Real time diagnostics of problem solving behavior for SD-based business simulations

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Abstract: Business simulations are composed of a (SD-)model which represents the complexity and dynamics of business structures and concepts. Within a simulation the participants can make decisions to control the modeled enterprise. A business simulation can make the interdependencies between the different activities within an enterprise transparent to the participants. From an economical perspective the success within a business simulation can be measured by the development of core variables. The Balanced Scorecard is a well-known concept for this purpose.

From an educational perspective the structure of the cognitive system which is responsible for the economical success is relevant. A subsequent aspect refers to the possibilities to support the elaboration of the mental model during the activities within a business simulation. Furthermore in the context of web-based learning environments there is the issue how to foster self-regulated learning processes.

A prerequisite for an effective feedback which supports learning is a continuous diagnosis of the problem solving process, in particular the diagnosis of the information-retrieval and decision-making processes.

This paper describes the basic concept of the diagnostics within a prototype of a web-based business simulation called *solarSYDUS*. Besides the SD-model this simulation contains a component for recording information-retrieval and decision-making processes during the simulation for analyzing problem solving behavior.

Keywords: Complex problem solving, web-based business simulations, assessment, decision-making

Introduction

Simulations and games are used in the context of computer-based learning and instructions since the 1960s. They have depicted a specific phenomenon within a model that is executable on a computer. This paper refers to phenomena in economical contexts, in particular enterprises competing with each other in a simulated market. The model of the enterprises and the market represents the complexity and dynamics of business structures and concepts the participants within the simulation have to cope with. The use of business simulations can target different objectives (BREUER et al. 2004):

- Acquisition of structural knowledge
- Development of domain-specific problem-solving competencies
- Elaboration of holistic views toward complex phenomena

- Fostering meta-cognitive competencies (self-regulation and self-monitoring)
- Support for the ability of role-taking
- Build-up of the ability for coping with dynamics

The traditional concept of using business simulations could be divided into three phases: briefing, simulation or gaming and debriefing (CAPAUL 2001). Within the first phase (briefing) the participants receive an introduction into the structure and the rules within the model. This is necessary to activate prior knowledge which can be referred to by the participants. Within the briefing the participants get confronted with a problem they ought to solve within the follow-up simulation, e.g. to gain a higher market share within a growing market. Because learning with business simulation refers to the paradigm of problem-based learning the selection of an appropriate problem is an important aspect. The participants should elaborate their mental model about the concepts represented within the simulation model by solving a given problem, i.e. the appropriate knowledge to solve the problem isn't available at this point of time. Otherwise from the perspective of the participants the presented 'problem' would be a task only. In this situation learning takes place in the sense of automating existing knowledge. Therewith it is referred to the distinction between tasks and problems which DÖRNER (1976) has introduced. In business simulations the participants are often faced with complex problems. According to the definition of DÖRNER these problems have a more general goal that needs to be elaborated before and during the problem solving process.

Within the simulation phase the participants are fostered to solve the given problem. Based on the knowledge about the structure and rules underlying the model and the analysis of the initial state of "their" enterprise the participants have to make decisions in order to reach the goal stated in the presentation of the problem. After all decisions are made the model is simulated for one time step and the outcomes of the decisions can be analysed. The participants are expected to analyze the new state of the simulation in respect of the expected effects of their decisions. Discrepancies could point out misperceptions about the structure of the model. The perceived discrepancy could initiate a reflection process by the learner in order to validate and correct theirs mental model of the simulated enterprise/market and hence the represented economical concepts and their dynamics (DÖRNER and WEARING 1995).

With their research on complex problem solving behavior DÖRNER and associates could identify some significant differences between successful and unsuccessful participants in simulations (DÖRNER and WEARING 1995). It is referred to these differences more in detail later in this paper. During a simulation the moderator could give additional feedback regarding the problem solving process itself. While the feedback during a simulation is more specific to the individual problem solving process the phase of debriefing can be seen as a comprehensive view of the activities during the simulation and second to reflect and generalize the learning outcomes (CAPAUL 2001).

Besides the effort to analyze the individual problem solving processes to give an individual and appropriate feedback there is a technical issue for using a business simulation. At least there has to be a computer running the simulation model within a simulation software, e.g. Powersim Studio or Vensim. Further the participants need a possibility to enter decisions and analyze effects. That causes mostly the need of additional computers and a local network. To avoid the technical overlay, the idea of web-based (business) simulations arose in the late 1990 with the development of e-learning environments (MANDL et al. 2001).

A second intent was to make business simulations available to a broader audience. By the use of standard technology, i.e. a standard internet browser, the access to a business simulation does not depend on specific software installations. Simply a connection to the internet is required. While there is standard technology on the client side to explore the model structure and observe the results of the simulation, the simulation model itself is run on a web server. Using this web-based approach has at least two side effects. A broader audience causes a higher effort to analyze individual problem solving processes in order to give an appropriate feedback. And second because of the web-based setting participants can access a business simulation from different locations at different times a direct feedback by a moderator could not be given to each participant within a simulation. In addition although web-based learning is assumed as more self-directed an instructional support is needed. Especially novices can be overburdened by the complexity of a business simulation, which could lead to lower learning outcomes (STARK et al. 1998). Hence besides a simulation model a web-based business simulation needs an instructional support that supports learning respectively problem solving. To avoid an overextension of the learner several problems that reflect different levels of difficulty should be integrated within a business simulation. The different problems reflect the chosen didactic strategy, e.g. a gradual increase of complexity. Therewith the cognitive load that is caused by the problem does not lead to an overburden of the learner but allows further learning processes (KIRSCHNER 2002).

Another aspect of designing instructional support of web-based simulations is the transparency of the simulation model. In the context of business simulations there is an approach based on the idea of a glass box model, i.e. the structure and the rules of the simulation model are made transparent to the learner (ALESSI 2000; BERENDES 2002). Because business simulations represent a complex environment with many interconnected variables and different delays of effects an analysis of the different consequences of decisions would be hardly possible within a black box approach. Therefore a black box approach could even hinder the learning by reducing it to an inefficient and time-consuming trial and error process.

Although the transparency of a model is a prerequisite for efficient learning processes, the learning process itself has to be supported, too (HILLEN 2004). This paper presents an approach to realize a continuous feedback for the problem solving activities during a web-based business simulation. This approach addresses a mirco-adaptation as LEUTNER (1992; 1997) proposed. Micro-adaptation describes a continuous adaptation of the learning environment referring to the learner in short intervals in order to improve learning processes.

Success within business simulations

The traditional approach to assess the success of controlling an enterprise in a business simulation refers the analysis of core-variables. A main advantage of this approach is the easy retrieval of the value as a result of the simulation. A main difficulty is to find a set of variables that represent the state of the enterprise in a condensed way. Because this is a typical problem in economics there are several systems of core-variables which are partly orientated at variables from the accounting in enterprises. Therewith one can compare the performance of each learner at the end of the simulation in relation to a given set of core-variables. Because these are only end-states regarded the problem solving process itself isn't taken into account. One mistake during the simulation can overlay a very successful problem solving process and distort the comparison between the participants. Therefore there is a modified (or additional) process orientated approach of measurement necessary. Besides the end-state of a variable the relative improvements (or deteriorations) during a simulation could be measured (HASSELMANN 1993).

As mentioned the core-variables often derive from the accounting. A more comprehensive and holistic view of the processes within an enterprise is represented by the concept of the

Balanced Scorecard (BSC) by KAPLAN and NORTON (1997). In contrast to other sets of variables this concept integrates explicitly the strategy on an enterprise. In this paper this concept cannot be elaborated in detail. BERENDES (2002) has extended this economical concept with the indicators “goal-orientation”, “stability” and “foresight” to measure the competency of controlling a simulated enterprise.

The underlying assumption of the measurement of core-variables is that the values of the core-variables are the result of the decisions. The decisions are based on the mental model the learner have of the simulation model. Hence the better the mental model the better the decisions and at the end the performance of the learner (STERMAN 2000).

Besides the problem of the interpretation of the meaning of the core-variables the measurement provides only one part for the analyzing and supporting the problem solving process. The values are easily retrieved from the simulation but how the learner has come to his decision is not taken into account. From that perspective it could be said that the measurement of core-variables can be seen as the economical view on business simulations. Using well-known economical instruments can increase the ecological validity of a business simulation from the learner view and hence their motivation to cope with the simulation. However from an educational perspective the state of the BSC is ‘only’ a result of a learning process. For an instructional support there is the necessity of further analysis of the problem solving processes to explain how the learner develop decisions.

Analysis of the Problem solving activities

For analyzing the problem solving activities we can refer to the framework of problem solving by DÖRNER (1989; DÖRNER and WEARING 1995):

1. Goal-Elaboration
2. Hypothesis Formation
3. Prognosing
4. Planning and Decision-Making
5. Monitoring
6. Reflection

But as DÖRNER and WEARING have pointed out: ”…neither will these different phases of action regulation always show up in the behavior of subjects, nor is this sequence always sound.” (DÖRNER and WEARING 1995). Thus it cannot be seen as linear sequence how to solve complex problems but as a systematic framework to compare successful and less successful problem solvers by their activities.

Several research studies by DÖRNER have revealed typical deficits in solving complex problems (DÖRNER and WEARING 1995). He could observe that the goal-elaboration and orientation phase of experts last longer while novices tend to start earlier with making decisions. During the simulation the novices show a muddling-through behavior while the experts were more organized. In the phase of hypothesis formation DÖRNER distinguishes between *general orientation*, *special orientation* and *exploration*. While *general* and *special orientation* describes the scope of desired information, *exploration* focuses on the supposed effects resp. consequences of possible actions. In respect to business simulations *exploration* could be illustrated e.g. by a question for the possible effect of a higher price on the current market share. While novices often move between or within general and special, orientation the experts acted more on the level special orientation and exploration. The forecasting phase takes into account the estimation of possible developments. It has been shown that it is difficult for humans to estimate non-linear and/or delayed developments. Therewith the argument about the relation between the mental model and the performance of controlling an enterprise mentioned above could be supported. The better the elaboration of mental model the better the forecasting of the development of the simulation can be, and vice versa. Hence the discrepancy between forecasted and simulated values could be an indicator of the appropriateness of the mental model.

In the phase of decision making the experts follow a goal hierarchy where the main goal becomes divided into sub-goals. Decisions become connected to each other. In the scope of business simulations if an expert wants to gain more market share by lowering the price there for example would be an increase of the production rate to serve the expected demand. Novices in contrast make more isolated decisions. In relation to decision making another deficit can be observed. The effect of the decisions isn't monitored in many cases and hence wrong decisions are not corrected and deeper knowledge about the rules within the simulation model hardly built up. DÖRNER called this type of decision-making *ballistic decisions* as an analogue of a cannonball; once fired the flight could not be corrected anymore (DÖRNER and WEARING 1995). The last phase refers to reflection of the appropriateness of actions. Within a business simulation this phase can be triggered by an effective feedback.

Regarding the problem solving process it is not possible to give a feedback in the way of a 'right' problem solving schema. The expert-novice-comparison has revealed some specific deficits of novices. Hence a strategy for giving feedback focusing on the deficits could be a promising way to improve the problem solving behavior. From a more general perspective for the support and improvement of the learning respectively problem solving process an analysis of the exploration and decision-making processes within a business simulation is necessary.

One instrument to analyze and visualize the exploration and decision-making processes can be derived form the research with the *Strategic Management Simulations* (SMS) by STREUFERT and coauthors (STREUFERT and SWEZEY 1986; BREUER and STREUFERT 1995). SMS are quasi-experimental in the design in contrast to the business simulations which are based on a mathematical simulation model. The order of events within a SMS is mostly predefined and cannot be changed by the participants. The participants however receive the information about the effects of their actions in a way that they have the impression their decisions have an effect to the environment. This is done by varying the content of some of the messages by the moderator in dependency of the prior action of the participant. With that design each simulation is structural comparable and hence the environment of the performance of the participants. The actions of the participants are recorded. The decision-making process is visualized by the time-event-matrix (see Figure 1). The matrix shows the action of one participant in different scopes of decision dependent on the simulation time. The time-event-matrix can be used as a feedback tool to visualize the behavior to each participant and to point out specific inappropriate pattern of decision-making for example ballistic decision-making. A continuous and individual feedback for each learner based on the analysis of the problem-solving behavior, i.e. the exploration and decision-making processes can be considered as a mode of micro-adaptation sensu LEUTNER (1992; 1997).

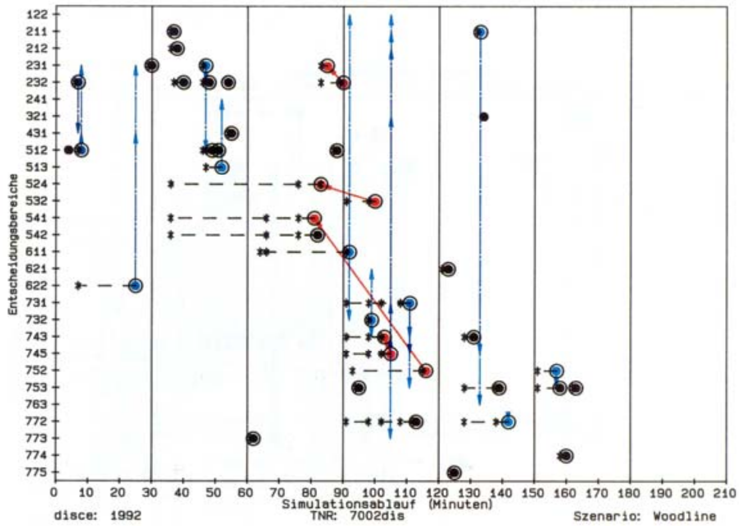

Figure 1: SMS graphic representation of the decision-making process of a participant

The business simulation *solarSYDUS*

For the development and testing of a micro-adaptation mode a prototype of a web-based business simulation is developed at the chair of vocational education and training at the University of Mainz. The business simulation is called *solarSYDUS* and represents an enterprise that produces and sells solar panels in a simulated market. On the market there are two additional enterprises, all three are in competition. The structure of the enterprises in *solarSYDUS* refers to the value chain by PORTER (1985). Therewith a well-known concept within the business administration community is used, which divides an enterprise into different activities, e.g. inbound logistics, production, etc. The value chain emphasizes the process perspective of enterprises and hence the systematic interdependencies of the different activities.

The SD-model is based on the former *SYDUS*-model by BERENDES (2002) which reflects the complexity of business structures. The improved model is now embedded within a web-based learning environment where the model is implemented at a web-server. The simulation runs on this server. The learner can access the simulation with a standard internet browser without any needs for additional installation of software. Besides the reduction of technical requirements the necessary instructional support of a SD-model is addressed to realize an individual support of each learner regarding the different cognitive structures and problem solving processes.

In *solarSYDUS* the glass box approach is applied. That means that the structure of the model is transparent to the learner on different levels. Besides the textual information about each activity and the enterprise itself the learner can access the model structure with definitions of each variable (see Figure 2, red arrow). Furthermore the learner can explore the model on different levels of resolution (see Figure 2). A detailed view on each single activity of the SD-model is possible as well as an overview of the whole model.

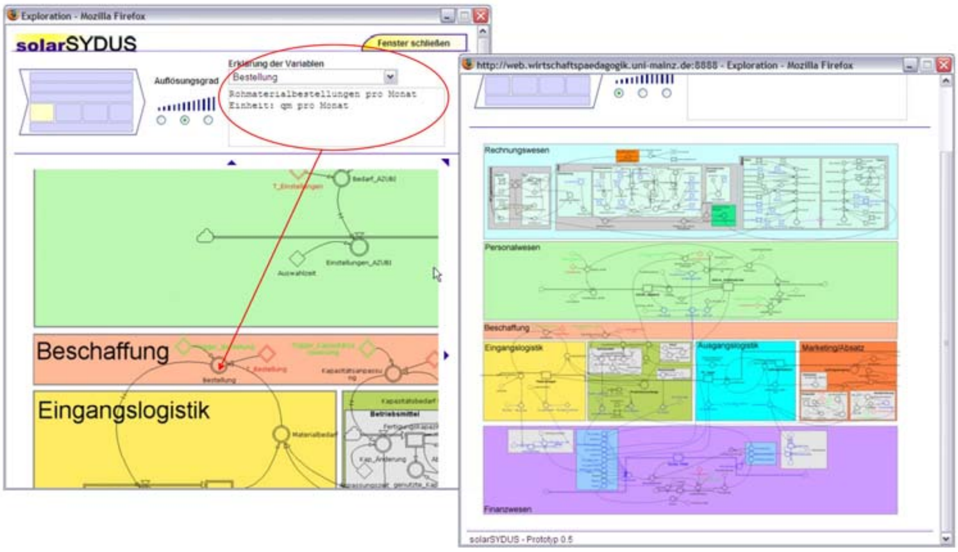

Figure 2: Transparency of the model in *solarSYDUS*

Besides the information specific to the enterprise the learner can find more general information about the market and technology of solar cells. Therewith the authenticity of the learning environment is addressed. Before the learner starts with a simulation he has to choose a problem he wants to solve. At the current version there are three problems that represent different levels of difficulty or complexity. While the first problem addresses the exploration process to get the necessary structural knowledge about the model, the further problems focus on controlling an enterprise starting controlling one activity, e.g. inbound logistics to controlling the whole enterprise. Therefore the learner has to coordinate his decisions according to a more general strategy. During a simulation the other two enterprises are controlled by automated decisions rules. The learner can activate these decision rules in his enterprise, too, similar to a decision support system.

The different presentations of problems should address the different prior knowledge of the business simulation of different learners. Therewith the aspect of a cognitive overload of the learner by facing him with too much complexity regarding his current cognitive structure is taken into account. According to the *Cognitive Load Theory* a cognitive overload could circumvent learning processes and hence the improvement of the mental model (KIRSCHNER 2002)[1].

For the feedback of the effects of the decisions there are different reports in each activity available. Figure 3 shows a report of the activity inbound logistics as the actual numbers and the graphical progression during the simulation. As a more comprehensive view of the state of the enterprise an adaptation of a Balanced Scorecard is integrated. Because the structure of this specific report is quite the same like presented in Figure 3, an additional figure is dispensed.

[1] A further elaboration of the Cognitive Load Theory could not be done within this paper. An introduction and reviews of the research within the context of this theory can be found in *Learning and Instruction, 12, 2002.*

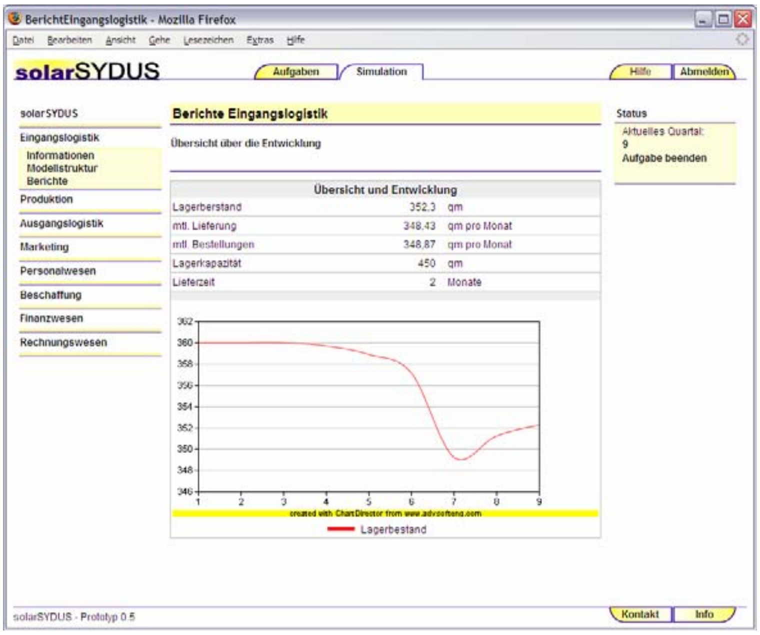

Figure 3: Reports in *solarSYDUS*

The 3rd problem within *solarSYDUS* fosters the learner to control the enterprise by making individual decisions. Figure 4 shows the decision form of the activity *inbound logistics*. The learner can choose between using the automatic decision rule (option “Auto” in Figure 4) or to enter a value, i.e. in the context of *inbound logistics* to order new raw material. If the participants make decisions by their own they have to make forecasts referring to several direct or indirect connected variables. The forecast comprises the options “no effect”, “decreasing”, “steady”, “increasing” or setting a concrete value (dropdown menu in Figure 4).

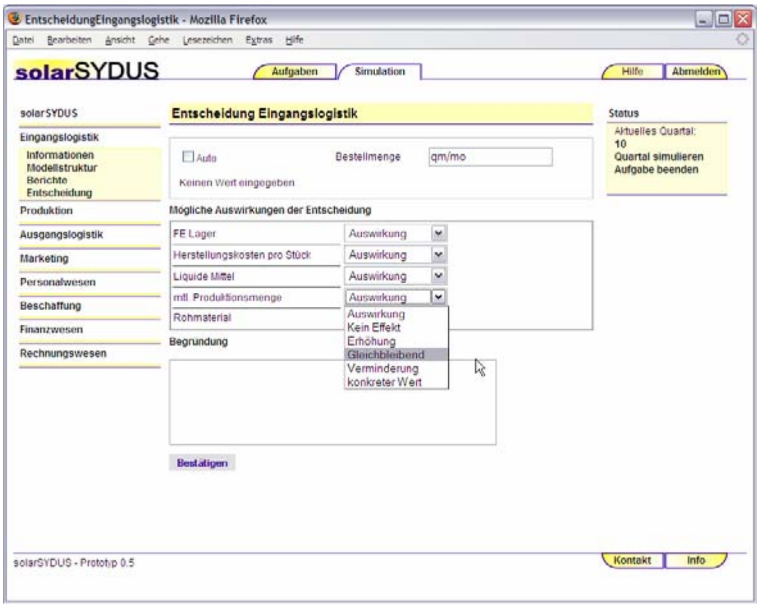

Figure 4: Decision form in *solarSYDUS*

With the concept of forecast the discrepancy between predicted and simulated values is addressed. Therewith an analysis of the appropriateness of the mental model referring to the simulation model is intended as described in a previous chapter. In this understanding a higher discrepancy could be interpreted as a higher inappropriateness of the mental model in relation to the SD-model. An analysis of the discrepancy could result in a feedback for the learner regarding specific relations between variables to direct exploring processes and hence the understanding of the structure of the SD-model of *solarSYDUS*.

For analyzing the exploration and decision-making processes, the activities have to be recorded. Therefore a database-server as a second component besides the web-server is needed. The database of *solarSYDUS* contains the values of the different variables, for the reports as well as every decision the learner makes during a simulation run. Furthermore the database stores the exploration and decision-making activities. Therefore each relevant activity like requesting the balance sheet is coded with a specific ID. If the learner requests for example a report or makes a decision, this activity is stored with a timestamp in the database. Therefore all relevant activities referring to exploration and decision-making processes can be reconstructed.

The data is available immediately during a simulation run and can be analyzed in order to find inappropriate patterns of problem solving behavior. Therewith a feedback referring to the activities of a learner could be given with a modified time-event-matrix (see previous chapter). The matrix could illustrate the behavior of the learner in general and could point out deficient patterns of behavior, e.g. ballistic decisions in order to induce self-reflective processes. The effects of this kind of feedback can be observed by the behavior of the learner in the follow-up simulation steps. And second the feedback should improve the performance of the learner. Therewith a link back to the economical perspective within business simulations is drawn.

Perspectives

With the use of web-based business simulation in tandem with a database-server a combination of the traditional measurement of success within business simulations *and* the measurement of problem solving behavior becomes possible. This approach can provide a more individual feedback to the participants within business simulations combining the learning processes and outcomes. Therefore the approach of embedding a huge SD-model within a web-based learning environment could enhance the potentials of learning with SD-models considerably. Because business simulations represent a complex environment with many interconnected variables especially novices could be overextended by this complexity due to the lack of an appropriate structure of their cognitive system to handle the complexity. The additional instructional support could avoid the risk of a cognitive overload caused by presenting different presentations of problems which reflect different grades of complexity. This ensures that learning processes can take place and that feedback could be regarded as a support for their problem solving and not as a source of additional and overextending cognitive load.

Furthermore the described concept of real time feedback does not only refer to the result of the problem solving process but it takes into account the process itself. This concept displaces the traditional (summative) assessment of problem solving behavior at the end of a simulation to a formative assessment during a simulation. The combination of both, behavior and performance analysis could provide a more detailed insight into the learning processes with SD-models. Because the described concept of the real time feedback refers to the problem solving behavior by identifying inappropriate patterns it could be applied not only to business simulations but to simulations in general to train problem solving behavior within a specific domain represented by the specific SD-model.

Although web-based business simulations could contain an instructional support to foster self-directed learning only the first two phases regarding the process of performing a business simulation are addressed in this paper. The *debriefing* is left out because to support this phase additional methods are needed.

The technical concept of the prototype *solarSYDUS* is currently tested by students. The first look at the generated data of the processes and the feedback of the students based on a questionnaire endorsed the chosen technical approach. Hence the next step will be to analyze the data automatically in order to find patterns of inappropriate actions in exploration and decision-making behavior. And likewise to analyze the effects on the learning processes by given a comprehensive feedback to the learner's problem solving behavior. It is expected that this improves the performance of learners within business simulation and would be the main aspect of further experiments with the business simulation *solarSYDUS.*

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