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The Impact of Functional Fidelity in Simulator-based Learning of Project Management*

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Following previous research on the effectiveness of simulators in teaching project management, and research on the impact of history recording mechanisms on learning and forgetting, at individual level and at team level, this study focuses on the functional fidelity of the simulator. The simulator with high functional fidelity used in this study had two advanced project management functions: the ability to hire/fire employees and the ability to split activities. A group of 199 industrial engineering students were divided into two main groups with only one group having access to the advanced functions. Within each group the students were subdivided into sub-groups that used three different history-keeping modes: automatic (simulator-controlled), manual (student-controlled), and a third mode with no history keeping. All the groups used the same scenarios for training. The performance of participants who were running the simulation with higher functional fidelity (i.e., with advanced functions) was significantly better than that of participants running the simulation without these capabilities. Furthermore, the students' decisions on when to record the history during the training process had a particularly strong enhancing effect on the learning process.

Keywords: project management; simulator fidelity; decision making

INTRODUCTION

PROJECT MANAGEMENT deals with a one-time effort to achieve a specific goal within a given set of resources and budget constraints [1] in a non-repetitive environment. The learning process in this complicated domain is comparable to flying an airplane because both tasks are performed under uncertainty and demand simultaneous skills [2]. The theory of skill acquisition by experience learning includes four basic levels of the learning process: concrete experience, reflective observation, abstract conceptualization, and active experimentation [3]. Pilots are trained in a dynamic environment, while the backbone of most teaching and training programs in the area of project management is based on static models and case studies. The successful use of a simulator called PMT (Project Management Trainer) for teaching project management at the individual level has been reported [4–6]. The Project Management Trainer (PMT) was used in those studies as a teaching aid designed to facilitate the learning of project management in a dynamic, stochastic environment. The Project Management Trainer is designed 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. Past research on PMT focused on the effect of a history recording mechanism on the single-user (individual) learning process. Two types of history mechanism were tested: the automatic history mechanism, in which predefined scenario states are always saved, and the manual history mechanism, in which the trainee has to show an active involvement and save selected states manually. In [4] the study focused on how project mangers' decisions to record the history affected the learning process and on the effects of history inquiry when the ability to restart the simulation from a past state is not enabled. In [5] the study focused on the forgetting phenomenon and on how the length of a break period and history mode affected the learning, forgetting, and relearning (LFR) process.

Recently, an enhanced simulator for teaching project management at the team level PTB (Project Team Builder) was reported [7]. PTB was used to

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investigate three factors that affect team learning: previous experience, history recording mechanism, and the team debriefing process. In this paper, the study focuses on the complexity of scenarios used for training. Specifically the impact of functional fidelity on simulator-based learning is investigated. The simulator used in this study had two advanced functionalities: the ability to hire/fire employees and the ability to split activities. These functionalities can be made available to trainees upon the will of the trainer.

Simulators are widely used as a teaching tool, in academic areas and in business areas. Simulations have been used in teaching project management [8, 9]. In order to enable the user to acquire experience and to learn from previous results [10] in a lab setting, a simulation-based teaching environment is used. Simulations and games are recognized as an efficient and effective way of teaching and learning about complex, dynamic systems [11–13]. Commercial simulators are widely used [14]. Simulators as a learning tool have some well-known advantages [15]: simulators enable one to gain practical experience and allow an immediate response of the learned system to the user's decisions and actions. The nature of simulators as online devices yields a higher level of efficacy than traditional lectures [16]. In addition, simulators provide a reduction in the gaps between the learning environment and the 'real' environment, and the availability of training in situations that is difficult to obtain in the 'real world'. Simulators can meet the needed skills of strategic planning and thinking that are not easy to develop [17].

The transfer of learning is defined as the use of knowledge that was accumulated while learning one task to another task. The transfer of learning is considered as a determinant of simulator effectiveness [18]. A typical experimental paradigm of adaptive transfer examination is to look at the experimental structure of teaching and training on one task and then examine the performances in a different task. This experimental structure can be used to evaluate the effectiveness of a simulator.

A learning history mechanism is introduced in several simulation-based teaching tools in order to provide the learners with feedback on their progress. Learning histories encourages students to monitor their behavior and reflect on their progress [4, 5, 19, 20] and enable analysis of the decision-making process as opposed to analysis of the results alone. Learning history might be very effective, because the direct influence on the user's actions can be seen. History recording can be achieved either by automatic mode or by learner control. The user of these systems obtains access to past states and decisions and to the consequences of these decisions. In automatic history recording, the simulator determines when to record a given state in the learning process (based on pre-determination of the simulator designer). Nevertheless, in a learner-controlled mode, the learner determines if and when to keep a specific state in the learning process [4–6]. Giving the learners some control over the learning environment by letting them actively construct the acquired knowledge was shown to produce more effective learning [21–25].

The fidelity of the simulator has been recognized as a critical factor influencing the transfer of learning [26]. Traditionally, the fidelity of a simulator has been categorized as: perceptual, functional, and model fidelity [27]. Perceptual fidelity refers to the level of realism it evokes in terms of its look and feel relative to the real system. Functional fidelity refers to how the user or trainee uses and controls the simulation, its behavior and responses to user actions. Finally, model fidelity refers to the extent to which the mathematical or logical model underlying the simulation is close to the real processes and phenomena. In our previous studies, we have employed a relatively high perceptual and model fidelity [4–6]. However, the previous studies did not examine the possible impact of functional fidelity.

The question arises whether the combination of higher functional fidelity and the history of learning mechanism can have an enhanced impact on learning and the transfer of learning. The basic hypothesis underlying the study reported here is that there is an interaction between the functional fidelity of the simulator and the history mechanism used. In this paper, we examine the effects of using advanced project management capabilities and learning history keeping on learning. The simulator contained two advanced capabilities. The first is the capability to split activities during execution so that an activity can start, be stopped for a while and continue later. A second capability is to hire (or fire) employees. The impact of the history-keeping mode was assessed both in the learning phase of a given scenario in the PMT and in the transfer of learning to a different, more complex scenario.

RESEARCH DESIGN

Experimental design

The experimental design focused on three variables.

- Functional Fidelity. This variable included two conditions: A group with the enhanced capabilities (hire/fire and split activity), and a group without the enhanced capabilities.
- History Recording Mode. This variable included three conditions: automatic history recording, manual history recording, and a control group with no history recording.
- Undo. This variable included two conditions: learning with the undo option and learning without the undo option. (The undo option is not relevant for 'no history' recording.)

The two functionality conditions were fully crossed with the five conditions of the last two factors resulting in ten experimental conditions. All conditions, experimental and the control groups, were between-participant factors. Consequently, the

Table 1. Study design groups

Group	History-keeping mode		Enhanced capabilities
	History mode	Undo capabilities	
1	Automatic	NO	NO
2	Manual	NO	NO
3	NO history	NO	NO
4	Automatic	YES	NO
5	Manual	YES	NO
6	Automatic	NO	YES
7	Manual	NO	YES
8	NO history	NO	YES
9	Automatic	YES	YES
10	Manual	YES	YES

study design included ten groups presented in Table 1.

The paradigm used by Davidovitch et al. [5] was also employed in this study:

Phase I: Basic Learning—Participants were assigned to one of the ten groups. Participants in all ten groups were given the same single-project management scenario. Each scenario was run three times.

Phase II: Transfer—Participants in all ten groups were given a new multi-project management scenario. History-keeping mechanism and undo capabilities were removed for all participants running this scenario.

Project Management Trainer

The PMT simulator includes predefined projects. The following data are provided for each project: the distribution of the duration of each task; the predecessors of each task; resources and their availability; and the project cost. In addition, when using advanced project management capabilities the predefined project includes the max/min amount of workers allowed and the hire/fire cost. The user is required to finish the project by the due date and maximize profit. In the case of late completion of the project, a penalty is paid. In the case of early completion, a bonus (per day) is added to the project profit. The simulation is stochastic in the duration and cost of the tasks. The simulation time scale is in days. A task takes an integer number of days to complete.

Project planning—the task execution mode is selected in the Network view by changing the status of the task from undefined to plan. The planned start day is automatically calculated according to the predecessors of the tasks and their finish time. The user can plan the project according to the Normal time/Normal cost, i.e. selecting modes with minimum resources. The Gantt view is based on the most likely time of the planned task. Resource planning is performed using the resources graph. The graph includes information about the maximum availability of each resource. The project budget planning is supported by budget screens. A value in the graph indicates the accumulated daily income/cost and the maximum available cash.

Running the simulation—while running the simulation, the planned task time is changed to the actual task time, which is randomly generated by the simulator. Owing to uncertainty, actual values may differ from the plan. The user might change the task start time manually in order to satisfy the resource limitations. Project control is based on three elements: Actual Cost/Income report, Budget Control table and Performance Control table.

Simulation scenarios

The participants run two types of scenario. The first was a single-project (SP) scenario, considered to be an easier one, and the second was a multi-project (MP) scenario, considered to be more difficult. The simulation scenarios in the PMT version 4.0 include three screens: general, task information, resource information.

The general information included the following: no. of projects in the scenario (SP—1, MP—2), number of tasks (SP—16, MP—24), the project's required duration (SP—40, MP—60), initial cash—the amount of cash at the beginning of the project (SP—12000, MP—24000), bonus per day (SP and MP—5000), penalty per day (SP and MP—3000).

The task information included the following: tasks listed by name, task number and predecessors; the precedence type in the simulator is start–finish.

The resource information was the same for SP scenario and MP scenario and included the following: resource name, quantity per day, cost per day—daily cost of the resource while performing a task, idle cost per day—daily cost of the resource while not performing a task.

Measurements

Learning and transfer were measured using the profit performance indices: the cumulative profit at the end of the simulation run was considered as the best indicator of the effectiveness of the trainee's management of the project.

Setup

Project Management Trainer, version 4.1, was used in this study. The random generators that govern the stochastic processes in the simulations were the same for all students, i.e. the same sequence of random numbers was generated for each student participating in the study.

Participants

A group of 199 fourth-year Engineering students participated in the experiment. The age of the students (both male and female) ranged from 18 to 35. None of the students had any practical experience with project planning and management.

Procedure

The experiments were performed in computer classrooms at the Industrial Engineering and Management Faculty of the Technion in Haifa.

These two rooms included 30 standard desktop personal computers with Microsoft Windows© XP and Microsoft Project© 2002. The subjects were divided randomly into experimental and control groups.

An introduction to the Project Management 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 the best possible result as the profit was used to calculate part of the final grade in the Project Management course in which they were enrolled.

Data analysis

The data were analyzed using two statistical tests: a t-test and Analysis of Variance (ANOVA). Both tests are aimed at testing whether the observed differences between the means of the data samples are significant according to the statistical hypothesis testing approach. 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 aimed at 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; 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 was 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 behavioral science as a significant difference.

RESULTS

Learning phase

The mean profit at the end of each of the three simulation runs was computed for the ten groups. These means are displayed in Fig. 1. A clear and consistent increase in mean profit can be seen for the groups that used the history mechanism as a function of the simulation runs. No such pattern was observed for the two groups that did not use the history mechanism.

Testing the impact of the history-keeping mode and enhanced project management capabilities

Univariate ANOVA was performed in order to test the differences between the groups based on a full model with the two factors: impact of the history-keeping mode and enhanced project management capabilities.

No significant difference ($p > 0.05$) was found among the mean profits between the groups based

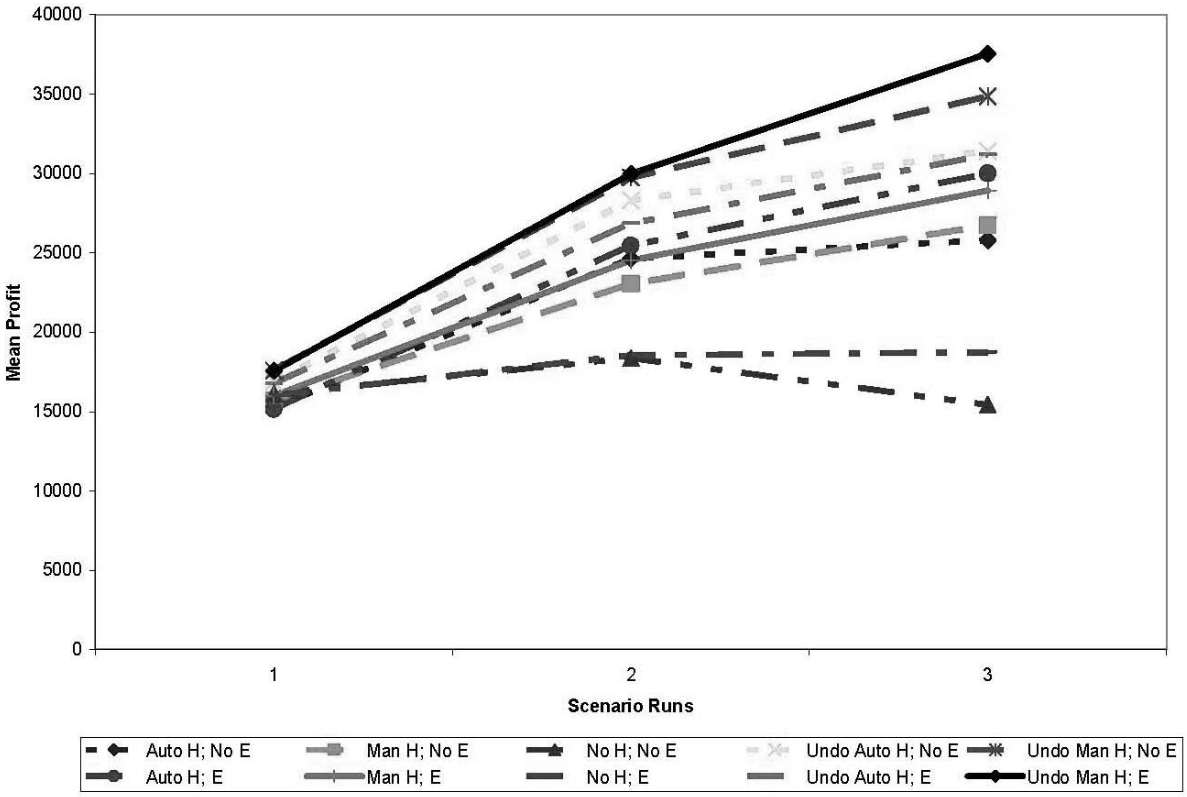

Fig. 1. The profit at the end of each of the three single project scenario runs for the ten groups.

on the two factors. For the interaction between factors; no significant difference ($p > 0.05$) was found among the mean profits based on the interaction between two factors.

ANOVA with repeated measures was performed in order to test the differences between the groups based on the full model of the two factors for the first, second and third runs. A significant difference ($F = 9.7$, $df = 1, 199$, $P < 0.05$) was found based on the history-keeping mode factor. Moreover a significant difference ($F = 4.3$, $df = 1, 199$, $P < 0.05$) was found based on the enhanced project management capabilities factor.

In order to expand the analysis, the statistical model was expanded. The model defined by using the history-keeping mode and the two new factors was analyzed with the factor of enhanced project management capabilities. These two factors were mode of history (automatic/manual) and using undo (with/without).

ANOVA with repeated measures was performed in order to test the differences between the three groups for the first, second and third runs. For each of the three main factors, the analysis results indicate a significant difference:

($F = 39.3$, $df = 1, 156$, $P < 0.05$) based on the undo capability.
($F = 5.3$, $df = 1, 156$, $P < 0.05$) based on the manual mode of history.
($F = 4.4$, $df = 1, 156$, $P < 0.05$) based on enhanced capabilities.

For the interaction between the factors, the analysis results indicate that there is a significant interaction difference ($F = 7.4$, $df = 1, 156$, $P < 0.05$) based on the interaction between the undo capability and the manual history mode. However, no significant difference was found in the other 2-level factor interactions and the 3-level factor interaction.

Testing the impact of the history-keeping mode

No significant difference ($P > 0.05$) was found among the mean profits of all groups for the first run. This verified that all participants started with a similar knowledge. ANOVA with repeated measures was performed in order to test the differences between the groups for the first, second and third runs. A significant difference ($F = 9.3$, $df = 1, 199$, $P < 0.05$) was found. No significant differences ($P > 0.05$) were found between the mean profits of manual history keeping without undo and automatic history keeping without undo, for all three runs. A significant difference ($F = 2.3$, $df = 1, 157$, $P < 0.05$) was found between manual history keeping with undo and automatic history keeping with undo for the first, second and third runs.

ANOVA with repeated measures was performed in order to test the differences between the groups that used undo capabilities and the groups that did not use undo capabilities. A significant difference ($F = 29.8$, $df = 1, 157$, $P < 0.05$) was found between the two groups.

In summary, the findings and analysis indicate that the history-keeping mechanism had a significant impact on performance. In all conditions where there was a history mechanism, mean profits increased significantly between simulation runs, whereas there was no improvement without history. Moreover, having the ability to undo—restart the simulation run from any point in a previous run—had a significant impact on performance for both history-keeping modes. In addition the option to use enhanced project management capabilities improved the profits and this factor is meaningful. The effect of the Enhanced capabilities factor on the history-keeping mode does not exist, while the performances remain better for using the manual history-keeping mode and using undo capabilities.

Transfer to a different scenario

The mean profit at the end of the fourth simulation run (multi-project scenario) was computed for the groups that used the history mechanism and the groups that did not use the history mechanism. These means are presented in Table 2.

Testing the impact of the history-keeping mode and enhanced project management capabilities

Univariate ANOVA was performed in order to test the differences between the groups based on a full model with the two factors: impact of the history-keeping mode and enhanced project management capabilities.

Table 2. The profit at the end of the fourth simulation run of the multi-project scenario for both experimental and control groups

Group	**History-keeping mode**		**Enhanced capabilities**	**Profit**
	History mode	**Undo capabilities**		
1.	Automatic	NO	NO	24787
2.	Manual	NO	NO	30121
3.	NO history	NO	NO	20158
4.	Automatic	YES	NO	32530
5.	Manual	YES	NO	34649
6.	Automatic	NO	YES	31731
7.	Manual	NO	YES	33478
8.	NO history	NO	YES	24137
9.	Automatic	YES	YES	31671
10.	Manual	YES	YES	34122

A significant difference ($F = 10.4$, $df = 1, 199$, $P < 0.05$) was found based on the history-keeping mode factor. Moreover, a significant difference ($F = 11.8$, $df = 1, 199$, $P < 0.05$) was found based on the enhanced project management capabilities factor. No significant difference was found for the interaction between the two factors.

In order to expand the analysis, the statistical model was expanded. The model defined by using the history-keeping mode and by new factors was analyzed with the factor of enhanced project management capabilities. These two factors were mode of history (automatic/manual) and using undo (with/without).

Univariate ANOVA was performed in order to test the differences between the three groups for the fourth run. For each of the three main factors the analysis results indicate a significant difference:

($F = 14.9$, $df = 1, 156$, $P < 0.05$) based on the undo capability.
($F = 9.6$, $df = 1, 156$, $P < 0.05$) based on the manual mode of history.
($F = 6.9$, $df = 1, 156$, $P < 0.05$) based on enhanced capabilities.

For the interaction between the factors the analysis results indicate that there is a significant interaction difference ($F = 14.4$, $df = 1, 156$, $P < 0.05$) based on the interaction between the undo capability and enhanced project management capabilities. However, no significant difference was found in the other 2-level factors interactions and the 3-level factors interaction.

Testing the impact of enhanced project management capabilities

A pair-wise t test was performed between the means of the groups with enhanced project management capabilities and the groups without these capabilities. The mean profit of the groups which used the history mechanism was significantly higher ($t = 2.8$, $P < 0.05$) than the mean profit for the groups that did not use the history mechanism.

Testing the impact of the history-keeping mode

It can be seen that the mean profit of the groups using the history-keeping mode at the end of the fourth run was higher than the mean profit of the groups without the history-keeping mode. A pair-wise t test was performed between the means of the two groups for the fourth run. The mean profit of the groups which used the history mechanism was significantly higher ($t = 9.7$, $P < 0.05$) than the mean profit for the groups which did not use the history mechanism. Furthermore, the mean profit of the groups that used the manual history-keeping mode was significantly higher ($t = 2.9$, $P < 0.05$) than the mean profit for groups that used the automatic history-keeping mode. The mean profit of the groups that used undo capabilities was significantly higher ($t = 3.2$, $P < 0.05$) than the groups that did not use the undo capabilities.

In summary, the findings and analysis indicate that when transferring to a complex multi-project management scenario and with no history-keeping mechanism, participants who had a history-keeping mechanism in the simple scenario achieved significantly higher profits than participants who did not previously have the history-keeping mechanism. In addition, participants who previously had manual history keeping achieved higher profit in the multi-project scenario as compared with having previously an automatic history-keeping mechanism.

In addition, having the ability to undo in the first three simulation runs had a significant impact on performance in the fourth run of a more complex scenario. With history-keeping, both manual and automatic, the mean profits were significantly higher than the respective manual and automatic conditions without undo.

The enhanced project management capabilities factor keeps the performances and the results of the significant differences based on the history-keeping mode. Moreover, the improved performances in the initial learning phase are kept for the transfer to a different scenario phase when considering the enhanced capabilities factor.

DISCUSSION

The research was focused on the learning process of project management using a simulator with higher functional fidelity implemented as advanced functionality to manage the project resources. The main issue that was investigated included the implications of the resource management and the activity split capability (advanced project management functionality) on the implementation of the history mechanism in designing the simulator and the optimal way in which to use this mechanism. The study included a single-session experiment with three identical simulation runs of simple scenarios (SP—single project scenario) and one simulation-run of a more complicated scenario (MP—multi-project scenario). The variables studied were using advanced project management capabilities, various history mechanisms and the transfer abilities of the learner.

The results indicate that using advanced project management capabilities enhanced learning for all user groups. The results show that in comparing the groups having history mechanism with the group without this mechanism, the groups that used the history mechanism achieved significantly higher profit and showed a better learning process associated with the use of the mechanism, while the groups that did not use the history mechanism had very little learning, as was found by Davidovitch *et al.* [4]. These results were found significant for both users that used advanced project management capabilities and for users that did not use them.

In the comparison between having a manual history mechanism and an automatic history mechanism, the findings show a better learning process for the participants with a manual history mechanism than the participants with an automatic history mechanism, and without any significant difference between simulation-run durations. Again, these results were found significant for both users that used advanced project management capabilities and for users that did not use them. Furthermore, observing the MP scenario performance, which reflected transfer abilities, it was found that the trend persisted and performance was better for the group that previously had the manual history-keeping mechanism. These findings support the hypothesis presented in the introduction to this paper, which suggested that manual learning history recording will have a greater positive impact on simulator-based learning as compared with the automatic history recording. It can be assumed that having the manual history-keeping mechanism forces the learner better to monitor their own progress, assess whether and when it would be best to keep the parameters of the simulation run, and then proceed with the simulation. These active cognitive activities may have contributed to the better understanding of the principles involved with project management and consequently provided the learner with a better capability to transfer and handle more complex scenarios. These findings are supported for the basic simulator capabilities as well as for advanced resources management capabilities.

In addition, for advanced capabilities, the comparison between having history mechanism with undo and without undo, during the basic learning phase, showed better performances for those having undo capability. The findings suggest that having the ability to undo in simulator-based learning can actually support and improve learning and not only improve performance.

CONCLUSIONS

The use of advanced resource management capabilities enhances the learning of project management. In addition, the history mechanism provides the user with a strong tool to enhance his or her learning process for both advanced resource management capabilities as well as for basic project management capabilities. The manual history mechanism should be implemented with undo abilities that aid the user to run simulation scenarios from saved store points. A better history mechanism is the manual one, which allows the user to save the desired simulation states based on their own decisions. In this way, the user is more active in the decision-making, both for saving actions and for retrieving and reviewing actions.

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