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Supply Chain Education—the Contribution of Gamification*

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Supply Chain Management is taught in many business and Industrial Engineering programs. In this paper we present our experience in using gamification in several university courses in this domain. More importantly, we present gamification design principles. In these courses we used the Supply Chain Simulator (SCS)—a new and innovative web based computer gaming/simulation application. Its goal is to enable students to gain a better understanding of supply chain management by providing a gaming oriented, virtual environment experience, enabling the simulation of a large variety of realistic and pragmatic situations. The instructor can build an unlimited number of scenarios. Students learn how to simultaneously consider diverse supply chain aspects such as costs, ordering policies, transportation modes, capacity, and uncertainty. Advanced students learn how to design and develop supply chain scenarios based on real or imaginary situations. This training approach using simulation has already been used to bring gamification into a number of courses and the students' satisfaction has been consistently positive. Gamification develops students' analytical abilities in conjunction with providing tangible experience in handling practical potential challenges in a fun gaming environment. We argue that gamification tools should be focused on a single domain and allow wide modelling flexibility within this domain.

Keywords: Gamification; Simulation Based Training; Engineering Education

1. Introduction

This paper presents our experience incorporating gamification into university courses. The gamification tool—the Supply Chain Simulator (SCS) is a computer based simulation tool which, on the one hand represents reality, but on the other hand takes what is important from real life for the student and emphasizes it beyond what is truly realistic. We teach both basic and advanced supply chain concepts in business and engineering schools. The tool belongs to a new genre of teaching methods that have emerged over the past century. Being confined to a classroom environment, traditional methods have struggled to translate expert intuition and theoretical knowledge into practical experience. An emulation of a real physical environment, indeed a simulation, is one way to invigorate education. Implementing this emulation efficiently and effectively, however, is challenging (see, e.g., [1–4]). Based on our experience we present design principles for the development of gamification tools.

Simulation is as old as mankind. The hypothesis that simulation evolved with mankind is presented by Revonsuo (2000) [5]. He postulates that the true purpose of dreaming is to perform a simulation. In his view, the brain is an expert simulation designer since, according to him, ". . . during dreaming, the brain constructs a complex model of the world in which certain types of elements, when compared to waking life, are underrepresented whereas others are over represented." As any good modern computer simulation designer knows, it is foolhardy to try to truly represent the real world. This maxim was best explained by Hari Seldon (a fictional character created by Isaac Asimov) when he stated "If you want to understand some aspect of the Universe, it helps if you simplify it as much as possible and include only those properties and characteristics that are essential to understanding. If you want to determine how an object drops, you don't concern yourself with whether it is new or old, is red or green, or has an odor or not. You eliminate those things and thus do not needlessly complicate matters. The simplification you can call a model or a simulation and you can present it either as an actual representation on a computer screen or as a mathematical relationship" (Asimov (1988) [6]).

Simulation has been extensively used in education through gamification, and in particular, computerized automated simulators have been used in this way. Combining gamification elements in educational computerized simulators increases students' motivation significantly [7]. Simulation creates an artificial environment that reflects and illustrates real-life experiences [8]. Simulation can even replace physical experiments without compromising student learning [9].

Students acquire needed knowledge during their experience with the artificial environment (simulation) and subsequently practice implementation of this knowledge, again in the simulation. One char-

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acteristic of an efficient simulation tool is its ability to facilitate learning that can be transferred to a real-life environment [10]. In the context of education, using simulation as a teaching methodology is commonly referred to as gamification or Simulation Based Training (SBT). In particular, we are interested in computer-based SBT.

SBT is an effective and dynamic educational tool as described in [11]. Though he does not use the term gamification, many of the reasons he presents for the effectiveness of this tool is in essence that with SBT comes gamification. The effectiveness of SBT and the associated gamification of the educational experience has been widely studied, not always in a positive light; see, e.g., [2, 12–13]. Nonetheless, many educators support the use of SBT techniques [14–18] as they enable students to practice what they are studying [19]. The gamification aspects of simulators mean that they can provide an attractive, novel, and entertaining environment so trainees are motivated to practice [20]. Students are more engaged in what they are learning when they use SBT [21].

Using SBT for education offers several advantages over traditional techniques, such as supplying hands-on practice and allowing for the development of skills at a faster pace [11]. Another advantage of SBT is that it provides an environment that is risk-free, i.e., mistakes can be made without anyone having to suffer negative repercussions. Indeed, students can manage a supply chain and lose money without suffering the negative consequences. Of course, losing money is not the point; learning is. If the simulators are properly designed and used, SBT makes the learning process effective.

To understand how gamification techniques can be used for knowledge transfer, consider how students in a classroom environment learn the concept of when an entity in the supply chain should place a replenishment order—specifically, on what basis should an entity place such an order. One possibility is to consider the on-hand inventory. This is the easiest, but it is commonly known to be sub-optimal for several reasons. For instance, when there is a (long) replenishment leadtime, net inventory position is clearly a better choice. Moreover, when considering a multi-echelon environment, the downstream inventory (echelon inventory) must also be considered. Whereas these concepts are well understood by the instructor, transferring this knowledge to students can be difficult. This is especially true using only frontal lectures. Students cannot fully appreciate these concepts until they "see" and "feel" them. This is where gamification comes in. Through a series of well-structured exercises and through some unstructured "play" time, the student can build an understanding of the concept that goes beyond knowing the correct answer.

To understand how gamification can be used to build knowledge, beyond just transferring knowledge, we must consider a non-standard supply chain concept. Consider, for example, inventory discrepancies. Even though the presence of discrepancies in inventory records is obvious, this is the motivation for inventory counts. Their effect on the supply chain performance, however, has only recently gained attention. Computer based simulation tools, can help researchers build an understanding of this phenomenon. By investigating systems that simulate the sources of inventory discrepancies (shrinkage, misplacement, and wrong scanning), the researcher can build hypotheses that can be tested via simulation and can be rigorously verified using mathematical models.

To close the introduction, we return to Revonsuo's (2000) hypothesis [5]. He states that "dream consciousness is essentially a mechanism for simulating threat perception and rehearsing threat-avoidance responses and behaviors." This is exactly what we feel that gamification does for students while they are awake.

2. Literature review

Given that the literature on gamification and SBT is too broad to cover here, we refer the reader to [22] and [23] for surveys on the topic. For the sake of focus, we restrict our attention to SBT in the supply chain management domain. There are several simulation tools in the supply chain management domain. These tools can be grouped into three primary categories: Role-playing simulations, physically based simulations, and computer based simulations [24]. We restrict our attention to the last category.

The Beer Game is by far the most famous supply chain management domain educational simulation tool. It was developed at the Massachusetts Institute of Technology in the 1960s. It is a one-scenario simulator, with no flexibility. Goodwin and Franklin (1994) [25] described this tool in their paper. Though it has been implemented on many platforms, the idea behind the game remains constant. The Beer Game simulates a supply chain comprising four facilities: A factory that supplies a distributor, which supplies a wholesaler, which supplies a retailer that fulfills customers' demand. Each facility is controlled by a team, composed of 2 to 4 students. The objective for each team in the game is for the team to minimize its own cost. The only decision each team has to make is how much to order in each period. The educational aim of this simulator is to highlight the well-known supply chain phenomenon called the Bullwhip Effect [26].

Since the 1960s, many computerized versions of the Beer Game have been developed. For the most part, they are "mainly" a translation of the original Beer Game to computers. For example, see the version described in [27] that in addition to the original goal of teaching the Bullwhip Effect, also demonstrates the value of information. Other examples can be found in [28]. In 2003, Hofstede et al. [29] developed a computerized supply chain simulator having the same educational objective as the original Beer Game. The main difference between Hofstede et al.'s [29] simulator and the Beer Game is that in [29], customer demand is stochastic as opposed to deterministic demand in the Beer Game.

In 2009, Chang et al. [30] developed a computerized simulator, SIMPLE, which has a one-player scenario and a multi-player scenario. As in the original Beer Game, the objective function, for each team, is to minimize its own cost. The principal difference between SIMPLE and the other simulators is that in SIMPLE there is an option for "information sharing". Employing this option results in all information of all players being available to everyone.

In 2008, Siddiqui et al. [31] developed a computerized simulator in which the player has access to three different scenarios that simulate an international supply chain. In all scenarios, the player acts as the manufacturer. The objective function is the same for the three scenarios: The player has to minimize the total cost of the supply chain.

Mobini et al. (2013) [32] developed a simulator that mirrors industry better, with the same objective function as Siddiqui et al.'s (2008) [31] simulator. This simulator mimics a wood pellet supply chain, from the manufacturer to consumers. The player builds his own supply chain, using a set of preexisting facilities. Again, the objective function of this simulator is to minimize the total cost of the whole supply chain; however, this time, the player controls all the facilities along the supply chain.

During the last decade there has been a major growth in Internet usage and with it, the advent of online games, including games in the supply chain management domain. The Supply Chain Game [33] of Littlefield Technologies is an example. They developed a factory simulator that allows students to compete with each other over the web while developing operations management skills.

Inspired by The Beer Game, MBA Crystal Ball ("MCB") developed the Supply Chain Management (SCM) Game [34], which is an online simulation tool of a simplified model of a supply chain using role-playing to experience challenges in managing supply chains. Another example of an online SBT tool is Supply Chain Strategies [35] developed by Supply Chain Online. It is a web tool with two scenarios, whose purpose is to teach how to control a supply chain experiencing supply uncertainty.

The Global Supply Chain Management Simulation [36] is an interactive online simulation environment that allows individuals or teams to try their hands at managing the complexities of a global supply chain by having them enact the role of a supply chain manager of a mobile phone manufacturer. The subjects covered by this simulation game are: Demand analysis, design, forecasting, operations management, product management, suppliers, and supply chain management.

Another web tool is SCM Globe [37], which has various case scenarios for beginner and advanced students. It allows students to apply the theories and concepts that they learn in the classroom. Additional tailor made scenarios can only be added with the help of SCM Globe experts.

3. The gamification tool

In this section we describe the gamification tool, SCS, which is a web based computer simulation application (see screenshot in Fig. 1) designed and developed at the Technion—Israel Institute of Technology. It is an educational platform whose goal is to enable students to gain a better understanding of supply chain management by providing a virtual environment for the student to experience managing supply chains. Students must simultaneously consider diverse aspects such as costs, ordering policies, transportation modes, capacity, and uncertainty. Students must also manage multiple (often conflicting) goals such as minimizing costs and maximizing service levels. SCS is based on the following principles:

- *Ease of use*: An intuitive and friendly graphical user interface (GUI) is designed to support intuitive actions with no need for prior knowledge or extensive practice, even though the simulator itself is an advanced and sophisticated tool.
- *Scenario based training*: Each exercise is a prepared scenario combining a detailed case study and specific instructions regarding the exercise's goals. The GUI and the data encourage the trainee to accomplish the specific assignments.
- *Flexibility*: it enables the modeling of deterministic as well as stochastic environments. Several standard and non-standard costs can be incorporated. Supply chain entities can be linked either serially as a tree, or even with cycles. Several supply modalities are available including different transportation modes and even transshipments.

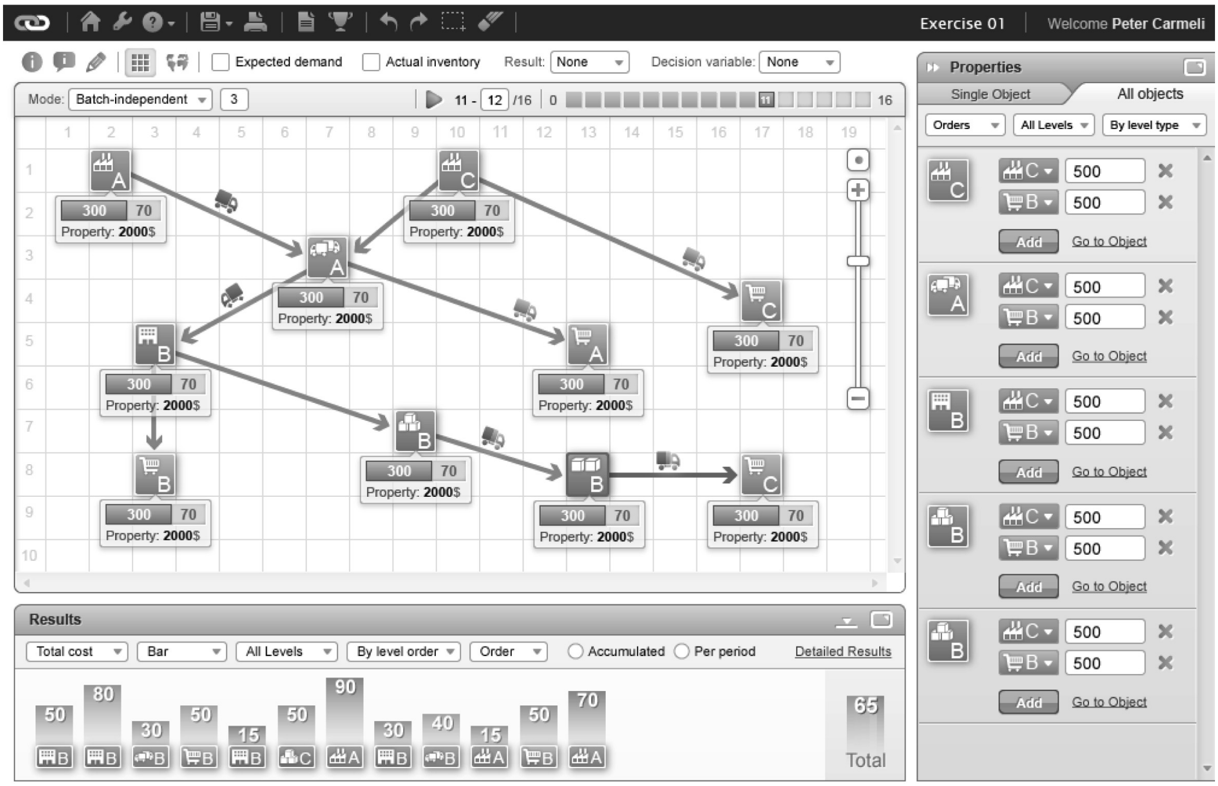


Fig. 1. Supply chain simulator screenshot.

- *Supportive data*: Supportive data-driven and comprehensive detailed reports facilitate the trainee's decision-making and coping with the scenarios' dynamic states.

SCS provides an advanced and enjoyable environment for training by enabling the simulation of a large variety of realistic and pragmatic situations. Advanced students can even design and develop supply chain scenarios based on real or imaginary situations. The instructor can build an unlimited number of scenarios. Each scenario can consist of different entities representing supply chain facilities such as manufacturers, warehouses, and retailers.

3.1 The main concept

SCS allows one to model general, discrete time supply chain model with a simple tool. Conceptually, it is based on entities that interact with each other. These entities can be a manufacturer, warehouse, or retailer. In general, each entity can receive products (from another entity or from production), store products, and distribute products (to another entity or to customers). The entities are connected by transportation links that allow the flow of products from one entity to another. As this description implies, the system can be represented as a graph where the nodes are the entities and the arcs are the transportation links. In this graph we allow multiple arcs between entities, with each arc representing a different transportation mode.

The models built with SCS are discrete time models. Given that processing of products takes time, products cannot arrive and depart from an entity in the same period. Leadtimes, i.e., the amount of time between products departing from an entity until they arrive at another entity, can be included in supply chain models. Indeed, both deterministic and stochastic leadtimes are available. Standard leadtime distributions are built into SCS. For faster (emergency) transfer of products, transshipment connections between the entities can be built into the model. In this way, products can be transferred between entities so that unmet demand in a given period can be met by products at another entity in the *same* period.

The products can have either discrete or continuous quantities, and the demand for the products can be either deterministic or stochastic. Again, standard demand distributions (both discrete and continuous) are built into SCS.

The basic decisions to be made once a model is built are: When and how much to order from what entity (or to produce) using what transportation mode. These decisions can be made manually by the student during the simulation or automatically. To facilitate learning, standard ordering policies have been built into SCS. In addition, there are decisions that can be made when the model is being built, for example, how many levels to put into the distribution chain and where to place warehouses.

Advanced decision making is supported too. For example, when inventory is limited, should priority be given to customers or to orders from other entities?

The student can make decisions based on what she views as important. Standard service level metrics and costs are measured and presented for each student individually and also on a public scoreboard. Costs are incurred whenever items are:

- procured,
- transported (with the cost depending on the transportation mode), or
- held in inventory.
- In addition, unmet demand can be either lost or backlogged, with the appropriate commensurate costs.

All costs can have both a fixed and variable (linear in quantity) component.

Another advanced supply chain concept is the notion of inventory discrepancies. The three basic sources of inventory discrepancies (shrinkage, wrong scanning, and misplacement) and their effect on the ordering policy (the use of inventory records instead of available inventory) are features of SCS. Similarly, the correction of the discrepancies, if an inventory count takes place, also exists.

The idea is to allow the student to experience a "real world" supply chain and experience the consequences of both good and bad decisions.

3.2 How gamification is achieved using SCS

Many game mechanics are incorporated in SCS and in the manner students are asked to operate it. For example:

- Decisions that a student needs to make during the exercise are based on stochastic events. This encourages students to think and act as if they were an inventory manager in a simulated world.
- Feedback and gaining points are part of any game. During the simulation the student gets immediate feedback regarding the inventory status and the score of the performance measures for each entity according to the student's actions and decisions. Fig. 2 shows the immediate feedback bubble window beneath an entity.
- Graphical illustrations of material and its movement illustrate the shipping process through several icons representing different shipping modes. Fig. 3 displays some of the icons illustrating movement of material.
- The instructor can limit the number of attempts a student has to play. This is parallel to gaming pressure. In this way, not only does the student try to do her best, but she must do so quickly, in no more than the predefined number of attempts. In addition, just as in more traditional gaming environments where there is a limited time to complete a task or a module, the student also struggles with the clock. The instructor cannot only limit the number of trials, but also the total time of these trials.
- At the discretion of the instructor, it is possible to provide students with a scoreboard. This is an important and powerful element in gamification in which the participants' performances are presented for all to see. Each participant can constantly monitor his exact position relative to the others and thus knows whether his performance is strong or weak. The scoreboard increases competitiveness among participants. Each wants to achieve the highest score, and once a participant knows his position, it spurs him to pursue a better score in an attempt to move ahead of his or her classmates. This situation establishes a public, live, ongoing competition. Moreover, the scoreboard can be based on one or more of the performance measures that are constantly calculated and integrated in the output reports.

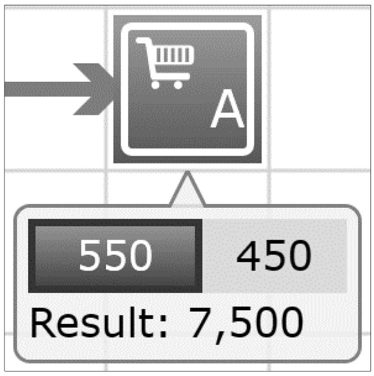


Fig. 2. Immediate result popup giving students real time feedback on their score.

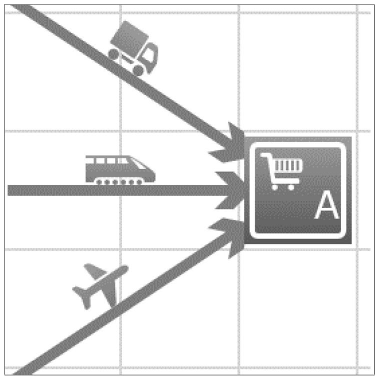


Fig. 3. Graphical movement of material

4. Classroom experience with gamification

We have used gamification in several undergraduate introductory courses with great success. This experience has been gained using SCS. The students, who had no background in simulation or in supply chains, were able to work effectively even before frontal lectures on the topic. They were given only one frontal hour of instruction on how to access and use the tool (information that is now available in a simple tutorial). The students were asked to run several pre-built scenarios that evaluated their abilities to manage supply chain models; they did so with great success.

Gamification using SCS has also been used in an advanced supply chain management course, but in a markedly different way than in the undergraduate courses. The students, very familiar with the theory, had to design supply chain scenarios to demonstrate an application of the theory. Each chose a different theoretical framework, designed a scenario accordingly and associated it with information to be used as background to run the scenario. The outcome was a set of case studies that can be used as additional exercises by the undergraduate course students.

Gamification using SCS has also been used in MBA courses. The students were given between one to three scenarios, each aiming to demonstrate different aspects of managing a supply chain. The students competed among themselves, acting as supply chain managers in a reality having tough market competition. As a result, students further developed their managerial skills.

Students from all the different groups have repeatedly reported satisfaction with the simulator and indicated that gamified scenarios were relevant for their future work as engineers/managers. Most of them believe that they will apply the skills they acquired during their experience with gamification in their future work. Participants also mentioned that even without a deep theoretical background, they learned skills that they feel will be valuable for them during their current studies as well as later on in their professional careers. We feel that this positive feedback was due the fact that gamification develops students' analytical abilities in conjunction with giving them tangible experience handling real-life potential challenges.

Our main insight from the above experience is that "one size does not fit all" [38]. A flexible gamification tool that can run different scenarios and even better, a tool that can be used by trainees to develop their own scenario is needed. This observation is the corner stone of the current design of SCS and the way we use it.

5. Example exercises using gamification

Gamification can be used to demonstrate concepts and to solve countless questions in many domains. These concepts are taught along with the traditional methods on the theoretical aspects of the domain. SCS, for example, is integrated traditional methods and is used as a supplement to classical lectures and books in the domain of supply chain management. Examples of questions that can be explored include:

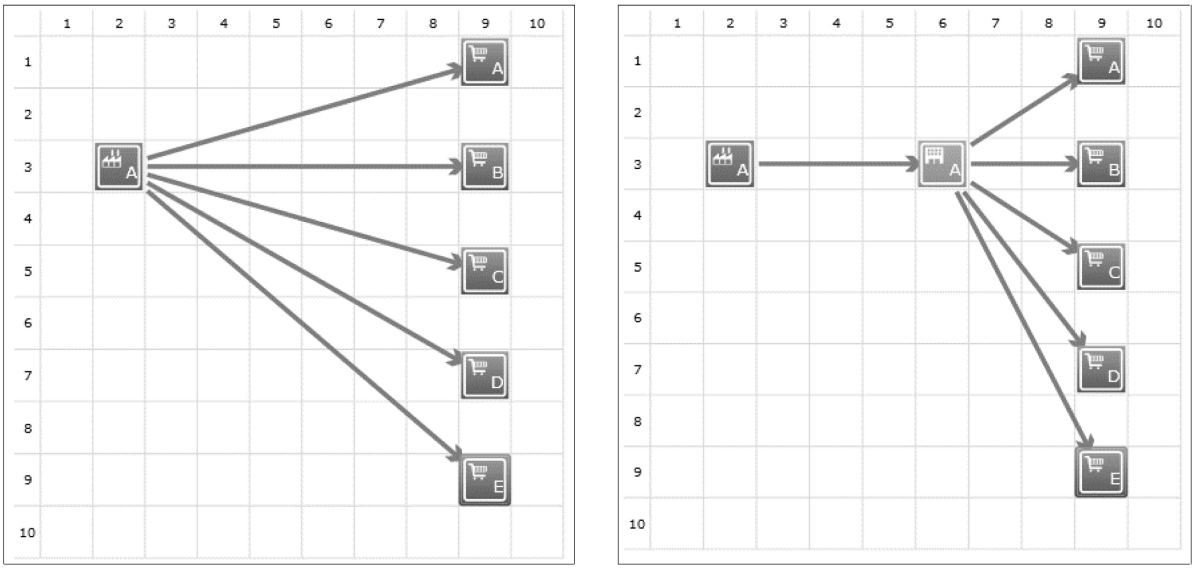
- What are the differences and consequences of ordering based on local inventory, inventory position, echelon inventory, or echelon inventory position?
- Where should a warehouse be located?
- When should a shipment be made by air and when by sea?
- What is the effect of installing a local (forward) warehouse?
- How should we design a supply chain strategy for a system that includes dozens of entities?
- What is double marginalization and how can the parties increase their profits together?

Each of the questions above is addressed through a detailed case study associated with one or more exercises. Each exercise is a designated scenario that comes together with instructions regarding the exercise's goal and the "lesson to be learned".

To clarify the apparatus of addressing a question, we elaborate using one possible question: What is the best way to supply multiple retailers from a single manufacturer? We consider two feasible alternative architectures: (1) The manufacturer supplies each retailer directly (see Fig. 4(a)) or (2) the manufacturer supplies a forward warehouse, which supplies each retailer (see Fig. 4(b)).

The investigation of this question is accomplished through a series of exercises each of which uses the objective function of maximizing the expected profit of the supply chain. These exercises demonstrate, e.g., the use of a forward warehouse as a source of inventory pooling. Using an Inventory Position ordering method with a base stock ordering policy for retailers and an Echelon Inventory Position ordering method with a base stock ordering policy for warehouses, we see that the pooling alternative is more efficient/cheaper than the direct one.

The investigation includes four exercises. It begins by examining the optimal ordering method for the retailers (Exercise 1). It then proceeds to examine the optimal ordering method for the warehouse (Exercise 2). Using the knowledge gained from these two exercises, the two architectures are compared (Exercise 3). Finally, alternative transportation modalities are compared (Exercise 4). The educational outcome of the exercises are as follows.



(a) (b)

Fig. 4. Two alternative architectures for supplying multiple retailers from a single remote manufacturing facility. (a) The manufacturer supplies each retailer directly. (b) The manufacturer supplies a forward warehouse, which in turn supplies each retailer.

- Exercise 1: Local Inventory versus Inventory Position
  The students learn that in the presence of leadtimes, it is best to use the inventory position (local inventory plus on order inventory) instead of just local inventory.
- Exercise 2: Inventory Position versus Echelon Inventory Position
  The students learn that an intermediate warehouse in a three-stage supply chain should base its ordering policy on an echelon inventory position (local inventory plus on order inventory plus downstream inventory).
- Exercise 3: Comparison between the Alternative Architectures
  The students learn that a forward warehouse can save money even if it lengthens the effective leadtime of supplying the retailers from manufacturer. The pooling advantages of the local warehouse can outweigh the increased leadtime disadvantages.
- Exercise 4: Plane versus Truck
  By performing a sensitivity analysis, students learn about the tradeoff when choosing between a fast expensive mode (plane) and a slow inexpensive mode (truck).

Another technique that can be used in an advanced course is gamifying the experience of designing the architecture for a real supply chain. Students learn how to design their own supply chain scenario by researching a real supply chain and collecting the data required for building the supply chain architecture. In this way, students integrate many theoretical concepts that they have learned working on a real supply chain. In particular, students experience firsthand the difficulty of integrating theoretical concepts in a real life situation.

6. Gamification design principles

Based on our classroom experience with gamification we have learned what makes a gamification tool effective. In particular, we have learned that the gamification tool must be easy to use. Whereas this is obvious, the imperative is greater than one would expect. We found that the following two principles are essential for making the gamification tool simple to use.

1. The tool should focus on a single domain and
2. The tool should allow one to model many scenarios within its domain.

To understand exactly what we mean, consider how simulators are designed.

Simulators can be classified according to the number of domains with which they are compatible and according to the number of scenarios they are able to simulate. On the one extreme, there are special purpose simulators incorporating one scenario (e.g., the beer game). They address one specific concept of a specific domain. On the other extreme, there are general purpose simulation languages (e.g., Arena) that have complete flexibility and can represent an endless number of scenarios. They are not designated for specific domain needs; their

Table 1. Two-dimensional classification of simulators

Compatibility for # of domain / # of possible scenarios	One domain	Many domains
One scenarios	The beer game	Empty by definition
Many scenarios	SCS	General Purpose simulation software, e.g. Arena

components and graphic user interface are generic. With such software tools the student has to master the whole software package and to include a lot of details in the building of the scenario. That is, they have the disadvantage of requiring a large setup time to be able to do anything. Between these two extremes there are special purpose simulators (such as SCS) that have the advantage that they can immediately and easily be used to model multiple scenarios for the domain for which they were built. The general purpose simulation languages have the advantage of being infinitely adaptable. Table 1 presents a two-dimensional classification of simulators and an example for each class.

All the educational supply chain simulators surveyed in the literature review above are inflexible to some degree or another. Typically, they are one-scenario simulators, addressing one specific concept of supply chain management. Even though two or three of these simulators can run more than one scenario, they are still limited to no more than three "hard coded" scenarios.

Each class of simulator in Table 1 has its own advantages. The simulators in the bottom right hand corner, i.e., the general purpose simulators, can do anything. The simulators in the top left corner, i.e., the single domain-single scenario simulators, can be an effective one time lesson. In our opinion, the simulators in the bottom left corner, i.e. the single domain–multiple scenario simulators, are where gamification should be heading and their use will soon be widespread. As we have learned from our classroom experience with gamification the benefits of our design principles are detailed as follows.

1. The tool should focus on a single domain
   - Courses usually focus on a single domain and as such the gamification tool should as well.
   - When the gamification tool focus on the domain of the course, it naturally becomes integrated with the course. The language of the tool and the language of the course are the same. When a gamification tool crosses domains the student must become familiar with all the domains in order to use the tool. This requires the instructor dedicate learning time to non-course material. In a single domain tool, no time is spent becoming familiar with, defining, and operating tool components that are not part of the lesson plan.
   - The setup time is minimized. The student knowing the domain in which the tool resides, can get right to work. Before even beginning the student knows what the "levers" will be.
2. The tool should allow one to model many scenarios within its domain.
   - In a single university course there are many aspects and "lessons" to be covered. Each single scenario simulator can usually cover only one aspect. Thus in order to cover several topics with SBT, students need to deal with several tools, each designated for a specific "lesson to be learned". However, in order to use each tool, students need to learn the ins-and-outs of each specific one, thus spending many study hours just learning how to administer the tools. With one flexible tool, students need to learn one interface and then are free to concentrate on learning the course material.
   - Many universities teach similar courses. However, each university and each instructor have a unique way of teaching and providing examples for students to practice the material covered. The inflexible tools, with predetermined scenarios, cannot satisfy every instructor's desires. This sometimes means that an instructor will not use a particular tool or, even worse, the instructor will change his course to fit the tool. With a flexible tool this phenomenon is minimized as the scenarios can be made to fit the instructor.
   - A flexible tool can be used to build a series of instructional scenarios that support a single, instructor-specific, story that incorporates different aspects and "lessons learned" throughout a course. The inflexible tools, even when used together, cannot create the needed continuity that a single course should provide.
   - A flexible tool is not limited to a certain skill level. Novices as well as advanced students can use such a tool and thus the tool can be used in several courses—for example, in a basic course and an advanced course.

Not many educational gamification tools can be said to belong in the lower left corner of Table 1. There are, however, a few. Besides SCS another example of such a flexible tool in a single domain, the project management domain is, the Project Team Builder (PTB) [39]. It is a flexible project management training simulator. Flexibility is designed into the PTB via a library of different project scenarios, each using different levels of the PTB's sophistication. More scenarios can easily be added to this library so that the instructor can build the SBT tool around his course. Real or imaginary projects are the basis for scenarios that focus on one or more of the following Project Management knowledge areas:

- Project scope management—determining the work that needs to be done to achieve the project goals and developing a plan that satisfies these goals by selecting the right operational alternatives.
- Product scope management—determining the features and functions or quality of the project deliverables and developing a plan that satisfies these goals by selecting the right combination of technological alternatives.
- Time management—determining the sequencing of project activities and the start time of each activity.
- Cost management—developing a plan that minimizes the total cost of performing the project while realizing the project goals. The costs included in the PTB are the cost of resources used to perform project activities as well as the cost of idle resources; the cost of assigning additional resources to the project and the cost of releasing such resources; the cost of splitting activities and the cost of materials and other fixed costs; and finally, a penalty cost for late completion or a bonus for early delivery.
- Risk management—determining the sources of risks, mitigating these risks and monitoring the project throughout its execution to correct any deviations from project plans.
- Resources management—determining the resources that are needed for the project, the time when these resources are needed and their quantities.
- Trade-off analysis—developing a plan that simultaneously takes into consideration the above knowledge areas by developing a Pareto efficient project plan.
- The goal of the simulation is to develop a project plan that minimizes the project cost while ending the project on or before a given due date and satisfying all the requirements. The plan is executed by the student who can monitor and control the project during execution and take corrective actions when necessary. Corrective actions are necessary when, due to uncertainty, the simulated progress of the project deviates from the plan, causing the project to be late or over budget.

The Project Team Builder is designed to support teaching of project management in two ways:

1. For the basic courses in Operations Management, a library of project case studies or scenarios is available. These scenarios are classified according to their level of difficulty (based on the presence and degree of uncertainty, limitations on the availability of resources and cash that impose tight and sometimes conflicting constraints). Easy scenarios are deterministic with practically unlimited resources and budget. Difficulty is introduced by uncertain duration of activities, breakdown of machines and no-show of workers as well as tight resource and cash constraints.
2. For advanced courses (typically, dedicated project management courses), a scenario builder is used and the students are asked to analyze a real project and to develop a proper scenario that they plan, monitor and control on the Project Team Builder.

As already discussed, SCS fits into the lower left corner of Table 1. To the best of our knowledge, it is the only gamification tool in the supply chain management domain that does so. SCS incorporates the best part of these two extremes. It operates in the single domain of supply chain management. It also has a flexible modular design with an intuitive, rich graphic user interface. The standard logical rules are built-in within this domain. In short, it can be used to easily build a practically endless number of scenarios in the supply chain management domain.

7. Effectiveness of teaching with simulators

Confucius said: "I hear and I forget. I see and I remember. I do and I understand." This is the essence of SBT. We have to experience things ourselves in order to really understand them. A well-designed simulator supports a process of action-based learning. Instead of talking about different ways of doing things, simulators offer an opportunity to try different ways of doing things without risking the consequences of doing so in the real world. As a result, games and simulations have become widely recognized methods for instruction and learning and are becoming increasingly more important.

The effectiveness of SBT depends on several characteristics as shown in [40]. For example it depends on the instructor's rationale for using simulations as learning tools [41]. Still, using SBT for education offers several advantages over traditional techniques, such as supplying hands-on practice and allowing for the development of skills at a faster pace [11].

Several experiments have investigated the hypothesis that using SBT can potentially improve not only the learning process but its outcome as well. For example, Parush et al. (2006) [42] tested the impact of SBT on the learning curve of students both for the case of repeating the same scenario and for the case of training with different scenarios. They found that performance and knowledge transfer in the area of project management were significantly better when the simulator was used. Davidovitch et al. (2008) [43] tested the impact of SBT on the learning-forgetting-relearning process and the impact of a learning history mechanism built into the simulator on the process. Davidovitch et al. (2009) [44] tested the hypothesis that the learning process improves with the functional fidelity in SBT of project management. The improvement in the learning-forgetting-relearning process and the impact of the functional fidelity were both significant.

Nembhard et al. (2009) [45] compared competitive and cooperative strategies for learning project management using simulators in teams and found that the best approach is to mix the two strategies. We note that this last result was obtained using SCS itself! Parush et al. (2010) [39] investigated the impact of SBT on team training, simulating resources allocation in a matrix structure organization. Cohen et al. (2013) [46] tested the effectiveness of SBT for the training of systems engineers.
These *experiments* show that SBT supports team learning and the training of experienced engineers.

Zwikael et al. (2013) [38] studied the impact of scenario flexibility (the ability to fit the simulated scenario to the trainees and to the course objectives) and found that "one size does not fit all". It is important to match the scenario difficulty to students' level of knowledge.

Based on these studies, it is clear that SBT through gamification has great potential to improve the way we teach and train, and that simulators such as the Supply Chain Simulator comprise a part of the beginning of a new era of gamification.

8. Conclusions and future work

This paper presents the contribution of gamification to supply chain education, using SCS which is a designated computer simulation application in the supply chain domain. SCS's design includes gamification features that are integral to its interface and engine. We have used SCS to teach both basic and advanced supply chain concepts in business and engineering courses. Students report satisfaction with SCS and believe this experience will be instrumental to their future professional work as engineers. They believe that SCS develops both analytical abilities and practical experience.

Based on this classroom experience, we have learned that simulation improves the way we teach and train. Moreover, we present design principles for the development of gamification tools for effective use of simulation tools.

We suggest that research continues in two directions. The first, which is maybe the most natural continuation of this paper is research to evaluate and rank the diverse gamifications features in order to improve the design principles presented in Section 6 for the development of gamification tools. The second direction of future research should be in studies that test whether gamification, or more specifically SCS, improves learning outcomes. For example, can an introductory supply chain course replace existing learning constructs (such as recitation) with work on SCS and improve not only student satisfaction, but also improve learning outcomes? In addition, future research can focus on the impact of supply chain SBT on the real strategy adopted by supply chain managers.

References

1. Z. Doulgeri and N. Zikos, Development, integration and evaluation of a web-based virtual robot task simulator in the teaching of robotics, *International Journal of Engineering Education*, **25**(2), 2009, pp. 261–271.
2. M. Gunes and A. F. Baba, Educational tool for design and implementation of an autonomous mobile robot, *International Journal of Engineering Education*, **25**(2), 2009 pp. 239–249.
3. M. Heuer, Foundations and capstone; core values and hot topics; ethics-lx; skytech; and the green business laboratory: simulations for sustainability education, *The Academy of Management Learning and Education*, **9**(3), 2010, pp. 556–561.
4. H. Leemkuil and T. De Jong, Adaptive advice in learning with a computer-based knowledge management simulation game, *The Academy of Management Learning and Education*, **11**(4), 2012, pp. 653–665.
5. A. Revonsuo, The reinterpretation of dreams: an evolutionary hypothesis of the function of dreaming, *Behavioral and Brain Sciences*, **23**, 2000, pp. 877–901.
6. I. Asimov, *Prelude to Foundation*, Doubleday, New York, 1988.
7. I. Kovačević, M. Minović, M. Milovanović, P. O. De Pablos and D. Starčević, Motivational aspects of different learning contexts: "My mom won't let me play this game. . .", *Computers in Human Behavior*, **29**(2), 2013, pp. 354–363.
8. B. S. Bell, A. M. Kanar and S. W. Kozlowski, Current issues and future directions in simulation-based training in north America, *International Journal of Human Resource Management*, **19**, 2008, pp. 1416–1434.
9. T. F. Wiesner and W. Lan, Comparison of student learning in physical and simulated unit operations experiments, *Journal of Engineering Education*, **93**(3), 2004, pp. 195–204.

10. B. Thompson and G. Bergus, Simulation in medical education, report of the task force on simulators in education, *CCOM Medical Education Committee*, June 2006.
11. E. Salas, J. L. Wildman and R. F. Piccolo, Using simulation-based training to enhance management education, *The Academy of Management Learning and Education*, **8**(4), 2009, pp. 559–573.
12. R. Bangert-Drowns, J. Kulik and C. Kulik, Effectiveness of computer-based education in secondary schools, *Journal of Computer-Based Instruction*, **12**, 1985, pp. 59–68.
13. T. De Jong and W. R. Van Joolingen, Scientific discovery learning with computer simulations of conceptual domains, *Review of Educational Research*, **68**, 1998, pp. 179–201.
14. P. W. Grimes and T. E. Willey, The effectiveness of microcomputer simulations in the principles of economics course, *Computers & Education*, **14**, 1990, pp. 81–86.
15. A. Kumar and A. W. Labib, Applying quality function deployment for the design of a next-generation manufacturing simulation game, *International Journal of Engineering Education*, **20**(5), 2004, pp. 787–800.
16. K. Zantow, D. S. Knowlton and D. C. Sharp, More than fun and games: reconsidering the virtues of strategic management simulations, *Academy of Management Learning and Education*, **4**(4), 2005, pp. 451–458.
17. D. M. Fraser, R. Pillay, L. Tjatindi and J. M. Case, Enhancing the learning of fluid mechanics using computer simulations, *Journal of Engineering Education*, **96**(4), 2007, pp. 381–388.
18. M. Milovanović, M. Minović, I. Kovačević, J. Minovićand and D. Starčević, Effectiveness of game-based learning: Influence of cognitive style, in *Best Practices for the Knowledge Society. Knowledge, Learning, Development and Technology for All*, Springer Berlin Heidelberg, 2009, pp. 87–96.
19. J. Hoheisel, F. Weber and G. Windhoff, New approaches for training and education of engineers by using simulation games, in J. O. Riis, R. Smeds and R. Van Landeghem (eds), *Games in Operations Management*, Kluwer Academic Publishers, Massachusetts, 1998, pp. 99–110.
20. C. Koh, H. S. Tan, K. C. Tan, L. Fang, F. M. Fong, D. Kan, S. L. Lye and M. L. Wee, Investigating the effect of 3D simulation-based learning on the motivation and performance of engineering students, *Journal of Engineering Education*, **99**(3), 2010, pp. 237–251.
21. B. D. Coller and D. J. Shernoff, Video game-based education in mechanical engineering: a look at student engagement. *International Journal of Engineering Education*, **25**(2), 2009, pp.308–317.
22. K. L. McClarty, A. Orr, P. M. Frey, R. P. Dolan, V. Vassileva and A. McVay, A literature review of gaming in education, *Gaming In Education*, 2012.
23. I. Caponetto, J. Earp and M. Ott, Gamification and education: a literature review, in *Proceedings of the 8th European conference on games based learning (ECGBL)*, 2014, pp. 9–10.
24. G. J. Summers, Today's business simulation industry, *Simulation and Gaming*, **35**(2), 2004, pp. 208–241.
25. J. Goodwin and S. Franklin, The beer distribution game: using simulation to teach systems thinking, *Journal of Management Development*, **13**(8), 1994, pp. 7–15.
26. H. L. Lee, V. Padmanabhan and S. Whang, The bullwhip effect in supply chains, *Sloan Management Review*, **38**(3), 1997, pp. 93–102.
27. P. Kaminsky and D. Simchi-Levi, A new computerized beer game: A tool for teaching the value of integrated supply chain management, *Global Supply Chain and Technology Management*, **1**(1), 1998, pp. 216–225.
28. R. Hieber and I. Hartel, Impacts of SCM order strategies evaluated by simulation-based 'Beer-Game' approach: the model, concept and initial experiences, *Production, Planning & Control*, **14**(2), 2003, pp. 122–134.
29. G. J. Hofstede, M. Kramer, S. Meijer and J. Wijdemans, A chain game for distributed trading and negotiation, *Production Planning & Control*, **14**(2), 2003, pp. 111–121.
30. Y. C. Chang, W. C. Chen, Y. N. Yang and H. C. Chao, A flexible web-based simulation game for production and logistics management courses, *Simulation Modelling Practice and Theory*, **17**(7), 2009, pp. 1241–1253.
31. A. Siddiqui, M. Khan and S. Akhtar, Supply chain simulator: A scenario-based educational tool to enhance student learning, *Computers & Education*, **51**(1), 2008, pp. 252–261.
32. M. Mobini, T. Sowlati and S. Sokhansanj, A simulation model for the design and analysis of wood pellet supply chains, *Applied Energy*, **111**, 2013, pp. 1239–1249.
33. The Supply Chain Game, http://www.responsive.net/supply.html, Accessed 13 January 2015.
34. Supply Chain Management (SCM) Game, Accessed 13 January 2015.
35. Supply Chain Strategies, https://www.supplychainonline.com/cgi-bin/preview/SCM102/1.html, Accessed 13 January 2015.
36. Global Supply Chain Management Simulation, https://cb.hbsp.harvard.edu/cbmp/product/6107-HTM-ENG, Accessed 13 January 2015.
37. SCM Globe, http://www.scmglobe.com/user_sessions/new, Accessed 13 January 2015.
38. O. Zwikael, A. Shtub and Y. Chih, Simulation-based training for project management education: mind the gap, as one size does not fit all, *Journal of Management in Engineering*, 2013.
39. A. Parush, L. Davidovitz and A. Shtub, Simulator-based team training to share resources in a matrix structure organization, *IEEE Transactions on Engineering Management*, **57**(2), 2010, pp. 288–300.
40. T. Sitzmann, A meta-analytic examination of the instructional effectiveness of computer-based simulation games, *Personnel Psychology*, **64**(2), 2011, pp. 489–528.
41. A. J. Magana, S. P. Brophy and A. M. Bodner, Instructors' intended learning outcomes for using computational simulations as learning tools, *Journal of Engineering Education*, **101**(2), 2012, pp. 220–243.
42. A. Parush, L. Davidovitz and A. Shtub, Simulation-based learning in engineering education: performance and transfer in learning project management, *Journal of Engineering Education*, **95**(4), 2006, pp. 289–299.
43. L. Davidovitch, A. Parush and A. Shtub, Simulation-based learning: the learning-forgetting-relearning process and impact of learning history, *Computers & Education*, **50**(3), 2008, pp. 866–880.
44. L. Davidovitch, A. Parush and A. Shtub, The impact of functional fidelity in simulator based learning of project management, *International Journal of Engineering Education*, **25**(2), 2009, pp. 333–340.
45. D. Nembhard, K. Yip and A. Shtub, Comparing competitive and cooperative strategies for learning project management, *Journal of Engineering Education*, **98**(2), 2009, pp. 181–192.
46. I. Cohen, M. Iluz and A. Shtub, A simulation-based approach in support of project management training for systems engineers, *Systems Engineering*, **17**(1), 2013, pp. 26–36.

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