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# LEARNING OPERATIONS MANAGEMENT WITH WEB-BASED MANUFACTURING SIMULATION

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## ABSTRACT

*Traditional learning methods in operations management are not ideally suited for externalising knowledge. In this paper, an iterative, gaming-like learning approach for practicing OM issues by using discrete event simulation model is proposed. The approach is utilising an existing learning environment called Delfoi Planner EDU. Its web-based architecture supports distance learning that is an asset in the Finnish University culture. The article also describes the current learning content. The environment enables adding new tasks and exercises easily and is designed to support 3rd party simulation models thereby facilitating learning content exchange between content producers. The initial evaluation with a pilot class suggest that the benefits of gaming have been realised but also underlines the importance of a tested, stable environment as a prerequisite for learning.*

## 1. INTRODUCTION

The goal of operations management teaching is oriented towards educating future OM practitioners. However, operations management is a complex discipline requiring a multitude of skills. Bringing this complexity into the classroom is not easily accomplished. This article proposes discrete-event simulation games as a solution.

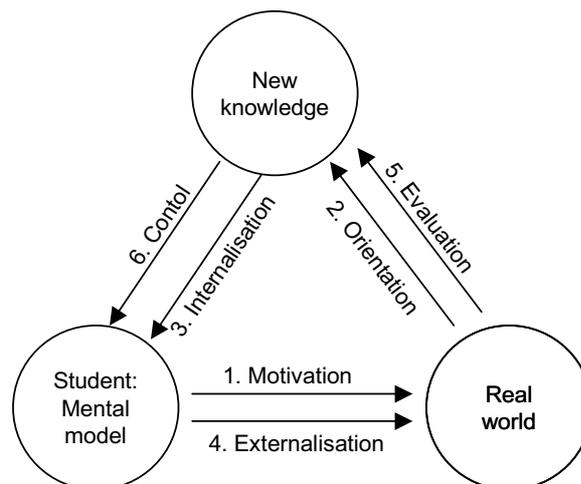
### **The learning process**

A mental model is a person's internal interpretation of some area of the world. Learning is defined as the creation of holistic and active mental models concerning of the real world and the learner's own

activities. The learning process is therefore an interaction between the new knowledge that the learner is supposed to master, the mental model under construction, and the reality where the learner will need the new knowledge. (Engeström, 1984)

The perfect learning process contains six discrete steps (**Figure 1**):

1. Motivation: When the learner perceives a conflict between what he knows and what he needs to know motivation occurs. In other words, his mental models are not sufficient for handling the situation on hand, and therefore they need to be modified.
2. Orientation: As the willingness to learn exists, some basic orientation is needed. The aim of the orientation step is to create a preliminary data structures and concepts needed for resolving the conflict that was invoked in step 1.
3. Internalisation: means changing existing mental models using the new knowledge.
4. Externalisation: means utilising the newly internalised knowledge for solving real-world problems, change the reality or create something new. The externalising phase brings the link between the new knowledge and its application. The interaction between internalisation and externalisation creates understanding.
5. Evaluation: The new knowledge is evaluated based on the experiences from utilising it for the real-world problems
6. Control: In the last step, the student evaluates his learning process.



**Figure 1: Perfect learning loop (applied from Engeström, 1984).**

The ideal scheme for teaching operations management would therefore include motivating the students by letting them face such situations in manufacturing settings that they cannot handle. The orientation part includes introducing basic concepts and principles used in OM. For internalisation, classical teaching methods such as lectures and textbooks are appropriate. The externalisation step is where the teacher runs into problems. What is needed is a way to let students apply their newly internalised skills. Successful externalisation is also a prerequisite for accomplishing the last two steps: evaluating the learned concepts and the success of the learning process.

### **Externalisation in teaching operations management**

The externalising of the knowledge is not well covered by the traditional methods. In operations management, externalisation includes applying the learned theories in real manufacturing settings and solving real manufacturing problems. The following approaches are in use:

- Calculation exercises can be used for solving isolated problems, such as determining optimal inventory control parameters using a given formula. However, the calculations exercises are of greater utility in mathematics and physics or as computer exercises for computer sciences than in operations management.
- In many universities and polytechniques, there are laboratory equipment and even small-scale manufacturing lines. From the OM teaching point of view, these do provide externalisation of the skills. The drawbacks are high costs in initial investment, maintenance/running and keeping the equipment up-to-date. There are limited possibilities to practice in different types of environments and machine configurations.
- There are also practical assignments to the real companies but the learning content of these assignments – due to the nature of company involvement – are not very well controlled by the teacher.

The approach of using a discrete-event simulation model in teaching could ideally provide OM the precise externalisation benefits the teacher aspires while avoiding the high cost of laboratory manufacturing equipment. It also provides an environment with easily configurable new exercises.

### **Simulation as an externalisation tool**

Games are played when one or more players compete or cooperate for payoffs according to a set of rules. Simulations are working representations of the reality. Simulation games are powerful learning tools as they, opposed to real situations, can be tailored for certain learning purposes. The student involvement is usually very high. The games often include more than one academic discipline, and thereby enable interdisciplinary learning. (Saunders, 1995; Crookall and Kiyoshi, 1995). Thereby, the simulation games give a unique opportunity to externalise new knowledge in a safe, controlled but motivating environment.

The idea to use of simulation as a pedagogical tool is almost as old as the idea of simulation itself (e.g. Naylor, 1966). In operations management, a typical application has been the visualising of system dynamics. An application well known to most students who have taken a course in operations management is the beer game, originally developed at MIT in the early 1960s. Several computerised versions exist, such as the one provided by Simchi-Levi et.al. (2000). A frontrunner in the manufacturing area was Simens' FASI-plus application that was developed in early 70's, a rather simple tool for teaching the production scheduler's job (Zülch, 2000). A more developed application is the CEASAR system for education of manufacturing in the semiconductor industry (Axelrad, 1995).

A listing maintained by the special interest group Games for production management of the IFIP WG5.7 (Riis, 2002) contains descriptions of 29 games. Of these, 22 belong to the categories production principles, scheduling and supply chain management. 11 games are played on a PC, 4 using some smaller physical equipment such as a playing board, 4 using real manufacturing machinery and 3 have format unlisted. Among the 11 computerized games, 5 are based on discrete-event simulation. Only one game utilises a web-browser as user interface, but that one requires other special equipment such as videoconferencing. Consequently, although simulation games are common and operations management is often taught through gaming, the number of games utilising discrete-event simulation models for teaching operations management is limited. Most of these games are still played in classrooms during organised game sessions. In our literature review, we found only one web-based simulation application that possibly could be used for distant learning, reported by Dessouky's et al (2000). Their educational system includes configuring and running factories over the web.

## **Motivation for e-learning solution**

In Finnish technical universities the attendance to lectures are voluntary. It is not uncommon that the percent of students attending to lectures can be close to zero towards the end of the lecture series for some courses. Therefore, the role of textbooks is central in internalising. One major difference between the lectures and textbooks is that reading a book is not bound to a certain time and place.

The traditional methods of externalising in OM require simultaneous presence of both students and equipment, like in going to a laboratory to do the exercise or in the practical company assignment. Attendance to these kinds of exercises in HUT OM education is compulsory. A web-based learning environment, however, is able to free the student from the limits of time and – depending on Internet access for student – also place.

A web-based learning environment for manufacturing simulation therefore offers great potential for improving the externalisation aspect in OM teaching with much less costs and greater variety than laboratory hardware as well as the benefit of doing the exercises at times and even places of the student's choosing.

## **PROBLEM STATEMENT**

To overcome the problems with the traditional and existing OM learning methods, a novel approach was required. The goal was to design and build an OM learning environment that would allow learning OM knowledge by gaming-kind approach. The environment should support distance learning. The environment should allow building new “games” or exercises. In addition to the environment, a set of thought-out student exercises for teaching purposes should be provided. To achieve these goals, the OM learning environment needs to be

- allow building new learning content easily
- incorporate gaming
- be easy to use for the students
- enable distance learning

In the following chapter 4 describes the learning environment and its architecture. Chapter 5 details the current simulation model application as well as the existing exercises. Chapter 6 reports initial experiences with a pilot class and final chapter draws conclusions.

## **A WEB-BASED MANUFACTURING SIMULATION ENVIRONMENT**

### **Web-based architecture**

The architecture is designed and realised by a commercial software house, Delfoi, with a ten-year experience of manufacturing simulations. Figure 2 shows the overall architecture of the learning environment. Its user interface is a web-browser that can be connected to the Planner EDU server. The server can be accessed over LAN or Internet. The latter way is possible supposed that the firewall solution of the educational institution admits access. Architecturally, Internet access is not a problem.

The Planner EDU server contains the database where both user input and simulation model results are stored. These are stored separately for each user and each input-simulation run that in the Planner EDU is called a scenario. The server includes a commercial middleware, Delfoi Integrator that handles the messaging between simulation software Quest and the server.

The third main application is the simulator, Delmia QUEST, and the simulation model(s) used in the OM learning environment. Delmia QUEST must be installed in a PC and requires a licence even for

run-time version. There can be parallel QUESTs running at the same time in one PC but that slows down the performance considerably. The choice was to make use those workstations where the QUEST software is already installed for running the simulation. The student can specify at which workstation the simulation model. By default, the simulation runs from the same computer as where the browser is used.

Finally, there exists the configuration client for administration, like defining user names and passwords or installing new features or viewing and deleting scenarios of each user.

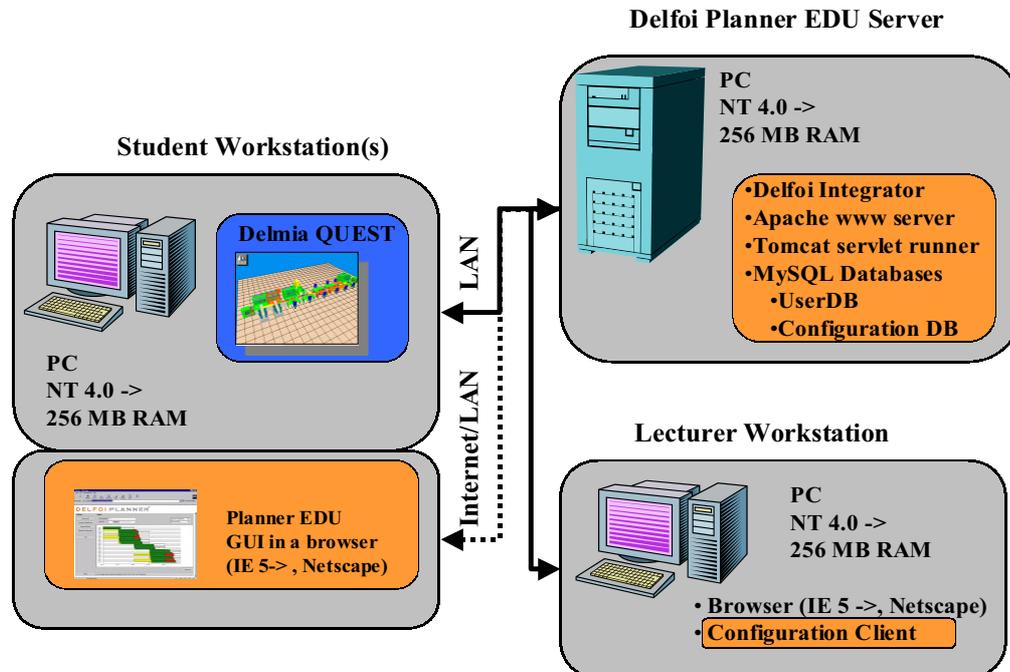


Figure 2: The architecture of the learning environment

### The user interface

A standard browser is used as the user interface. The actions that the user does through the user interface can be divided to defining the simulation run input parameters and examining the results of the simulation runs from the server database.

Defining the simulation run parameters consists of

- Choosing exercise and demand file
- Defining the manufacturing system configuration
- Planning the production schedule, required labour resources, material purchases and inventory control parameters
- Launching the simulation

The user interface is designed to follow the student workflow where for each exercise and set of orders one defines first the manufacturing system parameters, like amount of machines, chooses the production control principle from among Make-to-Order, Assemble-to-Order and Make-to-Stock and quality defects. Figure 3 (left-hand side) shows how one of the manufacturing system parameter definition sheets, the capacity-planning sheet looks like.

When defining the user interface, one key goal was to keep it simple so that as little as possible time would be spent on learning to use the tool, thus saving time for learning OM issues. Here the student

can choose the amount of machines for each machine from the pull-down menu (Amnt) and define processing time coefficient (KO) and set-up time coefficient (KS). In addition, the radio button choice of stochastic or deterministic processing times is located in this sheet.

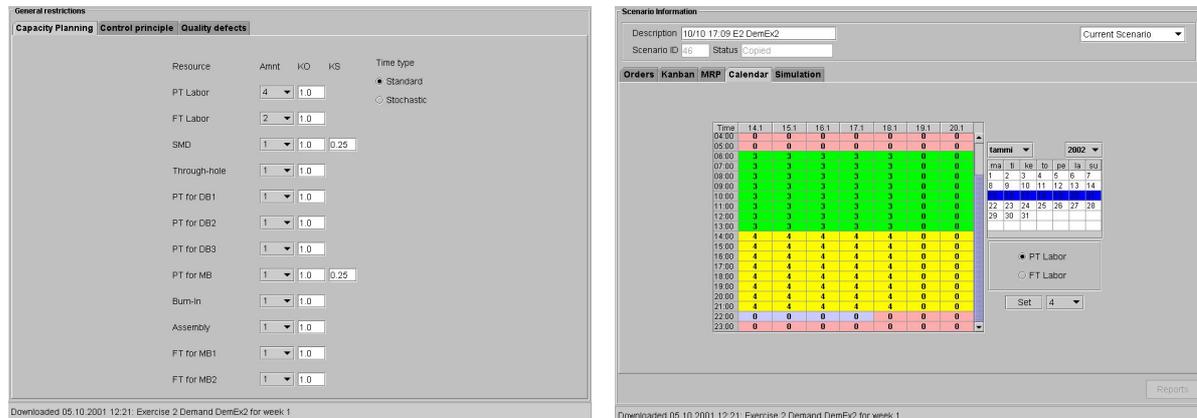


Figure 3: Capacity planning sheet (left) and labour planning calendar (right).

When the manufacturing system is defined, the student creates a new scenario with the specific system configuration. After creating a new scenario, he can begin planning operational schedule by doing the weekly schedules for orders, workers and, in some exercises, materials as well as deciding the inventory control parameters.

Figure 3 (right-hand side) shows one schedule-planning sheet, the one for labour schedule planning. The student can assign up to the maximum number of workers defined in the manufacturing system parameters to each calendar hour in the period. The cost calculation model includes extra costs for night shift, Saturday and Sunday work. There are two kinds of labour and the user defines working hours for both types.

### The user interface: simulation output

The student can choose simulation either with or without animation. The standard feature of QUEST is status highlighting, which means that the different states of machines and labour can be shown by colour coding where green is working, red blocked, down or set-up and yellow is idle. This feature – along with really being able to see what happens in during the simulation run – greatly facilitates understanding of the system behaviour.

After running the simulation, the student can view the results of the scenario with graphs as well as two HTML reports, the summary report and financial statement report. The graphs are implemented with Java and it is possible to zoom in and out in the graph with a mouse. The summary report shows run averages and summaries in figures, like time usage in work, set-up or idle classes per resource or inventory minimums, averages and maximums. The main difference apart from graphical vs. text data display between the graphs and reports is that graphs are functions of simulation time whereas reports are run overall or average results. The financial statement is a key report and its purpose, apart from providing a metrics for evaluating the relative efficiency of different actions and results, is to create a gaming-type atmosphere to learning.

### The simulation model

In all the currently implemented eight exercises, the same basic simulation model is launched. When the simulation is started the model identifies the student specific database by using the ip-address of the PC the student is working on. The model configures itself to present the respective exercise settings based entirely on the SQL-queries it makes from information stored in the identified database.

This information includes the number of the current exercise, indexes for completed runs and previously stored results. The number of the active exercise determines for example if material requirements for components are neglected or if MPR-orders are inquired from the database. The previous indexes are needed when storing the results of the current simulation run.

After reading in the schedule of the workers, the maximum number of each of the two labour types can be defined, and excess labour is called out from the model. As the in-built schedule management of Quest requires the existence of predefined multi-day schedules, which are constructed by combining predefined daily schedules, a customized logic for labour management in the model is used.

As the simulation proceeds, the model writes its status in the database. This information is shown in the status bar. Furthermore, each hour the amount of specified inventories and the utilization of the resource groups during the hour are stored in the database. The simulation model collects statistics such start and finishing time for each order, total throughput, inventory levels for each component, and utilisation rate for machines and labour. The statistics are stored in the database. After the run, the web user interface is re-activated, and the user can view the results.

## DELFOI PLANNER EDU: DESCRIPTION OF LEARNING CONTENT

At the present developing state of the OM learning environment, eight exercises are all implemented with an electronics manufacturing line simulation model. Each exercise has its learning topic, like set-up times, and has a varying number of tasks or sub-exercises where the manufacturing system configuration is changed to get new conditions for building the weekly schedule. The default values of the manufacturing line model are based on an existing electronics manufacturing facility, a facility that is described also in Hannula (1999). For the purpose of this article, the description of the manufacturing model must naturally be concise. However, it is expected that the student must familiarise himself thoroughly with the simulation model document with all of its details, including those that are omitted here, in order to gain understanding and achieve good financial results.

### The electronics manufacturing line model

There are eight different end products in the default simulation model. These are assembled from various combinations of two types of motherboard and three types of daughter boards. Only one purchased material is included, a printed circuit board which is understandably unique for each component. The material costs, sales margin and sales prices each differentiate end products.

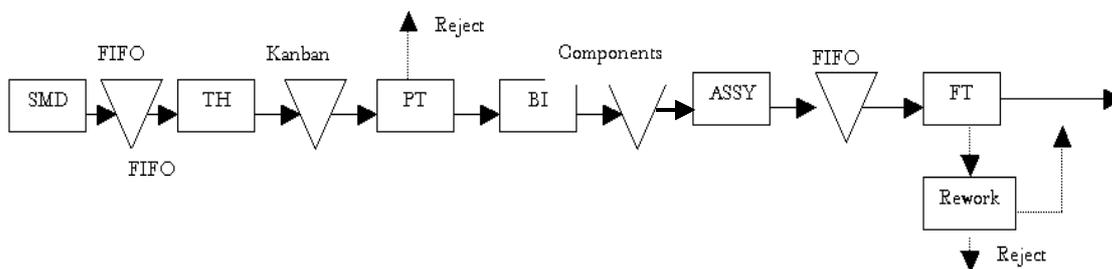


Figure 4: Flowchart of electronics manufacturing line model

The manufacturing stages in Figure 4 are: surface mount device (SMD), thru-hole insertion (TH), primary tester (PT), burn-in oven (BI), manual assembly (ASSY) and final testing (FT). This basic sequence of manufacturing stages remains constant in the model, even though the number of machines can be modified. Of course, rework station is not used when final testing yield is 100 %. Each of the stages has a processing time that is different for each module or product and stage. In addition to this, SMD-machine and primary testers have set-up times. The exact inventory and labour sequencing rules

are documented but not changeable. There are two classes of labourers: one takes care of SMD set-ups and primary testers and the other class final testers and component assembly.

### Working with Planner EDU

Figure 5 shows the iterative loops of planning, simulation, result analysis and re-planning. The inner loop (within the dotted circle) represents the production scheduler's work. The goal is to create an optimal weekly schedule given a certain demand pattern and a specified production system. The student sequences the orders, creates labour schedules and sets inventory control parameters. As he is satisfied with the schedule, he simulates one week of operation and then analyses the results. Based on the results, he can tune the schedule. For example, if worker utilisation is high and deliveries are late, more labour is probably needed.

When the student is familiar with the production scheduler's work, the next challenge is to enlarge the problem area to include tactical level decisions such as capacity investments (the outer loop). In these more advanced exercises, the student is allowed to change the production system. The educational goal is to study how changes in the production system set-up affects operative measures. For example, in the investment exercise, the task is to determine how much machine capacity is needed for meeting increased demand. To succeed, the student not only has to try different capacity levels but also create weekly schedules for each level (the inner loop).

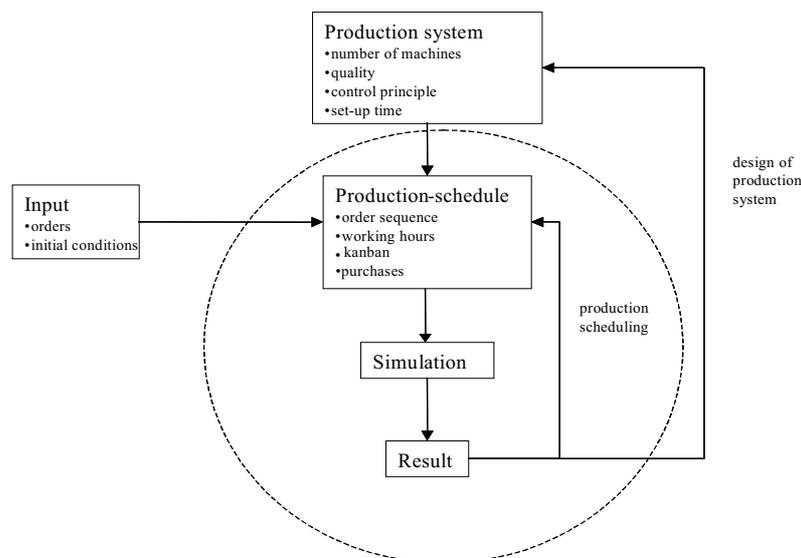


Figure 5: The two iterative loops in using Planner Edu.

### Description of the exercises

The current package includes eight ready-made exercises who all have their own teaching issue and, in the parenthesis, an outline of implementation

- Production scheduler's job (different order sets)
- Production set-up times (in bottleneck and non-bottleneck machines)
- MPS approaches (make-to-order, make-to-stock and assemble-to-order)
- Quality (yield, rework stations, overproduction in ATO)
- Investment decisions (increasing customer demand)
- Materials planning (basic MRP and what to produce in materials shortage)
- Product standardisation (ATO and MTS cases)
- Multiperiod planning (sales forecasts, effects of initial/ending conditions)

For these exercises, there are student’s instructions and questions as well as right answers for the teacher. It is easy to create new tasks by changing the ready-made order sets, creating new order sets and changing manufacturing system configuration. However, it is by no means equally easy to define such tasks where some desired OM issue surfaces, like having production lot size vs. inventory cost trade-off in a major role.

## EVALUATION RESULTS

The application has been tested with a pilot class at Hame Polytechnic in Finland. To start with, the pilot class students were given a two-hour introduction to the learning environment and the simulation model. Then a 6-hour workshop was held where the students were divided to nine groups of 1-4 students in each. In this workshop exercise 1 with its three tasks or subexercises were carried out. The observed results were that in the first task the groups had a lot of questions of which some had to do with the navigation, like “how can I see the results?” and other with the strategies of improving the results, like “how can get the result up?” The results that the groups achieved were between –2 % and + 15,3 % profit, when the maximum is 18,5 % and using the default values gives around – 10 %. In the second round, after the best group had explained how they reached their results, the variation of the results of the groups were smaller as well as help requests less frequent. In the third round there was not a single question or help request and in the end the results that the groups achieved were between 16,0 % and 17,4 %, where the smaller spread of the results indicate that overall strategies to improve the gaming results were learned. The impression based on the introduction session is that the students appreciate the gaming approach and also roughly get the idea in less than one day while the help requests stopped and results converged.

At this stage, 15th March 2002, 11 students out of 26 have completed the three compulsory exercises (1-3). The students evaluated their experience using a web questionnaire that was filled by 14 students (54% response rate). The respondents were all in their second year and between 20 and 25 years of age. Almost all (86%) indicated that they have studied production control previously. The guided introduction session was felt too short according to 57% of the respondents. Only 68% of respondents indicated that they finished all compulsory exercises. The technical environment was such that 93% had experienced problems with it, like this one answer: “yes, a lot of problems. I cannot remember a single time when the environment would have functioned properly.” In spite of that, 50% commented that they learned a lot or at least would if the environment had worked.

**Table 1: Survey results**

No	Question	Average	Min	Max	n
5	It was fun to use	0,64	-1	2	14
6	Time went fast with the exercises	0,07	-2	2	14
7	I would recommend the course	-0,93	-2	1	14
8	I would participate again	-0,23	-2	2	14
9	I learned practical skills	-0,21	-2	2	14
10	I got a feeling of real production	-0,64	-2	2	14
11	I learned how electronics line works in different situations	-0,79	-2	1	14
12	I learned new skills	0,00	-1	2	14
13	Written material was adequate	-0,93	-2	1	14
14	Guided introduction was necessary	0,93	-2	2	14

In general, the responses in Table 1 are negative, where the technical problems explain a lot. However, the answers to questions 5 and 6 that measure the game-like experience and fun are still positive so at least the authors as well as the teacher expects that it is a promising approach. She liked the idea and will try again next year (Heikkilä, 2002).

A download from the EduPlanner database was taken at the time of survey. For each of the eight groups that had made runs, the number of runs per task and the best result of the task was recorded. The correlation of the number of runs that the group made at subtask level to the standardised results, where best group was assigned 100% and worst 0%, was 0,48 ( $p < 0.005^{**}$ ). The improving results imply a learning effect. However, survey results (Table 1) show clearly that the learning did not take place as intended. Many students could not finish, and reposes indicate that it was due technical problems. Mattila (2002) explained that the biggest problems occurred in the synchronization of the communication between several simultaneous clients and the EduPlanner server when simulation was started. The problems turned out to locate both in the EduPlanner server and in the simulation tool's socket communication and are as now fixed.

## CONCLUSIONS

The paper presents a new OM learning environment, Delfoi Planner EDU. The learning environment offers a cheap, versatile and easily configured alternative to traditional learning methods in externalising the OM knowledge. It is intended for bridging the gap between the textbook and confusing, detail-rich real world environments

As the user interface is a web browser, the distance learning is possible. Some obstacles may remain in form of firewalls, and speed of lines. With present data transmission speeds, the 3D animation cannot easily be viewed through remote access. However, it seems that that still some in-class time is needed for explaining how to play with the environment and answer questions about user interface and gaming strategy. The architecture enables adding new tasks in existing exercises easily. It permits addition of new simulation models such as new manufacturing environments. This supports the formation of user communities that could exchange models and learning content with each other.

The pilot class experiment suggests that the goal of achieving the gaming benefits were achieved but due to technical problems, the educational effects of the concept could not be evaluated.

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