*	*instructional strategy*	*learner interface*
van Berkum et al.	van Joolingen & de Jong	Goodyear et al.	van Berkum & de Jong	de Hoog et al.
Models van Berkum et al. Section: 1	vJ & dJ Sections: 2, 3, 4, and 7	Goodyear et al. Section 5.5	vB & dJ Section 5.1	de Hoog et al. Section 5
Learning goals van Berkum et al. Section: 2	vJ & dJ Section: 8	Goodyear et al. Section 5.6	vB & dJ Section 5.2	de Hoog et al. Section 6.1
Learning processes van Berkum et al. Section: 3	vJ & dJ Section: 9	Goodyear et al. Section 5.7	vB & dJ Section 5.3	de Hoog et al. Section 6.2
Learner activity van Berkum et al. Section: 4	vJ & dJ Section: 9	Goodyear et al. Section 5.8	vB & dJ Section 5.4	de Hoog et al. Section 5

Table 2 *Structured overview of this document*

lowing articles each have sections discussing the themes in relation to the design component of the article. Table 2 presents an overview of the document indicating articles and sections that address a design component, a theme or the combination of both.

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