Learning histories in simulation-based teaching: the effects on self-learning and transfer

A. Parush*, H. Hamm, A. Shtub

Faculty of Industrial Engineering and Management, Technion—Israel Institute of Technology, Haifa 32000, Israel

Received 8 August 2001; accepted 13 May 2002

Abstract

Simulations are recognized as an efficient and effective way of teaching and learning complex, dynamic systems. A new concept of simulation-based teaching with a built-in learning history is introduced in several simulation-based teaching tools. The user of these systems obtains access to past states and decisions and to the consequences of these decisions. To date, there has been very little research on the effectiveness and efficiency of the learning history in simulation-based teaching. In this paper we report the results of a controlled experiment to evaluate the effectiveness and efficiency of a learning process that takes place in a dynamic simulation. This was done with and without recording and accessing the history of the learning process, along with the ability to restart the simulation from any point. The experiment was based on the simulation teaching tool called the Operations Trainer (OT) that simulates the order fulfillment process in a manufacturing organization, implementing an Enterprise Resource Planning (ERP) system. The findings show that with the learning history recording and inquiry available to the users of the OT simulator, a better performance was obtained during the learning process itself. Moreover, when the use of the history mechanism was removed after 2 weeks, the better performance still remained. In addition, performance was similarly better in a different context, than the one used in the original learning with access to the learning history. The findings are discussed with respect to the self-learning process in simulation-based teaching environments and the practical implications of using simulators in the growing field of Electronic Learning (E-Learning).

© 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Interactive learning environments; Simulations; Teaching/learning strategies

1. Introduction

Electronic Learning (E-Learning) environments and the digital university are becoming increasingly pervasive with the advent and popularity of the Internet and Intranet (e.g. Hazemi,
Old and new teaching methods and instructional strategies are being explored and developed. The common thread among all is that the learning process, in most cases, is individual. While much development and research effort is directed towards the new technologies, less focus is put on better understanding how the self-learning process interacts with those technologies. This paper focuses on this issue with respect to simulation-based teaching and learning.

Simulations are recognized as an efficient and effective way of teaching and learning complex dynamic systems. Efficiency is gained by reducing the time it takes to reach a specified level of learning, and effectiveness is gained by achieving better results in performing the tasks learned. In particular, simulations are becoming an integral part of management and engineering education as students learn by using and building simulations of complex systems and processes (Canizares, 1997; Cole & Tooker, 1996; Jones & Schneider, 1996; Lu, Oveissi, Eckard, & Rubloff, 1996; Nahvi, 1997).

Simulators can incorporate special teaching and learning mechanisms to support the individual learner. In contrast to the real world, which is being simulated to various degrees of fidelity, the students using a simulator are able to “stop the world” and “step outside” of the simulated process to review and understand it better. There can be a variety of simulation support mechanisms. Those include instructor-student interaction support, help and guidance mechanisms, group learning, and learning history recording and inquiry. Most support methods need serious modifications for the context of electronic learning. We focus here on history recording and inquiry.

Learning histories are particularly important because reviewing it can encourage meta-cognitive processes; encourage students to monitor their behavior and reflect on their progress (Carroll, Beyerlein, Ford, & Apple, 1996; Guzdial et al., 1996). It also enables analysis of the decision making process as opposed to analysis of results only.

The most basic and oldest view of history recording and inquiry in interactive computer systems is the temporal sequence of actions and events. In its simplest form, user actions are logged and recorded, and are then accessible in various ways for recovery and backtracking purposes (Vargo, Brown, & Swierenga, 1992). Such a mechanism is used in various programming and editing applications for “user recovery” or “undo”. Several recovery mechanisms have been developed ranging from a simple undo/undo or undo/redo history (e.g., Archer, Conway, & Schneider, 1984; Thimbleby, 1990; Yang, 1988) to complex structures, such as Undo Skip & Redo (Vitter, 1984), to graphical trees (Toriya, Satoh, Ueda, & Chiyokura, 1986). Simple historical data management can also be used for purposes of review only, such as in bank account applications (e.g. Ginsburg & Tanaka, 1986). In summary, this variety of history keeping and backtracking strategies reflects on both strictly linear and nonlinear temporal sequences of user actions.

History recording and inquiry have been reported for simulation-based teaching. For example, a simulation-based learning environment is described by Rose, Eckard, and Rubloff (1998) and Plaisant, Rose, Rubloff, Salter, and Shniederman (1999). This environment was used to develop simulations for semiconductor manufacturing (Lu et al., 1996) or a simulation of the Nile River Basin to explain complex river behavior and the management of its resources (Levy & Baecher, in press). A system to record, manage and visualize learning histories within the above described learning environment was developed and described by Salter (1999). Much research has been directed at history recording and inquiry of user actions and events in interactive systems and also for learning histories. However, the effect of history keeping mechanisms embedded in
simulation-based teaching tools is not fully understood yet. In particular, the effects of such mechanisms on learning itself were not explored sufficiently. In this study, we asked the following basic questions:

1. Can history recording and inquiry affect the self-learning curve during the training phase with the simulator?
2. Can history recording and inquiry affect the transfer of what was learnt with the simulator?

An important question is which simulator to use in order to explore answers to these questions. Our assessment is that learning and teaching to understand and manipulate physical, technical systems is different from learning and teaching to understand managerial and organizational processes based on highly dynamic and non-deterministic information. Consequently, a simulator for teaching the latter type of process can be a more sensitive test for the effects of learning histories on the learning itself. In the next section we describe a simulator used to teach complex information monitoring and decision making in the context of industrial engineering and management.

The Operations Trainer (OT) (Shtub, 1997, 1999, 2000) is designed to teach the complexity of supply chains and to train students and managers to exploit the ability of modern decision support systems to collect, store, process and present large quantities of real time information. The OT is a teaching and learning aid that integrates the case study and the modeling approaches. Different scenarios (or case studies) are taught using the OT. A Management Information System (MIS) and a Decision Support System (DSS) combining a database and a model base support the users. It is users who set the policies that govern “automatic decision making”, and users who decide when to override this automatic decision making process by switching to ad hoc actions.

A simple yet user friendly control system is built into the OT to support fast reaction to problems caused by the uncertainty built into the scenarios.

University courses based on the OT methodology were conducted in business schools for MBA students and in Engineering schools for Industrial Engineering students. In the business schools, the OT was used in courses in Operations Management and in courses on the use of Information Technology. It gave students an insight into the relationship between Operations, Marketing, Purchasing and Finance. Scenarios designed to teach the basic models used for supply chain management by Enterprise Resource Planning Systems (ERP) were used.

In the engineering schools the methodology was used as a basis for an introductory level course in Industrial Engineering and in a one-semester production planning and control lab. In the lab students performed a sequence of 14 experiments using the OT and a commercial ERP system. On each subject they had to learn the theory, then run an experiment based on a specific scenario that focused on the weekly subject, and finally run a similar example on a commercial ERP system. The students acknowledged the friendliness and simplicity of the simulator compared to the commercial ERP system. According to the students, by using the simulator, it was much easier to learn and much simpler to understand the concept of ERP and to practice its use in a dynamic, integrated manufacturing environment.

In order to answer the questions of this study, a history recording and inquiry mechanism was added to the OT simulator. This mechanism enabled the recording of any point during the simulation run. Also, the ability to inquire and review any previously recorded point, and finally to restart the simulation from any previously recorded point was now made possible. If learning
histories can enhance the learning process with simulation-based teaching and learning, we expect that students having the history mechanism in the simulator will learn better the decision making process involved in operations management. Moreover, we also expect that when the history mechanism is removed, students who use it will still show better understanding of the subject matter by transferring what they learnt to new contexts.

2. Methods

2.1. Experimental design

The experimental design was based on two conditions:

1. An experimental condition having a history recording and inquiring mechanism.
2. A control condition without the history mechanism.

The experiment flow was based on three phases during which the history mechanism was introduced and removed. It was designed to enable the testing of the basic learning and transfer to another context. The three phases, presented schematically in Fig. 1, are:

*Phase I: Basic Learning*—Subjects were divided into two groups according to the conditions. Subjects in both groups had to manage the same scenario—a flow shop manufacturing three different products from four types of raw materials, using four types of machines. Four functional areas are presented in the scenario: marketing, finance, purchasing and production. In each area the students had to set up policies, to monitor and control the process and to take ad hoc corrective actions when the preset policies did not produce the required results.

*Phase II: Transfer to the same scenario as in Phase I*—History recording and inquiry were not available to both groups. All the subjects ran the same first scenario once more.

*Phase III: Transfer to a different scenario*—History recording and inquiry were not available to both groups. All the subjects ran a different scenario once.

![Fig. 1. The study design in terms of the three phases and the learning and transfer implications as a function of the study groups and the presence/absence of the history mechanism.](image)
2.2. Measurements

Learning and transfer of learning were measured using the following performance indices:

*Profit*—A standard profit and loss statement is generated by the Operations Trainer. The cumulative profit at the end of the simulation run (6 months) is one indication of the effectiveness in which the student manages the delivery process.

*Due Date Performance* (DDP)—A second indication of effectiveness that measures the percentage of orders supplied on time by the student in the simulated scenario.

*Run Duration*—the elapsed time it took each student to run each simulation run was measured. Since it was possible for the experimental group to pause for analysis and evaluation at any point throughout a simulation run, this performance measure could answer the following:

1. Did the speed with which decisions were made by the students change as a function of the experimental conditions?
2. Did subjects having the history mechanism become more proficient using it?

2.3. Setup

The commercial Operations Trainer simulator (Shtub, 2000) was used in this study. In addition, a modified version of this simulator including the history mechanism was used for the experimental condition in the first phase. In this version, subjects could stop the simulation run at any time and save all the scenario parameters at that point. This could be done as often as the users decide. The users could also at any point stop the simulation run and load any previously saved point. Then they could either review it and continue the run as is, or restart the scenario from that saved point. The random generators that govern the stochastic processes in the simulations were the same for all the students, i.e. the same sequence of random numbers was generated for each student participating in the study.

2.4. Subjects

A group of 45 first year Industrial Engineering students participated in the experiment. The age of the students (both male and female) ranged from 18 to 30. All subjects had no previous experience with the Operations Trainer simulator that was used in the experiment.

2.5. Procedure

The experiment was run in a computer classroom at the Industrial Engineering and Management Faculty of the Technion. This room included 15 standard desktop personal computers with MS windows. The total of 45 subjects were divided randomly into three groups to enable the simultaneous running of 15 subjects in the computer room. Each of the 15 subjects were assigned randomly to either the experimental or control groups.

An introduction to the Operations Trainer was given prior to the first session. The introduction included oral and written instructions on how to use the simulation, explanation of the scenarios
and a discussion on the performance measures used. The students were motivated to achieve best possible result as the profit and Due Date Performances were used to calculate part of the final grade in the Operations Management course in which they were enrolled.

Each student had to run the same scenario five times representing the first two phases of the experimental design: four runs in the first phase and a fifth run in the second phase, which took place 2 weeks later. A second, different scenario was then introduced in the second session, representing the third phase in the experimental design, and the students had to manage this new scenario (a sixth simulation run) as well.

3. Results

3.1. General

The following hypotheses were tested:

1. There is a learning process, i.e. improvement in performances accrue as the number of repetitions increases during the first phase (four runs of the first scenario) in both experimental and control groups.
2. The history tracking mechanism enhances learning and therefore the mean profit and the mean DDP generated during the first phase (four runs of the first scenario) by the experimental group will be significantly higher than those generated by the control group.
3. The duration of running the simulation runs with the history mechanism is significantly higher than running the scenarios without the history mechanism.
4. There is a significant difference between the results (profit and DDP) achieved at the end of the second phase (simulation run number five with no history mechanism) by the experimental group (students who used the history tracking mechanism before) and the results achieved by the control group (students who did not use the mechanism).
5. There is a significant difference between the results (profit and DDP) achieved at the end of the third phase (simulation run number six) by the experimental group (students who used the history tracking mechanism) and the results achieved by the control group (students who did not use the mechanism).

3.2. Data analysis

The data were analyzed using two statistical tests: the $t$ test and the Analysis of Variance (ANOVA). Both tests are aimed at testing whether the observed differences between the means of data samples are significant according to the statistical hypothesis testing approach (Ferguson & Takane, 1989). The $t$ test is aimed at testing the significance of differences between two means for independent samples (the experimental vs. the control groups in this study). The ANOVA is geared for testing the differences between the means of more than two samples, and is based on the partitioning of the variance in the data into different sources. The resulting parameter of the ANOVA is a statistic called ‘$F$’.
The results of the statistical tests are reported here in the following format: $F$ or $t = XX; \text{df} = xx, P < XX$. The value of the statistic in the test that was performed, $t$ or $F$, is presented first. This is followed by the number of Degrees of Freedom (df) that were used in the test. Finally, the significance is indicated by $P$, which is the probability of making an error in claiming that the difference is significant. Any probability less than 5% is interpreted in the behavioral science as a significant difference.

3.3. Phase I: the basic learning process

3.3.1. Profit

Mean profit at the end of each of the four simulation runs was computed for both experimental and control groups. These means are displayed in Fig. 2. A clear increase in the mean profit can be seen for the experimental group as a function of the run number. No such pattern is observed for the control group. No significant difference ($P > 0.05$) was found between the mean profits of the two groups in the first run. ANOVA with repeated measures was performed in order to test the first two hypotheses with respect to the profit index. A significant difference ($F = 5.9, \text{df} = 1, 42, P < 0.05$) was found between the two groups. In addition, a significant difference was found among the four runs ($F = 3.1, \text{df} = 3, 42, P < 0.05$).

Multiple comparison tests were run within the ANOVA model since no significant interaction was found between the groups and the simulation runs. A significant interaction was found in the contrast comparing run number one and run number four with the groups factor ($F = 4.3, P < 0.05$). This interaction can be seen in Fig. 2 in the continuing increase in profit mean for the experimental group as opposed to the lack of continuing increase in the control group.

3.3.2. Due date performance (DDP)

Mean DDP at the end of each of the four simulation runs was computed for both the experimental and control groups. These means are displayed in Fig. 3. A clear increase in the mean

---

Fig. 2. The profit at the end of five simulation-runs of the first scenario for both experimental and control groups.
profit can be seen for the experimental group as a function of the run number. No such pattern is observed for the control group. No significant difference was found between the mean profit of the two groups in the first run. ANOVA with repeated measures was performed in order to test the first two hypotheses with respect to the DDP index. A significant difference \((F = 3.7, \text{df} = 1.42, P < 0.05)\) was found between the two groups. In addition, a significant difference was found among the four runs \((F = 16.25, \text{df} = 3.42, P < 0.01)\). Finally, an indication for an interaction was found between the group and the simulation runs \((F = 2.4, \text{df} = 42.3, P = 0.07)\).

Multiple comparison tests were run within the ANOVA model to explore further the interaction between the groups and the simulation runs. A significant interaction was found in the contrast comparing run number one and run number four with the groups' factor \((F = 5.2, P < 0.05)\). This interaction can be seen in Fig. 3 as a continuing increase in DDP mean for the experimental group as opposed to the lack of continuing increase in the control group.

### 3.3.3. Simulation run duration

Mean duration of running each of the first four simulation runs was computed for both groups. The means are displayed in Fig. 4. It can be seen that the mean duration of the runs for the experimental group were higher for all four runs. However, the mean duration decreased in the third and fourth runs. The mean duration of the first simulation run was significantly higher \((t = 3.5, P < 0.01)\) for the experimental group, as expected in hypothesis number 3. ANOVA with repeated measures was performed to further test this hypothesis. A significant difference \((F = 24.7, \text{df} = 1.42, P < 0.01)\) was found between the two groups. In addition, a significant difference was found among the four runs \((F = 3.7, \text{df} = 3.42, P < 0.01)\). However, a significant interaction \((F = 4.09, \text{df} = 3.41, P < 0.01)\) was found between the group and the run number factors.

### 3.3.4. Summary of Phase I

Both profit and DDP were significantly higher for the experimental group than the control group. The difference was higher at the end of the fourth run. This latter trend was particularly
pronounced with the DDP index. In other words, while there was a consistent increase in the performance indices of the experimental group, there was no corresponding trend with the control group. In addition, the initial time it took to run the simulation when using the history mechanism was significantly higher than running the simulation without it. However, this time decreased significantly towards the third and fourth run.

3.4. Phase II: transfer to the same scenario

3.4.1. Profit

Mean profit at the end of the fifth simulation run (same scenario, no history mechanism for both groups) was computed for both experimental and control groups. These means, along with the means of the first four runs, are presented in Fig. 2. It can be seen that the mean profit of the experimental group at the end of the fifth run was still higher than the mean profit of the control group. It also maintained the trend of the first four runs. ANOVA with repeated measures was performed in order to test hypothesis number 4. A significant difference ($F = 9.0$, df = 1.42, $P < 0.01$) was found between the two groups. An additional pairwise test was performed between the means of the two groups for the fifth run. The mean profit of the experimental group was significantly higher ($t = 2.4$, $P < 0.05$) than the mean profit for the control group.

3.4.2. DDP

Mean DDP at the end of the fifth simulation run (same scenario, no history mechanism) was computed for both experimental and control groups. These means, along with the means of the first four runs, are presented in Fig. 3. It can be seen that the mean DDP of the experimental group at the end of the fifth run was still higher than the mean DDP of the control group. It also maintained the trend of the first four runs. ANOVA with repeated measures was performed to
further test hypothesis number 4. A significant difference ($F=16.6$, $df=1.42$, $P<0.01$) was found between the two groups. In addition, a significant difference was found between the five runs, for both groups ($F=3.8$, $df=4.42$, $P<0.05$). An additional pairwise test was performed between the means of the two groups for the fifth run. The mean DDP of the experimental group was significantly higher ($t=2.6$, $P<0.01$) than the mean DDP of the control group.

3.4.3. Simulation run duration

Mean duration of running the fifth simulation run was computed for both groups. The means are displayed in Fig. 4. The same trend that occurred in the third and fourth runs in the first phase remained in the fifth run. ANOVA with repeated measures was performed in order to test hypothesis number 3. A significant difference was found among the five runs ($F=16.6$, $df=4.42$, $P<0.01$). No significant difference was found between the mean durations of the fifth run of both groups.

3.4.4. Summary of Phase II

Both mean profit and DDP were significantly higher for the experimental group at the end of the fifth run. This finding was particularly pronounced for the DDP index. In addition, the control group still continued the trend of no improvement. Mean duration of the fifth run showed no difference between the groups.

3.5. Phase III: transfer to a different scenario

Mean profit, DDP, and the duration of the sixth simulation run were computed for both experimental and control groups. The mean DDP for the experimental group was significantly higher ($t=2.1$, $P<0.05$) than the mean DDP for the control group. No significant differences were found between the mean profit and the mean duration between the two groups.

In summary, the experimental group exhibited better performance only with respect to the DDP index, and was not significantly better with respect to the profit relative to the control group. Thus, the group that used a history mechanism with a given scenario shows better transfer to a completely different scenario only with respect to the DDP.

4. Discussion

4.1. The basic effect

In the first phase of this study, the experimental group had the option to review its learning history and restart the simulation from various points in that history. The control group did not have this option and just tried to learn the subject matter following an individualized learning process via the simulator. Since the experimental group achieved significantly higher profit and better DDP throughout this phase, it seems to reflect a better learning process due to the use of the learning history mechanism. There was very little learning for the control group. It should be emphasized that the usual way of learning with the OT is with a human instructor who serves as a “reviewing” mechanism. In other words, the findings of this study indicate that simulation-based
learning must be supported by a reviewing mechanism if self-learning (i.e. without a human instructor) is performed.

One could be concerned about the extra time it may take to run simulation-based learning with an additional history inquiry mechanism. The findings here show that while it did take the experimental group longer to complete the first two runs, this duration decreased significantly till it matched the duration of the control group. This decrease in the duration of the simulation run seems to reflect an increasing efficiency in using this mechanism in the experimental group.

Christina and Bjork (1991) and Schmidt and Bjork (1992) have emphasized that improved performance during the learning process itself, such as the one observed in the first phase of the study, does not necessarily reflect better learning; i.e. long-term retention and transfer to related tasks or altered contexts. This possibility was tested in the second and third phases of this study. In the second phase neither of the groups had the history mechanism option. Both ran one more time the same scenario that they had run in the first phase. At the end of this additional run (run number 5 of scenario 1), the experimental group that used the history mechanism during the first phase still maintained better performance in the second and third phases when the history mechanism was removed from their use. This can reflect that the knowledge and understanding, initially acquired with the aid of the history mechanism, were transferred to a situation without the history review. The positive effects of previously using the history mechanism did not wear off after two weeks and long-term retention was demonstrated. In addition, the removal of the history mechanism did not have an adverse effect on the duration of the run by the experimental group. Both groups still ran the scenario with the same duration.

The findings of the first and second phases can be interpreted as reflecting only a significantly better learning of the scenario. In the third phase, both groups ran a different scenario and both without the history mechanism. In this phase, the experimental group still achieved a significantly better DDP. Thus the initial use of the history mechanism enhanced the acquisition of some knowledge and understanding that were beyond the specifics of a given scenario. In the following discussion we analyze the difference between the profit and the DDP indices as a possible explanation for the findings of the third phase and offer a better understanding of the effects of using the history mechanism.

4.2. Skill and meta-skill acquisition

A scenario in the OT simulator is characterized by a manufacturing company with a given set of operating parameters. The company in the scenario operates within given market parameters, such as cost-to-demand relationships. Consequently, one process that could have taken place in the first phase of our study was that the use of the history mechanism aided the experimental group to become more familiar with the parameters of the first scenario. This, in turn, enabled them to achieve better profit and DDP. This latter effect was still present 2 weeks later.

However, there were additional aspects to the performance of the experimental group in the first and second phases. The better performance was particularly stronger with the DDP. Moreover, the experimental group achieved a better DDP in the third phase which included a different scenario. These findings can be accounted for by the differences between profit and DDP. Learning to increase the profit is a matter of learning the characteristic of the cost/demand specific function, and understanding where the optimal point of that function is. In other words, the
profit is scenario-dependent. On the other hand, the Due Date Performance (DDP) requires actions such as keeping enough stock and proper planning of the manufacturing capacity. Such activities are scenario-independent since they reflect general strategies of how to approach, monitor, understand, and make decisions related to supply chain management.

The implications of the differences between profit and DDP suggest an additional learning effect, due to the use of the history mechanism, beyond better scenario familiarity. This effect can be viewed as aiding the users of the history mechanism to acquire and/or develop the meta-skills for solving problems and making decisions with managerial scenarios.

4.3. The dynamics of learning with history inquiry

Some of the earlier learning theorists distinguished between the “habit strength”—long-term retention and performance—and the “momentary response potential” (Hull, 1943) or “response strength” (Estes, 1955) which represent more the performance during learning. A more recent modification to this distinction was presented by Bjork and Bjork (1992). In their “new theory of disuse”, following Thorndike’s “Law of Disuse” (1914), they made the distinction between “storage strength”—representing the degree of learning—and “retrieval strength”—representing the ease of accessing the learnt material. Retrieval strength weakens in the course of time if the storage strength was not built properly during the learning process. In both versions of the theory, learnt responses decay over time if not “used”, that is, not accessed continually or at least used intermittently.

In our study, the use of history supported the building of retrieval strength which was reflected in the better performance during the learning phase. However, it also built storage strength which prevented or at least slowed significantly the decay of the response strength. The history mechanism enabled the building of storage strength by providing the learners with continuous access to the learnt material. Moreover, this access did not create a specific and transient learning context but probably provided exposure to more possible subject matter elements. This in turn, not only strengthened the storage but made it possible to better understand the process underlying the learnt material.

4.4. Practical implications and future agenda

The current trend of using the Internet and Intranets for learning needs a better understanding of the self-learning processes so that adequate teaching environments can be developed. Simulation tools such as the OT, which were originally developed for classroom teaching with human support, can be a part of electronic learning if proper modifications are made. These modifications are possible because of our better understanding of the self-learning process associated with simulators.

The findings of this study have strong implications for simulation-based learning and electronic teaching and learning environments. In those environments where the learner is expected to have individualized simulation-based learning or where the learner is expected to acquire meta-cognitive skills related to the subject matter, then an additional review mechanism is required. In our study we demonstrated that the review of the learning history and the ability to restart the simulation at any point of the learning process has a strong enhancing effect on learning.

The study uncovered many more questions that need further examination. It is possible that the students’ decision when to record the history had a particularly stronger effect on learning. It is
not clear whether history that was recorded automatically will have different effects than history that was recorded by the learner, as was done in our study. In addition, the effects of history inquiry alone, without the ability to restart the simulation are still an open question. Finally, more aspects and perspectives of visualizing and manipulating the learning history mechanism need to be explored as well as their possible effect on learning.

References


