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Self-directed learning in simulation-based discovery environments

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Abstract SIMQUEST is an authoring system for designing and creating simulation-based learning environments. The special character of SIMQUEST learning environments is that they include cognitive support for learners which means that they provide learners with support in the discovery process. In SIMQUEST learning environments, a balance is sought between direct guidance of the learning process and sufficient freedom for learners to regulate the learning process themselves. This paper describes the basic mechanisms of the SIMQUEST learning and authoring environments. The functionality authors have in providing the learner with guidance and some of the experiences on how authors use these opportunities and learners employ the cognitive support are reported.

Keywords: Authoring systems; Computer-based learning; Discovery learning; Self-directed learning; Simulation

Introduction

In educational systems, the instruction and learning process is generally characterised by the traditional lecture, in which the teacher explains to the students rules and principles of the domain. There is now a general conviction that this traditional way of *expository teaching* is not optimum for training employees that the market requires and who need *deep, flexible,* and *transferable* knowledge. This need has led to new pedagogical philosophies in which constructivism is the key item. In this philosophy learners construct knowledge themselves, and the learning process is characterised by placing a high responsibility into the hands of the learner instead of the teacher. Simulations are extremely suited for this type of learning since they encourage *discovery learning*, learners experiment and construct knowledge as 'scientists': they provide the simulation with input, observe the output, draw their conclusions, and go to the next experiment (Lewis & Want, 1980; van Joolingen & de Jong, 1997). Experience and studies, however, show that learners are not always

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capable of handling their own learning process. de Jong and van Joolingen (in press) have summarised a large number of studies that illustrate a wide variety of problems learners may experience in discovery learning. In summary, learners encounter problems with all processes characteristic of discovery learning such as stating hypotheses, designing experiments, interpreting data and regulating the learning process (monitoring and planning).

In the EC sponsored SERVIVE project (Telematics Programme project ET1020) an authoring system, named SIMQUEST, that supports the creation of discovery learning environments was developed. The SIMQUEST system is a follow-up of the SMISLE environment (see de Jong *et al.*, 1994; de Jong & van Joolingen, 1995), still following a similar learning and authoring philosophy (van Joolingen *et al.*, 1996). The learning philosophy focuses on eleviating learning problems by introducing cognitive support for the learner which consists of several 'learning tools'. Learners may ask for small exercises (so-called assignments) that help them plan their actions and that can point them to specific phenomena; while experimenting learners can ask for background information in the form of definitions, relations to the real world etc. (this can be any kind of multi-media material); the simulation model can be presented to the learner in small steps that increase the model in complexity (so-called model progression); learners have tools that help them to monitor what they have been doing in a simulation session, that help them replay simulation sessions, compare outcome series, and make sound interpretations of the data; and, finally, also learners will have tools that help them to compose and check hypotheses.

One of the central questions in the project concerns the level of control that can be placed in the hands of the learner and that taken by the system. In this paper two characteristics of SIMQUEST learning environments that are most relevant for this question are emphasised: the nature of assignments, and the timing and obligation for learners to use these assignments.

Assignments as a support for discovery learning

The educational function of assignments

One of the paramount problems of learners in the discovery learning process is the regulation of their learning behaviour. Obviously, in self-directed learning environments the demand on regulative capacities of learners is larger than it is in traditional lectures. Planning and monitoring are central to regulation. Unsystematic planning and monitoring in simulation-based discovery environments is a wide spread phenomenon and is reported by Lavoie and Good, 1988; Simmons and Lunetta (1993); Shute and Glaser (1990); Schauble *et al.*, (1991). Veenman *et al.*, (1997) who followed learners in a number of simulation-based discovery environments report an effect of metacognitive abilities on the discovery learning process and learning results. Charney *et al.* (1990) and Teodoro (1992) claim that subjects have considerable problems with setting goals for themselves. Supporting the learner in the planning and goal setting process has already been taken up by Showalter (1970) who used *questions* as a way to guide the learner through the discovery process. His questions focused the learners attention on specific aspects of the simulation (see also Zietsman & Hewson, 1986). Tabak *et al.* (1996) have added such questions with the aim of setting goals in a biological simulation. White (1984; 1993) helped learners to set goals in a simulation by introducing games that ask learners to reach a specific state of the simulation. In SIMQUEST learning environments the mechanism of *assignments* has been used to help learners in their goal setting behaviour.

Assignments in SIMQUEST learning environments

Authors using the SIMQUEST authoring environment are offered templates for different types of assignments. Characteristic for all assignments is that they present the learner with a specific task. In SIMQUEST five different types of assignments are distinguished.

do-it assignments, give the learner the general assignment to explore the simulation model. As such, they do not advise the learner into a specific direction. The only thing authors can do is to put the simulation in a specific state (or more states from which the learner may select).

investigation assignments ask learners to investigate the relation between two or more given variables. After exploring the simulation learners may select an alternative from a list of predefined alternatives (a more complex investigation assignment can be specified by asking the learner to select all the correct alternatives from the list of propositions given) and feedback is given. This feedback can be direct feedback on the alternative chosen (in the form of multimedia content), or following a selected alternative the learner can be directed, for example, to another assignment.

explicitation assignments always have an initial state or sets of initial states for the simulation associated with them, the role of the learner being to run the simulation (with these different initial sets) and to observe the impact on the simulation. Learners are then presented a set of propositions that describe the phenomenon or phenomena observed, and they are asked to select the correct alternatives). Figure 1 gives an example of an explicitation assignment from a SIMQUEST environment in the physics domain of collisions.

specification assignments require the learner to predict the values of certain variables when the associated simulation stops. The values predicted by the learner are allowed to deviate from the values as specified by the author in either absolute or relative terms. The author also specifies when the simulation stops by assigning values to variables.

optimisation assignments require the learner to vary the values of the simulation's variables so that the constraints specified by the author are not broken and a target specified by the author is reached. Figure 2 shows such an assignment from a SIMQUEST environment in the physics domain of motion.

Authors have the possibility of creating assignments so that they may help the learner in planning the discovery process. Assignments may help the

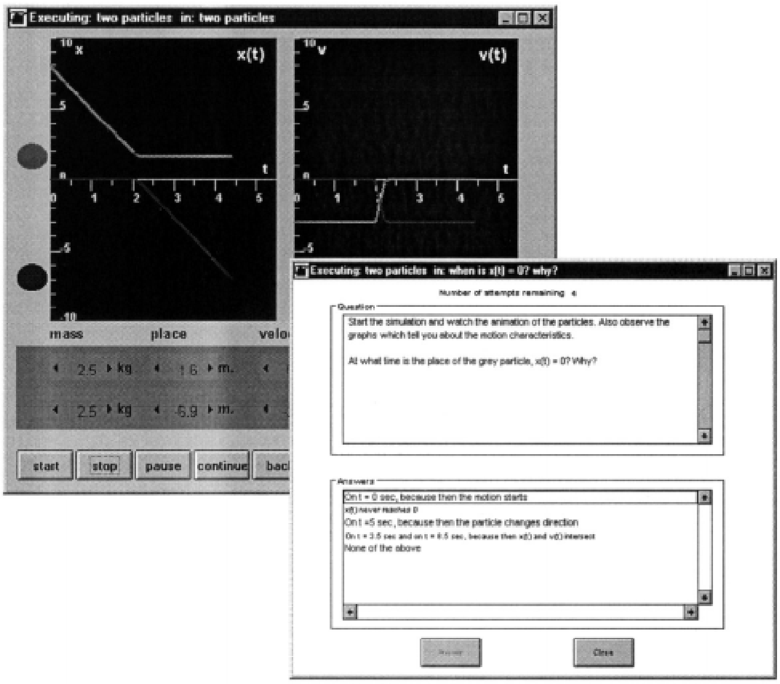

Fig. 1. Explicitation assignment from an environment on collisions
(The simulation was created by Hans Kingma (University of Twente)
based on work by Ernesto Martin (University of Murcia))

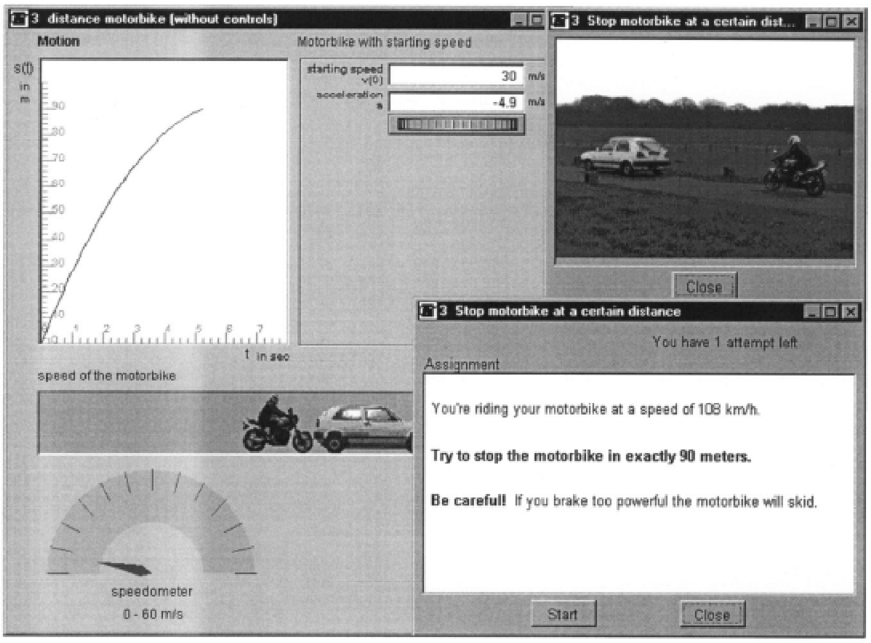

Fig. 2. Optimisation assignment from a SIMQUEST learning environment on motion
(The simulation environment was created by Jan van der Meij (CINOP))

learner to decide on what to do next and may also help (by presenting the right variables and by putting the simulation into certain states) to cover all relevant aspects of the model to be learned. Experience with a number of environments being created by authors (teachers) from university and vocational courses is being accumulated and, in a number of cases, there has been careful evaluation of the authoring process (Kuyper *et al.*, 1997). From these evaluations it became clear that authors also see assignments as an important instructional tool and they use the whole variety of types. There are, however, two deviations from using assignments in the way that was intended. The first is that authors see assignments as the central mechanism in the learning process whereas they were originally seen as a support means that a learner might use if the self-directed discovery process got stuck. A second deviation is that sometimes authors tend to use assignments as intermediate tests, telling learners first to discover the rules and then use assignments to see if they understand them.

In a number of empirical studies the influence of assignments on the learning process have been observed including three studies, each covering a different domain from physics. These are transmission lines (de Jong *et al.*, 1996), collisions (de Jong *et al.*, submitted) and harmonic oscillations (Swaak *et al.*, in press). One of the critical observations in these studies was that learners saw assignments as 'the' guidance for their discovery process. In cases where they were not forced to do any assignments (see also in the next section on 'control') they made the maximum use of them and it was frequently the case that learners saw the completion of all available assign-ments as the goal of their work ("I am done, I have completed all assign-ments"). In fact, students were right in recognising the importance of assign-ments. In the studies mentioned above it was possible to estimate the effect of them by comparing the same simulation environments with and without assignments. Overall, in conditions where assignments were present, learning gains (if measured as 'intuitive knowledge', see Swaak & de Jong, 1996) were higher than in conditions where assignments were not available.

Control over the environment

Structuring the discovery process

Whereas single assignments help learners to plan their immediate actions, several studies have indicated that learners also have problems in the overall planning of their learning process. Glaser *et al.*, (1992) found that successful discoverers make plans for whole experiments, whereas unsuccessful learners concentrate on local decisions. Lewis *et al.*, (1993), Njoo & de Jong (1993a; 1993b), White (1993), and Shute & Glaser (1990) give examples of studies where learners are led (in a more or less compulsory way) through a fixed sequence of actions (e.g. devise an hypothesis, design an experiment etc.). Some studies that have compared structured and unstructured environments gave beneficial effects of structuring. Other studies (e.g. Veenman & Elshout, 1995) could not find these effects, or could only find these effects for specific groups of subjects. In summary, existing studies are rather inconclusive on the effects of structuring the environment. The differences in outcome can possibly be attributed to the differences in how the environment was structured, but also to differences in characteristics of the domains involved and of the characteristics of the learners.

Control structure in SIMQUEST

SIMQUEST learning environments use a control mechanism that has a distributed character (see also van Joolingen & de Jong, 1996). Each instructional measure has an internal state. All instructional measures can assume the states 'disabled', enabled', or 'active'. Specific instructional measures can add more values for the state variable. For instance, assignments also can have the state values 'failed' or 'succeeded', which describes the results of the learner's interaction with the assignment. The complete state of the learning environment is defined by the collection of all states of the instructional measures. Instructional measures also contain a set of rules. These rules determine the change of state. For instance, a rule may say that when the state of an assignment becomes 'failed', another instructional measure must change state to 'active', which means that this instructional measure will display itself and is ready for interaction with the learner. Rules can be attached to any change of state. Typically, there will be rules which arrange the learning environment (i.e. open up the appropriate simulation interface, display an introductory text, etc.) and rules which respond to the behaviour of the learner (like the activation of an explanation on assignment failure or success). A special state value is that of 'enabled'. This means that the learner will see the instructional measure on a list and is able to inspect a description of it. The learner can select and activate instructional measures that are enabled. In this way, learners can take initiative in the learning interaction by choosing for themselves *if* they need support from the enabled instructional measures and *when* they need it. The rules inside the instructional measures will ensure that the learning environment itself remains consistent.

The control structure in SIMQUEST is dedicated to making learning environments in which the responsibility for choosing 'actions' is distributed between the learner and the environment, meaning that the initiative for activating instructional measures (e.g. assignments or explanations) can depend on both the preferences of the learner and on the internal state of the learning environment (see van Joolingen & de Jong, 1996).

Learner experience and author experience

Experience with authors using the control structure in SIMQUEST (and SMISLE) shows that they tend to structure the environment quite strictly and force the learner to go from assignment to assignment. In this way, authors, use only a limited part of the functionality that the SIMQUEST environment offers them for structuring the learning environment. One of the reasons for authors to work in this way is that they believe that this very constrained structure is necessary for an optimum learning process. For this reason a study was carried out with two environments (called *CIRCUIT* — created by Vincent Blokhuis (ROC Oost Nederland)). In one the learner could always choose freely from all assignments and was never forced to perform one (all assignment were always 'enabled'), and in another learners were led from assignment to assignment ('exiting' one assignment 'activated' another assignment). The domain was from a physics topic, electrical circuits, and the learners came from a middle vocational training college. In the 'free' environment there were 21 subjects, 20 working with the 'constrained' environment. A full description of the study can be found in Swaak *et al.* (1997). The main conclusion from the study was that constraining the students in their freedom in using support by forcing them to complete all assignments at one level of model progression before proceeding to another level did not make much difference. Neither the post-test scores nor the interaction data and navigation data as recorded in the log-files, identified major differences between experimental groups. The explanation put forward for the absence of major differences between the conditions is that just the presence of assignments is sufficiently directive. Although the students in the free condition were completely free in doing or not doing assignments, they completed on the average 14 of the 19 assignments, and although this number is lower than the 17 completed assignments of the structured condition it is not substantially lower. The number of simulation runs and explanations consulted did not differ significantly in the two conditions. In addition, the navigation measures show that the numbers of model progression switches differ between the two experimental groups, but that the time spent on each of the model progression levels did not show any statistically significant differences. In a second study (see also Swaak *et al.*, 1997), also in the field of electricity and in middle vocational training the same two types of environment were used, one free and one constrained (this environment was called *ElectricA* — designed by Mercedes Gutierrez (Salesianos Zaragoza)). This time in-depth data of 10 students (five in each condition) was collected. The questionnaire data showed that, though the contents of the two versions of *ElectricA* were exactly alike, they were perceived differently by the students. The 'free' and the 'constrained' versions of *ElectricA* had precisely the same appearance, contained the same assignments, explanations, feedback, etc. and only differed in the amount of freedom given to the learners. Nevertheless, most ratings from the students of the 'free' condition were more favourable than the ratings from the 'constrained' condition. The students from the 'free' condition gave a higher quality rating to the several features and parts of *ElectricA*, appreciated the instructional measures more, reported to have less problems on keeping track of what they had learned, and on knowing how to proceed. Furthermore, students of the 'constrained' condition indicated to be more frustrated by the possibilities of the environment, reported to need more information on how to operate *ElectricA*, and more background information. When students of both conditions were directly asked to report on the extent to which they felt constrained, the ratings of the groups were nearly similar. Yet, students' perception of freedom, was higher in the 'free' condition as compared to the 'constrained' condition.

Building on current experience

This paper has discussed how the SIMQUEST authoring environment provided authors with functionality for creating learning environments with a mixed initiative for learner and system. Both authors and learners used these facilities in ways that do not follow the intentions and reduces simulation learning environments to restricted environments where the predominant objective seems to be to perform a fixed sequence of assignments. This phenomenon is partly due to the natural tendency of authors and learners to return to something familiar: a book with exercises at specific points, and should disappear over time when authors and learners have more experience with simulation-based discovery environments. To alleviate this conservatism, two initiatives have been taken. One initiative concerns the learner and addresses a kind of support for regulating discovery behaviour, associated with assignments, that intends to stimulate more self-directed discovery learning. The other initiative concerns the author and puts a 'pedagogical adviser' in the SIMQUEST environment, that authors may consult and that may help them in constructing more open environments.

Learner feedback

One of the reasons for learners to use assignments the way they do, is that the feedback currently given to assignments is mostly in the form of an explanation to the several alternatives presented in the assignment. A tool is currently being developed that can be used to generate feedback that is more discovery process oriented and that analyses the experiments a learner has been doing in relation to the alternative chosen in the investigation assignment. Figure 3 gives an example of the type of feedback that can be generated. This development is related to a so-called 'monitoring tool' which allows the learner to store, inspect, replay, and compare experiments. In order to enable this new feedback mechanism the control structure in SIMQUEST described earlier has been extended. In the description given, the state of the learning environment depends solely on the state of the instructional measures. In the case of explicit support on the discovery process itself this is insufficient, since most parts of the discovery process are reflected in the interaction of the learner with the simulation. For recording this a 'watchdog' or 'daemon' has been added. A daemon monitors the state of the simulation and changes its instructional state once a certain, pre-specified simulation state has been reached. In this way the daemon transfers events from the 'simulation domain' into the 'instructional domain'. At the moment there are three kinds of daemon: one 'timer' which measures the time that has passed since its activation and exits when a certain amount of time has elapsed, one that monitors the immediate state of the simulation and exits when a pre-specified state has been reached, and one that monitors (and analyses) the experiments performed by the learner. The latter is an example how learner modelling can be integrated within the system. Daemons can be created to monitor the experiments learners perform, the hypotheses they state, and the way they respond to questions. As daemons set an instructional state, the environment can react to these small learner models. This introduces an agent-like means of learner modelling where small daemons watch aspects of the learner behaviour. As daemons can be turned on and off during a session, the sophistication of the learner model can be adapted to the actual needs in a given situation.

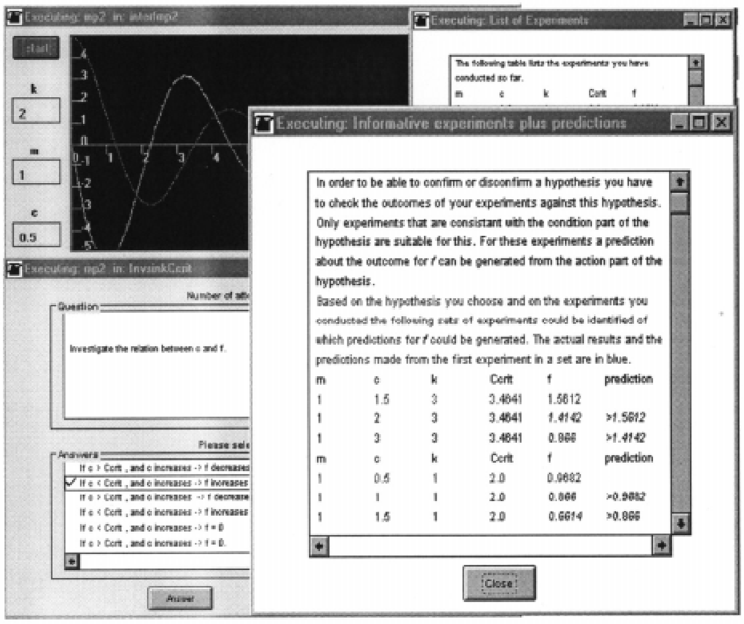

Fig. 3. Discovery process feedback to an investigation assignment

Guidance for authors

Authors quite often lack specific knowledge on how to design discovery learning environments. For this reason authors in SIMQUEST are now guided by a so-called advice tool. The advice tool is an elaborate hypertext system with textual and graphical information on how to design simulation-based learning environments. The advice tool is accessible through a main window or in a context sensitive way through the element of an application that is under development. For example, when editing an assignment the author has direct access to advice on assignments. The advice tool has two dimensions; one is the topic on which advice can be given about (e.g. model progression or assignments) and the other concerns a classification based on questions an author may have. There is a distinction between:

- *What is?* Tab sheets in the 'what is?' category give a definition of for example specification assignments, or explanations;
- *Example*. Tab sheets in this category show an example of for example instructional support, e.g. a video clip explanation can be given;
- In the *considerations* category there are all kinds of instructional reasons for making use of specific instructional measures, and also about learner characteristics, curriculum, and context characteristics.
- The *background* category gives information about studies in the literature.

Figure 4 gives an overview of the advice tool. In the content of the tab sheets a user oriented writing style is used, staying as closely as possible to the daily practice of teachers.

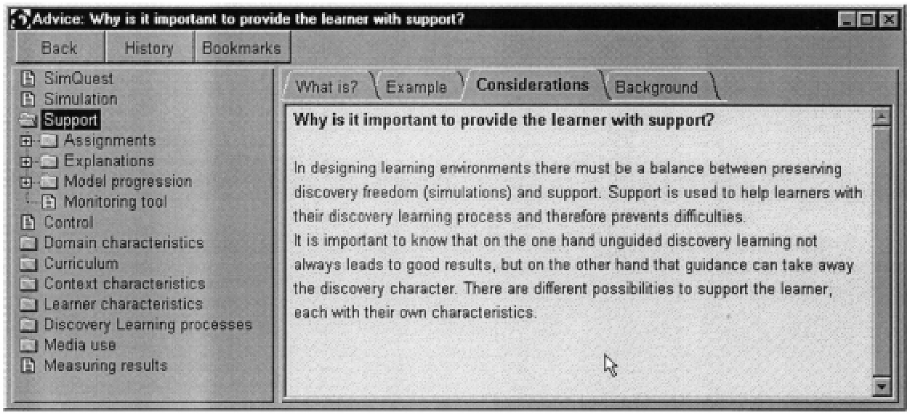

Fig. 4. Example screen from the advice tool

Conclusions

By providing the learners with tools that directly aim at stimulating central discovery processes (in addition to the learning tools already available) and by providing authors with good information and examples on how to create simulation-based discovery environments the aim is to work towards a situation in which learning is not directed by a single agent, but is the result of combined expertise of the system and the learner.

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