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Teaching Supply Chain Management to Industrial Engineering Students: Mixed vs. Pure Approaches in Simulation Based Training*

AVINOAM TZIMERMAN, YALE T. HERER and AVRAHAM SHTUB
Technion—Israel Institute of Technology, Haifa 3200003, Israel. E-mail: avinoamt@technion.ac.il, yale@technion.ac.il, shtub@ie.technion.ac.il

We investigate two approaches incorporating two types of intragroup interaction (cooperative and competitive) using simulation based training (SBT) with teams—a pure and a mixed approach—within the supply chain management domain. SBT commonly refers to the use of simulation in the context of education. We examine how a combination of these two interaction types would work in situations wherein both are used in succession. Our purpose is to improve teaching and establish better ways to educate industrial engineering students using SBT. The first hypothesis is that from a pedagogical perspective, it is more effective to use a mixed approach for intragroup interaction when using SBT techniques for engineering education than a pure approach. The second hypothesis is that when using a mixed approach, the order of the two interaction types affects the learning outcomes. The study examined the effects of a new advanced SBT computerized simulation environment on two classes of freshman undergraduates in an Industrial Engineering program in a premier technical university. Each student completed four exercises, of which the first and last were individual tasks and the middle two were done by teams of two students. The students' performance was statistically analyzed. The results, rendered as guidelines on how to use SBT for team training, indicate that when teaching using SBT, a mixed approach for intragroup interaction is better than a pure approach. Moreover, if a mixed approach is used, the order is significant. In particular, we found that it is preferable to start with competitive interaction and then move to cooperative interaction. Our findings suggest that at the training stage, it is better to train teams using both types of intragroup interaction, starting with a competitive interaction followed by a cooperative one.

Keywords: engineering education; simulation based training; teaching approaches; competitive and cooperative

1. Introduction

Over the past century, engineering education has grown and developed continuously. New programs have emerged while existing ones have been extended and enriched with upgraded content. These educational programs use various pedagogical methods that include frontal lectures, books, recorded presentations, seminars, group learning, etc. Confined to a classroom environment, traditional methods have struggled to translate expert intuition and theoretical knowledge into practical experience. Emulating a real-world environment is one way to facilitate this transformation [1]. Implementing this aspiration efficiently and effectively, however, is challenging and management education [2] has yet to accomplish this successfully [3–5]. Recent advances in infrastructure technologies that enable the use of modern tools to enhance learning have substantial implications for training and learning pedagogies [6].

One tool that has been extensively investigated and used in engineering education is computerized simulators. Simulation creates an artificial environment that reflects and illustrates real-life experiences [7]. Simulation can even replace physical experiments without compromising student learning [8]. An efficient simulation tool can facilitate learning that transfers easily to a real-life environment [9]. In the context of education, using simulation as a teaching methodology is commonly referred to as Simulation Based Training (SBT).

SBT can be grouped into three primary categories: Role-playing simulations, physically based simulations, and computer based simulations [10]. Our research focuses on the latter category. SBT is an effective and dynamic educational tool, as described in [11]. Some researchers, however, claim that the findings regarding the effectiveness of computerized simulators [12] are not definitive, that simulators do not necessarily provide a valuable training environment [3], and that they do not raise students' examination scores [13]. On the other hand, many educators support the use of SBT techniques [14–17] as they enable trainees to practice what they are studying [18]. Simulators can provide an attractive, novel, and entertaining environment so trainees are motivated to practice [19], and consequently, are more engaged in what they are learning [20]. Some researchers claim that SBT can also reduce long-term costs, such as classrooms and instructors [21], associated with traditional

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techniques; yet, SBT itself demands large setup costs [10].

The effectiveness of SBT depends on the rationale for using simulations as learning tools [22] and on the ability to provide a suitably challenging experience for students [23]. Using SBT for education offers several advantages over traditional techniques, such as providing hands-on practice and enabling development of skills at a faster pace [11]. Salas et al. (2005) [24] delineated seven basic stages of SBT development in education and Salas et al. (2009) [11] provided some practical guidelines as to how best to implement and use SBT in education—e.g., offer detailed focused feedback and directly measure outcomes. Some researchers [11, 25–26] asserted that SBT can be an efficient tool for education, but only when the gap between the trainee's *a priori* knowledge and the difficulty of the simulation exercise are matched. Inasmuch as SBT is important for current and future education, it is essential to identify the circumstances under which SBT is most effective.

SBT techniques have been implemented in a variety of domains: The military [27], healthcare [28], quality [29], project management [30–31], supply chain management (SCM) [32–34] and process re-engineering [35–36]. These implementations can involve a single trainee or a group of people sharing a goal or task. The techniques provide an environment that is risk-free, i.e., mistakes can be made without anyone having to suffer negative repercussions, as opposed to real-life situations [37].

In spite of both the growth in the use in SBT techniques and an increase in the areas in which they are applied, little research has focused on determining optimal SBT behavioral conditions [38], such as which type of intragroup interaction (i.e., competitive or cooperative) should be adopted in order to optimize and magnify the learning accomplished through simulators. Studies that investigated SBT behavioral aspects usually refer to operational aspects, such as when to provide information during the simulator's operation [39] or at what pace the trainee should be exposed to complex models [40].

In this paper, we investigate how to use SBT in engineering education. We focus on team learning and two approaches incorporating two types of intragroup interaction for using SBT with teams—competitive interaction and cooperative interaction. Cooperative interaction takes place when all team members' awards are based on and are directly proportional to the team's performance [41]. Cooperative interaction is characterized by team members' high individual accountability—each supports the others' effort to achieve a clear and well-defined common objective [43]. In contrast, when competitive interaction is used, team members compete against each other [42]. Fulfillment of one participant's goal usually comes at the expense of the other participants' ability to meet their goals [44]. Whereas the cooperative interaction described in this study aligns with the above characteristics, given that team members are graded according to the team's overall performance, the competitive interaction conforms to a somewhat broader definition of competitive interaction. The definition used here is analogous to that used in [45]: Team members compete less directly in terms of rewards for individual performance. In particular, team members form a competitive alliance. Our characterization for the competitive interaction is in line with other researchers such as Covington and Omelich (1984) [46], Johnson et al. (1986) [47] and Campbell and Furrer (1995) [48].

The question of what education style is the best is possibly as old as the discussions about the value of the Socratic Method. This paper focuses in on one aspect of this ongoing dialogue: How should students interact in the learning environment, competitively or cooperatively? Research has yet to determine which of these two types is better for training in teams. For example, Sherman (1986) [49] investigated learning in introductory educational psychology with cooperative and competitive goal structures and reported no significant differences in participants' achievements. Qin et al. (1995) [50] conducted a meta-analysis research investigating the impact of cooperative and competitive efforts on problem solving and found that the latter do not keep up with the former (see, for example, 42, 49, 51–55). No firm consensus has been reached.

Some researchers have taken the stance that the competitive intragroup interaction type is the best [56–57]. Other researchers have taken the opposite position, i.e., that the cooperative intragroup interaction type is the best. For example, a recent study on SBT intragroup interactions within the project management domain [45] indicated that cooperative interaction yields better results in the overall outcome. Still other researchers assert that different interactions are better for different situations. For example, Sherman's study (1986) [49] showed that each intragroup interaction type has its supporters and that there are no significant differences in cooperative and competitive learning. Nonetheless, the consensus among researchers is that the cooperative interaction is more effective [45, 51].

Past research on competitive versus cooperative learning appears to have demonstrated that there are merits to both intragroup interaction types. Accordingly, the question should not be "Which is the best intragroup interaction, competitive or cooperative?" but rather "How should students be educated?" It is through this prism that this paper explores the fusion of the two intragroup interaction types and asks, "Is a mixed approach (cooperative as well as competitive intragroup interaction) better than either pure interaction separately?" The hypothesis is that when students are educated using a mixed approach, they benefit from the best that each interaction type has to offer. The study also investigates the best way to mix the two intragroup interaction types. To the best of our knowledge, no study has examined how a combination of these intragroup interactions would work.

The research here differs qualitatively from research that classified cooperation versus competition in learning as 'pure' when cooperation was realized in both intragroup and intergroup relationships and as 'mixed' where there was intragroup cooperation but with intergroup competition [50]. Throughout the investigation here, there is always intergroup competition; only the intragroup interaction type varies. No other study has examined intergroup competition using a blend of intragroup interaction types—cooperation together with competition. That is to say, research has looked at the results of using one or the other interaction, but not at situations wherein both are used, one following the other. This is a lacuna that we come to fill. We investigate this issue using the framework of teaching SCM, which is a basic and fundamental subject in every industrial engineering student's education.

Supply Chain Management (SCM) is the "management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers" (Harland, 1996). It considers the integrated impact of all the parties involved in the production of goods and services such as suppliers, manufacturers, wholesalers, retailers, final consumers and even beyond, to disposal and recycling. SCM encompasses every aspect required to satisfy consumer demand, ensuring consumers receive the right products at the right time at an acceptable price and at the desired location. Being a major subject in industrial engineering education, many aspects of SCM are taught, e.g. inventory management [58], supply chain coordination [59], the bullwhip affect [60], etc. Thus teaching SCM has crucial future implications on industrial engineering knowledge and skills—both in the classroom and in the workplace. Using a computer simulation application for the supply chain domain, we investigate how industrial engineering students should be educated using SBT with teams.

The goal of this paper is to investigate from a pedagogical perspective, when using SBT techniques for industrial engineering students' education in the SCM domain, which approach is the most effective—the pure approach (strictly cooperative/competitive interaction) or the mixed approach (a combination of both types of interaction). A preliminary report on this research was presented in [61].

2. Experiment research design

This section provides an overview of the experimental design, starting with the hypotheses and culminating in the detailed experimental design. In the "Experiment Results and Analysis" section we report on the results of the experiment and analyze the data.

2.1 Hypotheses

Different parties comprise the supply chain, each desiring to meet their own goals. In this pursuit they can adopt diverse interaction types, including competitive and cooperative ones, in regard to relationships with colleagues. When students are being taught about interdependence among supply chain parties, the teacher can teach using one or both of these interaction types. As outlined in the Introduction, many researchers consider cooperative interaction to be more effective. Thus, if one is limited to employing a single interaction type, then using the cooperative interaction is a sensible choice. Yet, using a competitive interaction has its advantages and can be a reasonable choice as well. The hypothesis in this study is that using both interaction types—one way to expose the students to a variety of interactions—can be even more effective than either interaction type alone. The efficiency is manifested in students' *learning outcome*, which is the post-treatment performance (the treatment being the SBT training).

Our experiment tests the following hypotheses in regard to cooperative and competitive intragroup interaction when using SBT with teams:

Hypothesis 1: *Using a mixed approach (cooperative and competitive intragroup interaction) achieves better learning outcomes than using a pure (single intragroup interaction) approach.*

Hypothesis 2: *When using a mixed approach, the order of the two intragroup interactions affects the learning outcomes.*

Hypothesis 1 will be tested by comparing the average performance under a mixed approach and the average performance under a pure approach. Hypothesis 2 will be tested by comparing the average performance when the two intragroup interactions are used in different orders.

2.2 Experiment tool

To examine these pedagogical hypotheses we use a new advanced SBT computerized simulation envir-

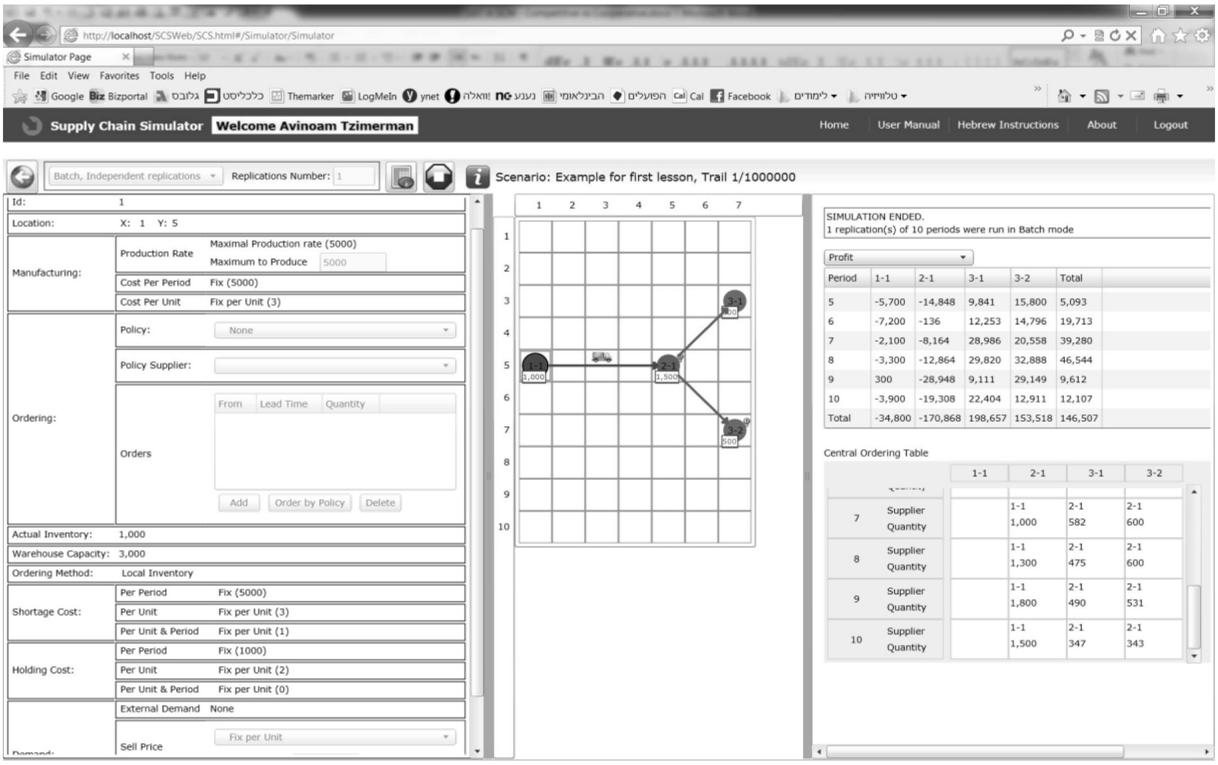

Fig. 1. The Supply Chain Simulator interface (screenshot from the introduction).

onment. The software, Supply Chain Simulator (SCS), is a web based computer simulation application designed by us as a part of a comprehensive research on SBT. It is an educational platform designed to help students gain experience and practical understanding in managing supply chains. SCS (Fig. 1) is based on the following principles:

(a) *Scenario based training*: Each exercise is a prepared scenario combining a detailed case study and specific instructions regarding the exercise's goals.
(b) *Ease of use*: A graphical user interface (GUI) is designed to support intuitive actions with no need for prior knowledge or extensive practice, regardless of how sophisticated the simulator itself is. The GUI is designed to encourage the trainee to accomplish specific assignments through gamification elements such as graphical illustrations and a scoreboard.
(c) *Flexibility*: It enables the modeling of deterministic as well as stochastic environments in a single- or multi-period setting. 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.
(d) *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 users can even design and develop supply chain scenarios based on real or imaginary situations. The teacher can build an unlimited number of scenarios. Each scenario can consist of different entities representing supply chain facilities such as manufacturers, warehouses, retailers, etc.

SCS is ideally suited to test our hypotheses as it provides a platform that allows teams to simultaneously work on a single scenario, with each member receiving immediate feedback. Moreover, the participants can easily manipulate the entities in a familiar environment.

2.3 Experiment design

Two classes ('Class Mixed' and 'Class Pure') of freshman undergraduates in their first semester in an industrial engineering program in a premier technical university participated in the experiment. The two groups, each of which comprised the entire respective class, took the identical introduction to industrial engineering course in two separate years (one right after the other). SCM was one module in this course syllabus, among other industrial engineering topics. No changes in admission to the program were made during the period that separated the two classes. The course syllabus was the same for each class and each had the same instructor for the tutorials and presentations related to the simulator, though they had a different instructor for other, unrelated, material. The motivation for participating in the experiment was the same for both classes. The assignments associated with the experiment were mandatory and students' performance in these assignments was a major part of their course grade. There were no apparent differences between the classes (e.g., demographics). Thus, we consider the students in the two classes as having come from the same distribution.

Class Mixed consisted of 134 students and Class Pure consisted of 121 students. The students did not have theoretical or formal training with SCM. Prior to their first exercise using SCS, the students received an introduction to SCM and SCS. The introduction included an oral presentation and a live demonstration of how to use SCS, instructions on how to carry out the SCS exercises and an explanation of the performance measure used (i.e., profit) and how it is calculated. Students were motivated to pursue the highest profit possible as this performance measure determined their grade in each exercise. Students completed four exercises; two of them were individual tasks (the first and fourth) and the other two were completed in pairs. Table 1 summarizes the experimental design; the nature of each exercise is described below.

Pre-Evaluation Exercise: Managing a supply chain with an intermediate level of difficulty. The supply chain comprised seven facilities of one company (two manufacturers, two warehouses and three retailers). At the beginning of each period the students had to make several managerial decisions such as the quantity to produce at each manufacturing facility, the quantity each warehouse and retailer would order, and the supply priority in case of a conflict between external demand (customers) and internal demand (orders from another facility within the supply chain). Students' goal was to maximize the overall profit over 12 time periods. Each student had ten trials and the best performance was recorded. The purpose of this exercise, as far as this research is concerned, was to expose students to the simulator and allow them to practice so that all groups of students would be aligned in their ability to operate the simulator. Hence this exercise was considered a pre-evaluation task.

There were some random factors in the scenario due to demand uncertainty. Each student faced a new demand realization in each trial. However, all students had identical "random numbers" in each trial, which is to say that the demand realization in a specific trial was the same for all students. In this manner, each student faced a "new" problem each trial; nonetheless, all students dealt with exactly the same trials and thus the demand realization was not an intervening variable that influenced the difference between students' performances. This technique was used in the next three exercises as well.

First and Second Team Exercises: Each class was divided into teams of two students. Additional segmentation was carried out as the teams were divided randomly into two cohorts (A and B). The students in the different classes (Class Mixed and Class Pure) and the different cohorts (A and B) within each class belonged to separate groups that were individually graded; each combination of class and cohort was in fact an independent cohort (Cohort Mixed-A, Cohort Mixed-B, Cohort Pure-A and Cohort Pure-B). The teams and cohorts remained unchanged for both team exercises. Each team exercise included a supply chain with an advanced level of difficulty that needed to be managed by the team. Each supply chain involved several facilities of one company (manufacturers, warehouses and retailers). In each team, one student was in charge of the "manufacturing division," which included the manufacturers and the warehouses, and the other student was in charge of the "marketing division," which included the retailers. Each student had the *individual* goal of maximizing his own facilities' profit over 12 time periods; team members—together—managed the same supply chain. In other words, even though the team acted as a single unit, each member was given personal responsibility and a separate grade in order to ensure that he or she participated fully in the

Table 1. Experiment design of the four exercises students completed during the experiment

	Class Mixed Cohort Mixed-A Mixed Approach	**Class Mixed Cohort Mixed-B Mixed Approach**	**Class Pure Cohort Pure-A Pure Approach**	**Class Pure Cohort Pure-B Pure Approach**
Pre-Evaluation Exercise	Individual	Individual	Individual	Individual
First Team Exercise	Cooperative	Competitive	Cooperative	Competitive
Second Team Exercise	Cooperative	Competitive	Competitive	Cooperative
Post-Evaluation Exercise	Individual	Individual	Individual	Individual

exercise and had a personal stake in it. This design minimized the free rider phenomenon.

The nature of the interaction among team members (intragroup interaction) was sometimes competitive and sometimes cooperative. The different intragroup interaction types were realized in the way students were graded. Every team had 20 trials for each exercise. In the competitive interaction setup, teams decided by themselves which single trial was to be used to determine their grades. They had to choose the same trial for both team members even though this trial would not necessarily represent the supply chain's best overall performance. Students in the same team also knew that they were being individually graded according to their individual performance, regardless of overall team performance. Clearly, team members were at odds with each other since each member would opt for the trial in which he or she excelled, which generally was not the one in which his partner excelled. When team members were unable to agree upon a specific trial, the average performance over the last ten trials was used as the grade.

In contrast, in the cooperative interaction students did not have to decide which trial would be considered for their grade; the trial that produced the maximum overall profit for the entire supply chain was used. Thus students were compelled to cooperate in order to jointly succeed. Nonetheless, students in the same team were still individually graded according to their individual performance.

Table 1 summarizes the assignment of interaction type to the teams in the two cohorts in the two classes. In Class Mixed, the teams in Cohort Mixed-A were assigned a competitive interaction for the first team exercise and a cooperative interaction for the second team exercise. The assignment to Cohort Mixed-B was reversed: Teams engaged in a cooperative interaction for the first team exercise and a competitive interaction for the second team exercise. For each class, both team exercises were actually the same, though the students were intentionally not made aware of this fact (the facilities of the supply chain were organized differently on the map, making it hard to find similarities between the two exercises. Moreover, the teams in each cohort ran only their specific cohort's exercises so they were unable to compare their results to those of the other cohort's exercise). Consequently, the potential performance (overall profit) of each exercise was the same.

In Class Pure, the cohort teams were always assigned the same interaction type. Teams in Cohort Pure-A were assigned the competitive interaction for both team exercises and teams in Cohort Pure-B were assigned the cooperative interaction for both team exercises.

Note that the pre-evaluation and first and second team exercises for the two classes were not exactly the same. They differed in their facilities' locations and their parameters, such as demand distributions, cost parameters, lead times, etc. The reason for this dissimilitude is that the classes were not given at the same time (as noted above, they were given one year apart). Changing the parameters prevented students from reusing solutions; some students could obtain the previous year's solutions from their friends.

Post-Evaluation Exercise: An individual task similar to the first exercise. The exercise had an advanced difficulty level, requiring each student first to design an efficient supply chain for one company using predetermined facilities and then to manage it. The goal was the same as in the other exercises, i.e., to maximize overall profit over 12 time periods. This exercise evaluated students' individual ability after they had learned and gained experience from the two team exercises. The post-evaluation exercise was exactly the same for the two classes, thus enabling us to compare the two classes' performances after they had completed the preceding three exercises.

3. Experiment results and analysis

Table 2 summarizes the number of individual results collected in the pre- and post-evaluation exercises and the number of team results collected in Cohort A and Cohort B for Class Mixed and Class Pure. The variation in the number of students participating in the various exercises was due to the fact that students enrolled in or dropped the course during the semester. Moreover, occasionally students did not participate in the exercises, even though they were mandatory. Given that the number of students adding and dropping the course was no different than normal; we believe that their reasons for doing

Table 2. Number of results collected in all four exercises for both classes

	# of individual results, pre-evaluation exercise	**# of team results, first and second team exercises Cohort A**	**# of team results, first and second team exercises Cohort B**	**# of individual results, post-evaluation exercise**
Class Mixed	119	32	34	127
Class Pure	112	30	31	111

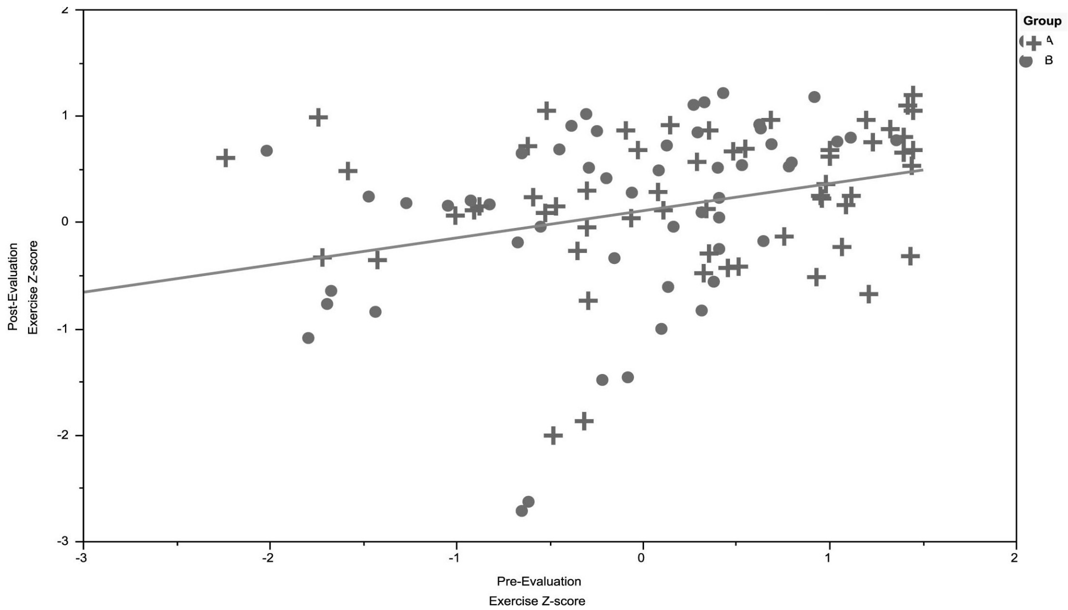

Fig. 2. Bivariate fit graph of Class Mixed: Pre-evaluation exercise z-score vs. the post-evaluation exercise z-score.

so were unrelated to the simulator. In addition, in each class there were 2–3 outlier observations that were removed according to the heuristic given in [62]: The magnitude of the ratio of the residual of the outlier to the error variance was greater than three. These outliers were usually due to a student starting an exercise and then abandoning it in the middle; basically, the student did not finish the exercise.

A simple t-test was not suitable for checking the hypotheses since the within-cohort variance masked the differences between cohorts. This phenomenon can be elucidated by a bivariate fit analysis of both classes' performances. When analyzing Class Mixed's and Class Pure's results, a significant correlation between the teams and their performance was revealed (Class Mixed p value < 0.002, Adjusted $R^2 = 0.077$; Class Pure p value < 0.001, Adjusted $R^2 = 0.137$). Figures 2 and 3 present the bivariate fit test results of the correlation between the teams and their z-score performance in the pre- and post-evaluation exercises in Class Mixed and Class Pure, respectively. The teams tended to show either high or low performance regardless of strategy. Due to the correlation findings and in order to

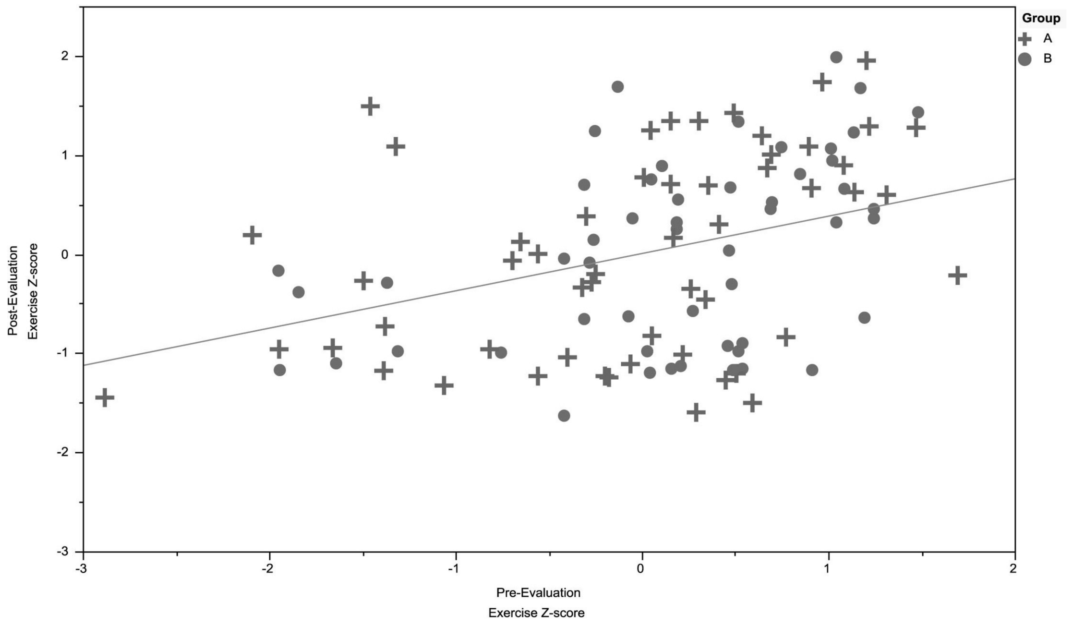

Fig. 3. Bivariate fit graph of Class Pure: Pre-evaluation exercise z-score vs. the post-evaluation exercise z-score.

Table 3. Students' performance (profit in $) in the post-evaluation exercise for each class (raw data results after eliminating outliers and data of students who did not participate in all four experiments

Class	Mean	Standard Deviation	Sample Size
Class Mixed	5,335,228	44,767	113
Class Pure	4,808,057	72,479	110

Table 4. ANCOVA results of testing the difference in the inter-class mean post-evaluation exercise performance using the pre-evaluation exercise as a covariant

Source	Degrees of Freedom	F Statistic	Sig.
Model	3	5697.070	0.000
Pre-Evaluation Exercise Performance	1	41.541	0.000
Class	2	3084.544	0.000
Error	220		
Total	223		

Table 5. Students' performance (profit in $) in the post-evaluation exercise for each cohort in Class Mixed (raw data results after eliminating exceptions and data of students who did not participate in all four experiments)

Cohort	A	B
Mean	5,373,446	5,304,224
Standard Deviation	57,680	70,914
Sample Size	57	54

reduce the within-group variance, in all statistical tests we used ANCOVA to test the significance of differences between the cohorts' mean student performance in the post-evaluation exercise (dependent variable) using student performance in the pre-evaluation exercise as a covariate.

3.1 Hypothesis 1

In order to test whether a mixed approach achieves better learning outcomes than a pure approach, we used ANCOVA to test the significance of the difference between the mean student performance in the post-evaluation exercise (dependent variable) in the two classes (Class Mixed and Class Pure) using the pre-evaluation exercise as a covariate; see Table 3.

Table 4 presents the ANCOVA results that indicate that the performance in the post-evaluation exercise is dependent on the class when correcting for the classes' performance in the pre-evaluation exercise. The significance of the model has a p value < 0.001 and the significance of the independent variable (class) also has a p value < 0.001. Cohen's effect size value ($d = 0.83$) suggests a high practical significance. Accordingly, we conclude that teaching using a mixed approach achieves better learning outcomes than using a pure approach.

3.2 Hypothesis 2

In order to test whether the order of the two intragroup interaction types significantly affects the learning outcomes when using a mixed approach, we used ANCOVA to test the significance of the differences between the mean student performance in the post-evaluation exercise (dependent variable) in Cohort Mixed-A and Cohort Mixed-B; see Table 5.

Table 6 presents the ANCOVA results that indicate that the performance in the post-evaluation exercise is dependent on the cohort when correcting for the groups' performance in the pre-evaluation exercise. The significance of the model has a p value < 0.001 and the significance of the independent variable (cohort) also has a p value of 0.007. Cohen's effect size value ($d = 0.14$) suggests a low practical significance.

In order to further test Hypothesis 2, we conducted an additional analysis. Motivated by the correlation findings, we decided to neutralize noise caused by the intra-cohort variance in a different way than by using a covariate. A t-test investigated the mean difference in the performance of the

Table 6. ANCOVA results for testing the difference in the inter-cohort mean post-evaluation exercise performance using the pre-evaluation exercise as a covariant

Source	Degrees of Freedom	F Statistic	Sig.
Model	3	4916.439	0.000
Pre-Evaluation exercise performance	1	8.490	0.004
Cohort	2	5.132	0.007
Error	108		
Total	111		

Table 7. Students' performance (profit in $) in the first and second team exercises and the difference in the performance of 'Cooperative minus Competitive' for each cohort in Class Mixed (number of teams in Cohort Mixed-A = 32, number of teams in Cohort Mixed-B = 34)

Cohort	Statistical measure	The First Team Exercise	The Second Team Exercise	'Cooperative minus Competitive'
A	Mean	1,885,471	1,922,995	37,524
	Standard Deviation	19,458	15,067	13,885
B	Mean	1,894,548	1,905,505	–10,957
	Standard deviation	14,691	16,133	11,549

cooperative exercise minus the competitive exercise for each team. In other words, the nominal performance of each team interaction type was not analyzed. Only one datum for each team was used: The result of their performance using the cooperative interaction minus their performance using the competitive interaction. This method eliminated the noise of each team's ability. For Cohort Mixed-A, this method meant using the difference between the results in the second team exercise and the first team exercise. Similarly, for Cohort Mixed-B this meant using the difference between the results in the first team exercise and the second team exercise. A t-test was used here as opposed to ANCOVA, which was used in the previous analyses, as we did not postulate that the students' initial abilities would affect the difference between these two exercises while before we had postulated that the students' initial performance would affect the students' absolute performance in the final exercise. Table 7 presents the students' performance in the first and second team exercises and the difference in the performance of 'cooperative minus competitive' for each cohort in Class Mixed.

The two-tailed t-test determined that results depended significantly on which interaction type was used in the first team exercise (p value < 0.001, Cohen's $d = 3.79$). Teams that started with the competitive interaction in the first team exercise performed significantly better. Moreover, the results show that teams that started with the competitive interaction had a positive difference (one tailed z-test with p value < 0.004, Cohen's $d = 2.70$); whereas teams that started with the cooperative interaction demonstrated no significant difference between their performances using both interaction types, i.e., the mean difference was not significantly different than zero. Figure 4 presents the test results graphically. Accordingly, we conclude that the order of the two interaction types is significant

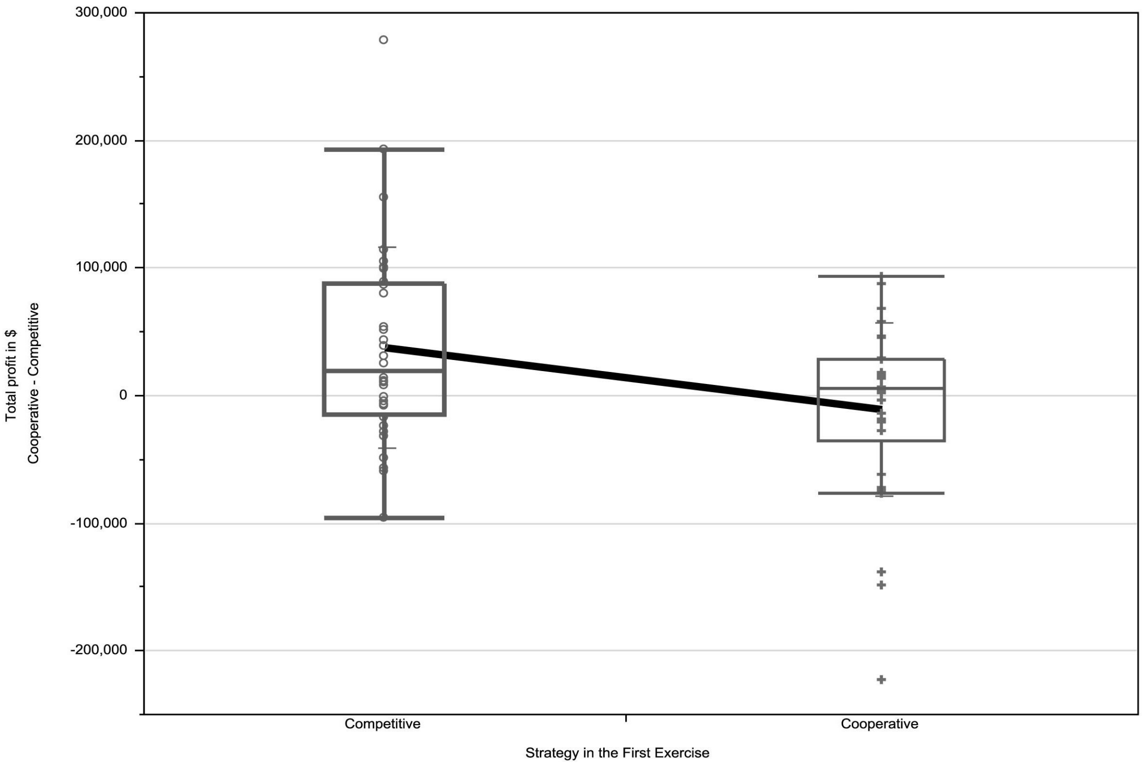

Fig. 4. One-way analysis graph of the performance in $ of Class Mixed Cohorts of 'cooperative minus competitive'.

and it is better to start with a competitive interaction and then move to a cooperative one.

4. Discussion

This research focused on team learning using SBT techniques in the industrial engineering education domain. We utilized a simulator that enables the virtual management of a supply chain to investigate two different approaches—pure and mixed—trying to determine which is the more effective when using SBT in the SCM domain. The results indicate that when using SBT with teams, it is better to teach using a mixed approach than to teach using only one (pure) approach. Moreover, if both interaction types are used, then the order of teaching is significant; it is better to start with a competitive interaction and then move to a cooperative interaction rather than the reverse.

In the post-evaluation exercise, Class Mixed students outperformed Class Pure students, which result supports Hypothesis 1 that it is better to teach using both interaction types rather than with only one. A possible explanation for the observed phenomena is that teaching using both interaction types exposes students to a broader experience than teaching using only one interaction type. This experience enriches the learning process and thus is more efficient.

Once a mixed approach is used, we found that it is better to start with a competitive interaction and then move to a cooperative one. This assertion derives from students' performance in the post-evaluation exercise. In this exercise, the Class Mixed students that started with the competitive exercise significantly outperformed students who started with the cooperative exercise.

It seems that the Class Mixed teams that started with a competitive interaction and then used a cooperative interaction (Cohort mixed-A) learned something extra from the order in which they performed the team exercises. The learning was expressed by their better team performance when using a cooperative interaction versus a competitive one; i.e., the second round performance was better than the first one. In contrast, teams that started with a cooperative interaction and then used a competitive one did not learn enough from the first round in order to improve their performance in the second round. This observation is supported by the zero difference in the performance of the first and second rounds for the teams using a cooperative and then a competitive interaction. This being the case, teams that started with a cooperative interaction apparently did not learn from the first team exercise as evidenced by the fact that their performance in the second team exercise was no better than their performance in the first team exercise (on average).

A potential explanation for the differences in the performances of the two groups in Class Mixed is that a competitive exercise causes the team to experience the negative effects of competition. Accordingly, during the next session, the team members appreciate and take advantage of the opportunity to cooperate.

Another possible explanation is that a team that started with a cooperative interaction has already internalized the benefits of cooperation before moving on to a competitive scenario. Thus when the team faces a competitive interaction (the second team exercise), its members did not act according to the competitive instructions, but continued to act as if they were in a cooperative exercise. The effect here was intensified because even though the competitive teams were motivated to act competitively, they were not compelled to do so—there was no direct penalty if they did not.

A more technical explanation for the above findings may perhaps be that a competitive exercise forces each team member to deal with the exercise (each team member must take care of himself if he wants to succeed, whereas in a cooperative exercise, each team member knows she can count on her partner). Thus, learning begins earlier when the competitive exercise is first.

A study design limitation of the current research was that the students who participated in the experiment belong to a single institute and thus are potentially a non-representative group. Yet, to the best of our knowledge, the characteristics of these students are not different from other industrial engineering students from other institutions.

Another limitation was that we checked the short term effect within the same semester and not a longer term effect. It is our assertion that this is the first step in examining this area; a short term effect is needed for a long term effect. The extent of the long term effect could and should be addressed in subsequent research.

5. Conclusions and future research

The goal of the research was to investigate, from pedagogical perspectives, which approach is more effective when using SBT in engineering education: pure or mixed. In reality, some supply chains are managed by cooperative interaction while others are managed by competitive interaction. From a practical point of view, cooperative interaction based on a win-win approach is preferable.

Our study indicates that at the training stage, it is better to train teams using both interaction types rather than to teach using only one (pure) interaction type. Furthermore, it is better to start with competitive interaction and then move to cooperative interaction rather than the reverse.

After considering the above results and their possible explanations, the following guidelines on how to use SBT for team training are offered:

1. Teach using a mixed approach—both cooperative and competitive interaction types (not just one of them).
2. When training teams and trying to encourage a certain behavior and eliminate another behavior considered to be negative, it is better for trainees first to gain experience with the negative behavior and its repercussions. Only afterwards should they be exposed to the targeted behavior and its benefits because in the latter situation, the differences are more obvious and the learning process is intensified.
3. When training teams in the reverse order (i.e., first the desired behavior and only afterwards the negative one), ensure that the teams follow the instructions and they should be motivated to actually act upon the negative behavior.

The experiment could be reiterated in different institutions, possibly from different countries, in order to reinforce the validity of this study's hypotheses and conclusions, increase the sample size and neutralize cultural and regional types of biases that might result from our study limitation (students belonging to a single institution; noted above). Along with conducting the experiment, student satisfaction from SCS could also be assessed.

We suggest that future research focus on the impact of supply chain SBT on the real strategy adopted by industrial engineers. The main question would then be whether a mixed training approach promotes cooperative management of real supply chains.

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Avinoam Tzimerman is a doctoral candidate in the Faculty of Industrial Engineering and Management at the Technion—Israel Institute of Technology. He has a B.Sc. and an M.Sc. from the Technion. He also has a LL.B. in law from Netanya College and an M.A. in law from Bar Ilan University. Avinoam served for seven years as a professional officer in the Israeli Air Force and has worked for many years for high-tech companies.

Yale T. Herer is an Associate Professor at the Technion—Israel Institute of Technology. He received his B.S. (1986), M.S. (1990), and Ph.D. (1990) all from the ORIE Department of Cornell University. His main research focus is on supply chain management. He is/has served on the editorial boards of NRL, IIE Transactions, and OR Letters. He has received both the IIE Transactions Best Paper Award and the Wagner Prize.

Avraham Shtub holds the Stephen and Sharon Seiden Chair in Project Management. He has a B.Sc. in Electrical Engineering from the Technion—Israel Institute of Technology (1974), an M.B.A. from Tel Aviv University (1978) and a Ph.D. in Management Science and Industrial Engineering from the University of Washington (1982). Prof. Shtub served as a Department Editor for IIE Transactions, was on the Editorial Boards of IIE Transactions and the International Journal of Production Research.