

Article

Fostering Collaboration and Sustainability Through Serious Games in Supply Chain Management Education

Eduardo Bastida-Escamilla ^{1,*} , Carlos Peña ¹ , Humberto Genaro Cisneros-Salinas ²  and Dan Trowsdale ³ 

¹ School of Engineering and Sciences, Tecnológico de Monterrey, Mexico City 01389, Mexico

² School of Engineering and Sciences, Tecnológico de Monterrey, Monterrey 64700, Mexico; a01723264@tec.mx

³ School of Mechanical Engineering, University of Leeds, Leeds LS2 9JT, UK

* Correspondence: eduardo.bastida@tec.mx; Tel.: +52-55-9177-8000

Abstract

This study examined changes in students' self-perceived Sustainability Action Competence (SAC) and Collaboration Competence (CC) associated with participation in the Tequila Game, a multiplayer serious game in which students assume the role of competing retailers and make operational, sustainability, and voluntary collaboration decisions in a shared market. A quasi-experimental pretest–posttest control-group design was conducted with 188 undergraduate engineering students across eight course sections. Students in the treatment group participated in the Tequila Game, whereas the control group completed alternative active-learning activities. Compared with the control group, participants in the Tequila Game achieved significantly larger gains in overall SAC and CC (both $p < 0.001$). Among the component dimensions, the largest improvements were observed for Learning ($t = 7.31$, $p < 0.001$, $d_z = 0.79$), Willingness to Act ($t = 7.01$, $p < 0.001$, $d_z = 0.76$), and Confidence in One's Own Influence ($t = 5.77$, $p < 0.001$, $d_z = 0.63$). Gameplay analyses complemented the survey findings by showing that collaboration was conditional rather than automatic: inventory sharing increased primarily when retailers held substantial surpluses, transportation sharing consistently improved vehicle utilization, and collaboration occasionally failed despite broad support and the absence of clear operational incentives for defection. These findings demonstrate that serious games can strengthen sustainability- and collaboration-related competencies while exposing students to the operational and behavioral complexities of collaborative decision making.

Keywords: sustainability action competence; collaboration competence; serious games; supply chain simulation; higher education; educational innovation



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1. Introduction

1.1. Background and Motivation

Higher education is increasingly expected to prepare graduates to be capable of addressing complex sustainability challenges that require not only disciplinary expertise but also the ability to navigate interconnected social, environmental, and economic systems. Within sustainability education, considerable attention has been devoted to identifying the competencies students should develop to contribute effectively to sustainability-oriented problem solving. Among the most influential frameworks, Wiek et al. [1] proposed five key sustainability competencies—systems-thinking, anticipatory, normative, strategic, and interpersonal competencies—and argued that they provide a useful reference for the design, implementation, and evaluation of sustainability-focused academic programs. Building

on this work, Brundiens et al. [2] refined the original framework through an international Delphi study and moved toward a more broadly shared reference model for sustainability education in higher education.

While competency frameworks have become widely adopted, demonstrating how educational interventions contribute to competency development remains challenging. Recent evidence suggests that substantial progress has been made in sustainability education research, particularly regarding pedagogical approaches, transformative learning, and competency assessment. Nevertheless, important questions remain concerning how learning processes translate into measurable educational outcomes and how sustainability-related competencies can be evaluated consistently across different educational contexts [3]. Consequently, the relationship between instructional design and competency development continues to represent an important area of inquiry.

These challenges are particularly relevant in supply chain management education. Modern supply chains operate in environments characterized by uncertainty, sustainability pressures, resource constraints, and the need for coordination among multiple stakeholders. As a result, future supply chain professionals require not only analytical and operational capabilities but also competencies associated with collaborative decision making and sustainability-oriented action. A recent review by Cantoni et al. [4] highlights the growing importance of these transversal competencies within logistics and supply chain management, arguing that technical expertise alone is insufficient to address contemporary supply chain challenges.

To address these educational needs, simulation-based learning and serious games have become increasingly common instructional approaches. Through interactive decision-making environments, students can experience uncertainty, coordination challenges, inventory trade-offs, supplier disruptions, and sustainability considerations in ways that are difficult to reproduce through traditional lectures alone. A systematic review by Kavota et al. [5] identified serious games as one of the most frequently reported approaches for teaching contemporary supply chain challenges, including collaboration, sustainability, network design, inventory management, and Supply Chain 4.0 concepts.

The broader educational literature similarly suggests that serious games can support learning, engagement, and competency development. In a systematic review of empirical studies, Connolly et al. [6] found consistent evidence linking serious games to improvements in knowledge acquisition, motivation, and learner engagement. Within sustainability education, Rooney-Varga et al. [7] demonstrated that simulation-based role-play activities can generate significant gains in sustainability-related knowledge, affective engagement, and willingness to act. More recently, Kaliani Sundram et al. [8] reported that game-based and simulation-based learning environments can enhance student engagement and learning outcomes by exposing learners to realistic situations requiring the management of competing objectives and uncertainty.

1.2. Research Gap

Despite this growing body of research, two limitations remain evident. First, many studies focus primarily on engagement, satisfaction, or disciplinary knowledge acquisition rather than on measurable changes in Sustainability Action Competence and Collaboration Competence. Second, relatively few studies connect what students actually do within a simulation environment to subsequent changes in competency-related perceptions and attitudes. Reviews of serious games in sustainability education continue to call for stronger empirical evidence linking game mechanics, learning processes, and measurable educational outcomes [9].

Collectively, these limitations indicate the need for empirical studies that evaluate competency development using validated assessment instruments while also incorporating behavioral evidence generated during the learning process. Such an approach can provide a more comprehensive understanding of how serious games contribute to competency development in supply chain management education.

1.3. Research Objectives

To address these research gaps, this study evaluates the educational contribution of the Tequila Game as a serious game for competency development in supply chain management education. During the simulation, students assume the role of independent retailers competing for market share while purchasing products from a shared supplier under uncertain demand and supply conditions. Participants make decisions regarding inventory management, transportation selection, and collaborative mechanisms such as transportation sharing, inventory exchanges, and proportional allocation of limited supply. Although profitability remains the primary performance objective, sustainability considerations are embedded through transportation-related CO₂ emissions and collaboration opportunities.

This study examines whether participation in the simulation leads to measurable improvements in Sustainability Action Competence (SAC) and Collaboration Competence (CC) beyond those achieved through established active-learning activities. In addition, it investigates whether behavioral evidence automatically recorded during gameplay provides complementary insights for interpreting these competency changes.

To achieve these aims, the following research questions guide the study:

- RQ1. Does participation in the Tequila Game lead to greater improvements in Sustainability Action Competence (SAC) than participation in conventional active-learning activities?
- RQ2. Does participation in the Tequila Game lead to greater improvements in Collaboration Competence (CC) than participation in conventional active-learning activities?
- RQ3. To what extent do gameplay behaviors provide complementary evidence for interpreting changes in Sustainability Action Competence and Collaboration Competence?

The three research questions are addressed through two complementary sources of evidence: questionnaire-based competency assessments and behavioral data automatically recorded during gameplay. RQ1 and RQ2 evaluate changes in Sustainability Action Competence and Collaboration Competence through inferential comparisons of pre–post gains between the treatment and control groups. In contrast, RQ3 adopts an exploratory perspective by examining whether behavioral patterns observed during gameplay provide complementary evidence for interpreting the questionnaire-based findings.

Figure 1 summarizes the proposed research framework, showing how the instructional conditions, evidence sources, and research questions are integrated within the study. Questionnaire data collected before and after the intervention are used to compare the treatment and control groups, addressing RQ1 and RQ2, whereas behavioral indicators automatically recorded during the Tequila Game provide complementary evidence for RQ3. Together, these sources of evidence provide a comprehensive assessment of the educational contribution of the intervention.

To address these research questions, Sustainability Action Competence was assessed using the Self-Perceived Action Competence for Sustainability Questionnaire (SPACS-Q) [10], whereas Collaboration Competence was measured using the Self-Assessment of Collaboration Skills (SACS) instrument [11]. In addition, gameplay records were analyzed to examine how students, acting as retailers within the simulation, responded to collaboration opportunities and sustainability-related operational trade-offs.

Despite growing interest in sustainability competencies, assessment remains an area of ongoing development. Cebrián et al. [13] observe that educational innovation has advanced more rapidly than the methods used to evaluate its outcomes, creating a situation in which many interventions claim to promote sustainability competencies without clear evidence regarding the specific capabilities that have been strengthened. This limitation has motivated researchers to seek more operational perspectives capable of connecting educational experiences with measurable student outcomes.

One influential response to this challenge emerged through the action competence tradition in environmental and sustainability education. Jensen and Schnack [14] argued that educational approaches focused primarily on knowledge acquisition or behavioral prescriptions are insufficient for preparing learners to address complex sustainability problems. Instead, they proposed action competence as an educational ideal centered on individuals' capacity to participate critically and democratically in processes of societal change. Expanding this perspective, Mogensen and Schnack [15] emphasize that action competence should not be understood as a specific behavior or outcome, but rather as an individual's ability and willingness to engage with sustainability challenges through informed, reflective, and purposeful action.

These theoretical developments provided the foundation for the Self-Perceived Action Competence for Sustainability Questionnaire (SPACS-Q) developed by Olsson et al. [10]. The instrument operationalizes action competence through three complementary dimensions: Knowledge of Action Possibilities (KAP), Confidence in One's Own Influence (COI), and Willingness to Act (WTA). KAP reflects individuals' understanding of actions that may contribute to sustainable development, COI captures the extent to which individuals believe their actions can influence sustainability outcomes, and WTA assesses their readiness to engage in sustainability-oriented action. Validation studies demonstrate strong psychometric properties and support the use of the instrument as a theoretically grounded measure of sustainability-related agency.

More recently, Olsson et al. [16] identified action competence as one of the most theoretically coherent and empirically supported traditions within sustainability education assessment. Their review highlights the continued need for studies that examine whether specific educational interventions influence learners' perceived capacity to contribute to sustainability transitions, particularly in professional domains where sustainability considerations must be integrated into operational and managerial decision making.

Together, these contributions reflect a gradual shift within sustainability education research from defining desired competencies toward understanding how those competencies develop and how they can be assessed. Within this broader discussion, action competence has emerged as a particularly relevant perspective because it emphasizes learners' perceived capacity to translate knowledge and understanding into purposeful action. As a result, it provides a useful lens for examining the educational outcomes of experiential and decision-based learning interventions.

2.2. Collaboration Competence

Collaboration is widely recognized as a critical competence in both higher education and professional practice. However, substantial variation exists regarding how collaboration should be conceptualized and assessed across disciplines. In a systematic review of collaboration research in higher education, Schürmann et al. [17] found that collaboration is frequently defined through diverse constructs ranging from general teamwork perceptions to specific behaviors involving communication, coordination, mutual support, and shared regulation. Their review highlights the need for assessment approaches that conceptualize

collaboration as a measurable competence enacted through authentic tasks rather than as a general attitude toward teamwork.

This perspective has influenced the development of collaboration assessment frameworks in engineering, management, and professional education. For example, the Comprehensive Assessment of Team Member Effectiveness (CATME) developed by Ohland et al. [18] evaluates collaboration through behaviorally anchored dimensions associated with effective team participation. Similarly, Thite et al. [19] emphasize the importance of structured assessment approaches that help learners understand and improve collaborative performance through observable behaviors. Together, these contributions reflect a broader shift from viewing collaboration as a personality characteristic toward understanding it as a competence that can be developed and assessed.

In the present study, Collaboration Competence is conceptualized using the Self-Assessment of Collaboration Skills (SACS) framework. Originally developed within inter-professional education, SACS defines collaboration through three dimensions: Learning (L), Team Support (TS), and Information Sharing (IS). According to Sargeant et al. [20], effective collaboration depends on communication, mutual respect, role awareness, and shared responsibility for collective outcomes. Building on this perspective, Braathen [11] validated the SACS instrument and provided evidence supporting its reliability and applicability across educational settings. Consequently, CC is operationalized in this study through these three dimensions.

2.3. Serious Games in Supply Chain and Sustainability Education

Serious games and simulation-based learning have become established pedagogical approaches for developing managerial and decision-making competencies in higher education. Foundational reviews by Connolly et al. [6] and the meta-analysis of Wouters et al. [21] demonstrated that serious games can improve learning outcomes, engagement, and problem-solving capabilities, particularly when gameplay is accompanied by instructional support and structured reflection. Similarly, Faria et al. [22] documented the long-standing role of business simulation games in management education and emphasized the importance of aligning game complexity with intended learning objectives.

Recent evidence has reinforced these conclusions while expanding attention toward sustainability and competence development. In a systematic review of business simulation games in higher education, Vélez et al. [23] found consistent evidence that simulation-based learning promotes intrinsic motivation, engagement, decision-making skills, and collaborative learning outcomes. Their review further suggests that simulations are particularly valuable when learners must make decisions under uncertainty and observe the consequences of those decisions within dynamic systems. Likewise, Kaliani Sundram et al. [8] report that gamification and simulation approaches in supply chain education enhance learning outcomes and collaboration-related behaviors, especially when game mechanics encourage interaction among participants rather than focusing exclusively on competition.

Within supply chain management education, simulations occupy a particularly important role because they expose students to dynamic feedback processes, delayed consequences, and decentralized decision making that are difficult to reproduce through lectures or case studies. Sterman [24] introduced the Beer Game as a foundational example, demonstrating how localized decisions can generate system-wide effects such as demand amplification and coordination failures. More recently, Deghedi [25] conclude that effective supply chain games should allow participants to experience emergent behavior arising from operational uncertainty, resource constraints, and interactions among decision makers.

The growing integration of sustainability objectives into supply chain management has expanded the educational scope of these simulations. Supply chains account for a

substantial share of global greenhouse-gas emissions, making logistics and transportation decisions central components of sustainability performance [26]. In this context, simulation environments provide opportunities for students to experience trade-offs among economic, operational, and environmental objectives. Koh et al. [27] argue that transportation planning, shipment consolidation, and coordinated logistics decisions represent critical managerial levers for reducing emissions while maintaining service performance. Similarly, Frommer and Day [28] demonstrate that incorporating environmental metrics into operations-management simulations makes sustainability trade-offs more visible and actionable for learners.

Beyond supply chain applications, De la Torre et al. [29] reviewed the use of simulation and serious games in teaching circular economy and sustainable energy concepts, concluding that these approaches are particularly effective for helping students understand complex system interactions and sustainability-related decision consequences. Their findings suggest that simulation environments can support sustainability learning by allowing participants to experiment with alternative decisions and immediately observe their environmental implications.

Despite the growing body of evidence supporting serious games, important methodological limitations remain. Machado Leitão et al. [30] reviewed serious games in business process management and found that most studies rely on relatively weak evaluation designs, with limited use of control groups, validated instruments, or rigorous assessments of learning outcomes. Similar concerns are raised within supply chain education, where Kavota et al. [5] observe that simulation-based interventions frequently emphasize student satisfaction and perceived usefulness while providing limited evidence regarding competence development. Consequently, although serious games are widely recognized as valuable learning tools, the mechanisms through which specific game features contribute to measurable competency gains remain insufficiently understood.

The present study addresses this gap by examining a supply chain simulation that combines operational uncertainty, sustainability trade-offs, and multiple forms of voluntary collaboration within a quasi-experimental design. Unlike many previous studies, it evaluates learning outcomes using validated instruments for sustainability action competence and collaboration, while also creating opportunities to connect observed game behaviors with changes in self-reported competencies.

3. Materials and Methods

3.1. Research Design

This study employed a quasi-experimental pretest–posttest control-group design [31] to evaluate the educational impact of a supply chain simulation on students' SAC and CC. Because the intervention was implemented within existing course sections, participants were not individually randomized. Instead, intact sections were assigned to treatment or control conditions according to instructional planning constraints.

Students in the treatment condition participated in the Tequila Game simulation, whereas students in the control condition completed alternative instructional activities commonly used in supply chain and operations management education, including the Beer Game, The Fresh Connection simulation, and instructor-led case analyses. The use of an active control condition allowed comparisons against established instructional approaches rather than against the absence of instruction.

3.2. Participants and Sampling

A purposive sampling strategy was employed. Participants were undergraduate students enrolled in third-year supply chain and operations management courses at a

private university in Mexico. Students were eligible to participate if they were formally enrolled in the selected courses, completed the assigned instructional activity, and provided informed consent for the use of their responses in the study. Students who had previously participated in a similar version of the Tequila Game were excluded.

The final analytical sample consisted of 188 valid paired responses collected from eight course sections, four assigned to the treatment condition and four assigned to the control condition. These responses were obtained from an enrolled population of 200 students, corresponding to an overall valid paired-response rate of 94.0%, as summarized in Table 1. The sample comprised 126 men (67.0%), 56 women (29.8%), one non-binary participant (0.5%), and five participants who preferred not to disclose their gender (2.7%). Most participants were enrolled in Industrial Engineering programs (89.9%), while the remaining students were enrolled in closely related engineering disciplines (10.1%). Age was not collected as part of the study. Nevertheless, all participants belonged to the same third-year undergraduate cohort, reducing variability in academic stage.

Table 1. Sample composition and participant characteristics.

Characteristic	Control	Treatment	Total
Course sections	4	4	8
Students enrolled	111	89	200
Valid paired responses	103 (92.8%)	85 (95.5%)	188 (94.0%)
Men	72 (69.9%)	54 (63.5%)	126 (67.0%)
Women	28 (27.2%)	28 (32.9%)	56 (29.8%)
Non-binary	0 (0.0%)	1 (1.2%)	1 (0.5%)
Prefer not to say	3 (2.9%)	2 (2.4%)	5 (2.7%)
Industrial Engineering	93 (90.3%)	76 (89.4%)	169 (89.9%)
Other related engineering programs	10 (9.7%)	9 (10.6%)	19 (10.1%)

Response rates are reported as the percentage of enrolled students who provided valid paired pre-test and post-test responses.

3.3. Simulation Environment

The intervention evaluated in this study was the Tequila Game, a web-based multi-player supply chain simulation designed to expose students to operational uncertainty, collaboration opportunities, and sustainability-related trade-offs. The platform is publicly available at <https://sellysim.web.app/>, accessed on 22 July 2026 [32]. Participants were organized into independent game sessions, typically consisting of four students. Within each session, every participant independently managed a retailer competing in a common market while interacting with a shared supplier. Retailers competed only against others within the same game session, whereas separate sessions operated independently. Unlike traditional supply chain simulations, in which participants jointly manage different stages of a single supply chain, the Tequila Game allows collaboration to emerge voluntarily among competing retailers rather than prescribing it as part of the game structure.

Before beginning the experimental session, participants completed a practice game to become familiar with the user interface, decision process, and game mechanics. Data generated during this practice session were excluded from all analyses. Participants then completed two full simulation games consisting of 20 decision rounds each. A typical game required approximately 30 min to complete, after which an instructor facilitated a structured debriefing focused on the operational, collaborative, and sustainability implications of the decisions made during the simulation.

Each retailer began with identical initial operating conditions, including inventory and financial resources, and sought to maximize profitability by balancing inventory availability, transportation costs, service levels, and overall financial performance. During each round,

participants independently submitted their decisions through the web platform. Verbal communication among retailers was permitted but not required, allowing collaboration to develop organically whenever participants perceived mutual benefit. Demand, supplier availability, and disruption events were generated through stochastic processes embedded within the simulation, creating dynamic operating conditions across decision rounds. Although the platform supports multiple parameter configurations for different instructional scenarios, all participants in the present study experienced the same simulation configuration. For reproducibility, the complete set of game parameters, including initial conditions, transportation settings, and stochastic event probabilities, is reported in Appendix A.

A distinguishing characteristic of the Tequila Game is the integration of sustainability considerations into operational decision-making. Participants selected among transportation alternatives that differed in capacity, operating cost, and transportation-related CO₂ emissions, creating explicit trade-offs between economic and environmental performance. The game also incorporated voluntary collaboration mechanisms among competing retailers, including transportation sharing, inventory exchanges, and proportional allocation of scarce supplier capacity during shortage situations. These mechanisms were designed to promote more efficient transportation utilization, reduce operating costs and transportation-related emissions, and encourage more effective use of available resources under uncertainty. Sustainability was therefore operationalized through both explicit environmental indicators (i.e., transportation-related CO₂ emissions) and collaborative operational mechanisms. Transportation sharing was implemented as a form of horizontal collaborative transport aimed at improving transportation efficiency and supporting more sustainable freight operations [33]. Inventory sharing was implemented as an inventory pooling mechanism that can improve service levels, reduce inventory-related costs, and promote more efficient resource utilization, with potential benefits for waste reduction and environmental performance [34]. Collaborative transportation decisions can also improve vehicle utilization while generating economic and environmental benefits through more efficient logistics operations [35].

To reinforce the relationship between operational performance and competitive outcomes, the simulation incorporated a market-feedback mechanism. Throughout the game, participants received information regarding their market share and competitive position relative to the other retailers within their game session. In addition, the retailer achieving the lowest operating cost in a given round received additional customer demand in the subsequent round. This mechanism reflects growing evidence that consumers increasingly value responsible and transparent business practices when evaluating firms and making purchasing decisions [36]. By linking operational decisions, sustainability outcomes, market share, and future demand, the simulation encouraged participants to consider the broader consequences of supply chain decisions beyond immediate financial performance.

At the conclusion of each round, the platform automatically recorded participants' decisions and operational outcomes using anonymous participant identifiers. Logged variables included replenishment decisions, transportation selections, transportation sharing, inventory sharing, proportional allocation decisions, inventory levels, fulfilled and unmet demand, shortages, transportation utilization, transportation costs, estimated transportation-related CO₂ emissions, market share, and financial performance. Participants simultaneously received structured performance feedback summarizing these outcomes, enabling them to evaluate previous actions, refine subsequent decisions, and observe how operational, collaborative, and sustainability strategies influenced system performance across repeated rounds.

3.4. Instruments

3.4.1. Sustainability Action Competence

SAC was measured using the Self-Perceived Action Competence for Sustainability Questionnaire (SPACS-Q) developed by Olsson et al. [10]. The instrument operationalizes Sustainability Action Competence through three dimensions: Knowledge of Action Possibilities (KAP), Confidence in One's Own Influence (COI), and Willingness to Act (WTA). The instrument has been applied in both secondary and higher education contexts and has demonstrated satisfactory psychometric properties for assessing sustainability-related agency [37].

Responses were collected using a seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

3.4.2. Collaboration Competence

CC was measured using the Self-Assessment of Collaboration Skills (SACS) instrument [11]. The instrument operationalizes Collaboration Competence through three dimensions: Learning (L), Team Support (TS), and Information Sharing (IS). Although originally developed within interprofessional education contexts, the instrument has demonstrated applicability across diverse educational settings where collaboration represents an important learning outcome.

Responses were collected using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

3.4.3. Scoring and Reliability

Dimension-level scores were calculated as the arithmetic mean of the items associated with each dimension. Overall SAC and CC scores were calculated as the mean of all items belonging to their respective instruments.

Internal consistency was evaluated using Cronbach's alpha coefficients for both pretest and posttest administrations. Reliability estimates for all dimensions and constructs are presented in Table 2.

Table 2. Internal consistency of the instruments.

Construct	Index	Pretest α	Posttest α
Collaboration	IS	0.518	0.504
	L	0.684	0.782
	TS	0.681	0.783
	Overall	0.74	0.788
Sustainability	COI	0.891	0.898
	KAP	0.859	0.89
	WTA	0.884	0.899
	Overall	0.895	0.9

α = Cronbach's alpha.

3.5. Procedure

Baseline questionnaires were administered electronically during the first weeks of the academic term, before any simulation-based learning activities were conducted. Responses were matched across measurement points using anonymous participant identifiers.

Students assigned to the treatment condition participated in a two-hour Tequila Game session. All participants completed two full simulation games consisting of 20 decision rounds each. Depending on the pace of play and student interest, some groups elected to play a third simulation game during the remaining class time. Students assigned to the

control condition completed their corresponding instructional activity during a comparable class period.

Posttest questionnaires were administered immediately after completion of the instructional activity in both conditions. Consequently, treatment-group students completed the posttest immediately after participating in the Tequila Game, whereas control-group students completed the same instruments immediately after their respective learning activity.

3.6. Gameplay Data

In addition to questionnaire responses, the Tequila Game automatically recorded gameplay data generated during simulation sessions. These records included replenishment orders, transportation selections, inventory exchanges among retailers, transportation-sharing agreements, participation in proportional supply-allocation arrangements, fulfilled demand, unmet demand, transportation costs, and transportation-related CO₂ emissions.

The gameplay data provide an objective record of participant behavior within the simulation environment and complement the self-reported competency measures collected through the questionnaires. Particular attention was given to behaviors associated with CC, including transportation sharing, inventory exchanges, and participation in proportional-allocation agreements, as well as behaviors associated with sustainability-related decision making, including transportation choices and resulting emissions.

Because questionnaire responses were collected at the individual level whereas gameplay decisions were recorded at the retailer level, direct respondent-to-decision matching was not possible. Consequently, gameplay indicators were analyzed at the simulation level and contrasted with aggregated competency outcomes reported by students participating in the corresponding sessions. This approach allows the study to explore consistency between observed behaviors and reported learning outcomes while avoiding unsupported individual-level inferences.

3.7. Data Analysis

Analyses were conducted at both the construct and dimension levels. Internal consistency was evaluated using Cronbach's alpha coefficients for the pretest and posttest administrations.

Prior to the inferential analyses, the assumptions underlying the parametric procedures were evaluated. For paired comparisons, normality was assessed using the Shapiro–Wilk test applied to the pre–post difference scores within each condition. Homogeneity of gain-score variances between the treatment and control conditions was evaluated using the Brown–Forsythe version of Levene's test (median-centered Levene's test). To evaluate the robustness of the parametric analyses, Wilcoxon signed-rank tests and Mann–Whitney *U* tests were conducted as nonparametric sensitivity analyses for within-group changes and between-group gain comparisons, respectively. Complete assumption diagnostics and sensitivity analyses are provided in Appendix B.

Baseline equivalence between treatment and control groups was examined using Welch's independent-samples *t*-tests applied to pretest scores. Intervention effects were evaluated through paired-samples *t*-tests conducted separately for treatment and control groups. Mean scores, standard deviations, confidence intervals, and pre–post gain scores were calculated for all constructs and dimensions.

Effect sizes were estimated using Cohen's d_z for paired comparisons. Relationships among SAC and CC outcomes were examined using Pearson correlations calculated from gain scores (posttest minus pretest). Additional descriptive analyses of gameplay indicators were conducted to characterize behavioral patterns observed during the simulation.

All statistical analyses were conducted using Python 3.13.9 with the NumPy 2.3.5, Pandas 2.3.3, SciPy 1.16.3, and Matplotlib 3.10.6 libraries. Statistical significance was evaluated using an alpha level of 0.05.

4. Results and Discussion

4.1. Baseline Equivalence

Table 3 presents the pre-intervention comparison between treatment and control groups. No statistically significant differences were observed for any sustainability or collaboration index, indicating that both groups started from comparable baseline conditions.

Table 3. Baseline equivalence between control and treatment groups.

Construct	Index	Control M	Control SD	Treatment M	Treatment SD	<i>t</i>	<i>p</i>
SAC	Overall	4.31	1.01	4.36	1.05	0.34	0.738
	KAP	4.21	1.24	4.34	1.37	0.70	0.482
	COI	4.44	1.28	4.40	1.33	−0.22	0.828
	WTA	4.29	1.28	4.35	1.26	0.32	0.753
CC	Overall	3.00	0.61	2.95	0.65	−0.63	0.531
	L	3.03	0.73	2.95	0.73	−0.77	0.444
	TS	2.88	0.98	2.95	0.97	0.49	0.627
	IS	3.10	0.96	2.92	0.97	−1.26	0.210

Welch's independent-samples *t*-test was used for group comparisons.

This result is important because participants were assigned through intact course sections rather than individual randomization. The absence of baseline differences reduces the likelihood that subsequent group differences are attributable to pre-existing variations in sustainability- or collaboration-related perceptions. Consequently, observed post-intervention differences can be interpreted more confidently as being associated with the instructional activities completed by each group.

4.2. Effects of the Intervention

Table 4 and Figure 2 summarize the pre–post gains observed in both conditions. Across all SAC and CC dimensions, students who participated in the Tequila Game exhibited larger gains than students in the control condition. Although small positive and negative changes were observed in the control group, none of these changes reached statistical significance and should therefore be interpreted as ordinary sampling and measurement variation rather than meaningful improvement or decline. Because the control condition consisted of established active-learning activities rather than the absence of instruction, the primary comparison of interest is the difference in gains between instructional approaches. The consistently larger improvements observed in the treatment group therefore suggest that the Tequila Game provided additional opportunities for strengthening students' perceptions of their sustainability and collaboration competencies beyond those offered by the comparison activities. It is also important to note that the outcome measures used in this study assess students' self-perceived SAC and CC rather than objective knowledge acquisition. Consequently, instructional activities may reinforce conceptual understanding without necessarily producing measurable changes in students' confidence, willingness to act, or perceptions of their collaborative capabilities. The immersive and experiential nature of the Tequila Game, which required participants to repeatedly make decisions under uncertainty, observe the consequences of those decisions, and voluntarily engage

in collaborative strategies, may help explain the larger observed competency gains in the treatment group.

Table 4. Comparison of pre-post gains between control and treatment groups.

Construct	Index	Control Gain M	Control Gain SD	Treatment Gain M	Treatment Gain SD	Difference	<i>t</i>	<i>p</i>
SAC	Overall	0.05	0.45	0.64	0.75	0.59	6.38	<0.001
	KAP	0.09	0.93	0.51	0.99	0.42	2.96	0.003
	COI	−0.04	0.92	0.67	1.07	0.71	4.81	<0.001
	WTA	0.09	0.84	0.73	0.96	0.64	4.79	<0.001
CC	Overall	−0.03	0.47	0.41	0.48	0.44	6.27	<0.001
	L	−0.05	0.58	0.52	0.66	0.57	6.25	<0.001
	TS	0.02	0.95	0.32	0.93	0.30	2.17	0.032
	IS	−0.05	1.14	0.19	0.92	0.24	1.62	0.107

Gain was calculated as post-test minus pre-test.

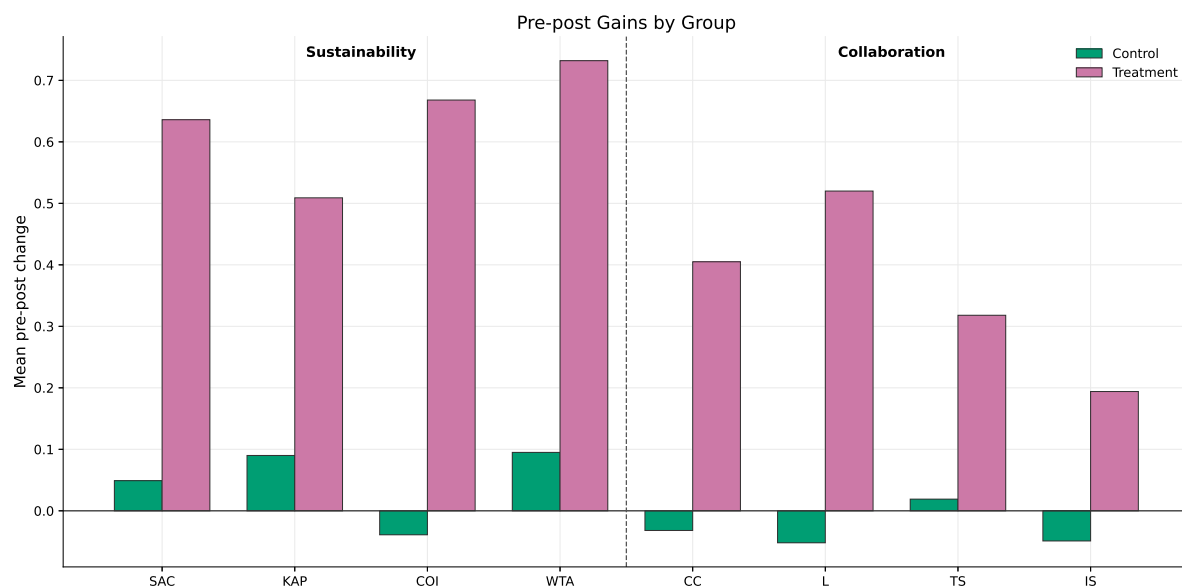


Figure 2. Comparison of pre-post gains between treatment and control groups.

The largest differences between groups were observed in L, WTA, and COI, whereas TS and IS exhibited comparatively smaller gains.

The consistency of this pattern across SAC and CC dimensions suggests that the Tequila Game generated learning experiences extending beyond disciplinary knowledge acquisition. Unlike the instructional activities used in the control condition, the simulation repeatedly required participants to balance economic, operational, and environmental objectives while interacting with other actors operating under uncertainty. Such conditions exposed students to the interconnected nature of sustainability and collaboration challenges in supply-chain settings.

Although positive gains were also observed in the control condition, all participating students completed active learning activities. The larger improvements observed in the treatment group therefore suggest that the specific decision-making environment created by the Tequila Game provided additional opportunities for competency development beyond those offered by more traditional instructional approaches.

4.3. Magnitude of Observed Changes

Table 5 presents the within-group pre–post comparisons for students who participated in the Tequila Game.

Table 5. Treatment group pre-test and post-test results.

Construct	Index	N	Pre M	Pre SD	Post M	Post SD	Δ	<i>t</i>	<i>p</i>	<i>d_z</i>
SAC	Overall	85	4.37	1.05	5.00	0.99	0.64	7.87	<0.001	0.85
	KAP	85	4.34	1.37	4.85	1.33	0.51	4.73	<0.001	0.51
	COI	85	4.40	1.33	5.07	1.13	0.67	5.77	<0.001	0.63
	WTA	85	4.35	1.26	5.08	1.24	0.73	7.01	<0.001	0.76
CC	Overall	85	2.94	0.65	3.35	0.71	0.41	7.81	<0.001	0.85
	L	85	2.95	0.73	3.47	0.83	0.52	7.31	<0.001	0.79
	TS	85	2.95	0.97	3.27	1.03	0.32	3.14	0.002	0.34
	IS	85	2.92	0.97	3.12	1.05	0.19	1.95	0.054	0.21

M = mean; SD = standard deviation; Δ = post-test minus pre-test; *d_z* = paired Cohen's effect size.

The strongest effects were observed for the overall SAC and CC scores, together with the WTA and L dimensions. Moderate effects were observed for KAP and COI, whereas TS and IS exhibited comparatively smaller changes.

The prominence of WTA is particularly noteworthy because action competence has long been conceptualized as extending beyond knowledge acquisition toward individuals' readiness to participate in addressing sustainability challenges. In their foundational work, Jensen and Schnack [14] argued that sustainability education should prepare learners not only to understand environmental and societal issues but also to engage with them through informed action. Similarly, Mogensen and Schnack [15] emphasized that action competence involves both the willingness and the perceived ability to participate in change processes. Viewed through this lens, the strong gains observed in WTA suggest that the intervention influenced a central component of sustainability action competence rather than merely increasing awareness of sustainability-related issues.

One possible explanation is that sustainability was experienced as a consequence of managerial decisions rather than as an abstract topic. Participants repeatedly observed how operational choices generated environmental consequences within the simulation environment. This type of experiential engagement aligns with the argument of Lozano et al. [12], who contend that sustainability competencies are more likely to develop when learners actively participate in decision-making situations that require balancing multiple objectives and evaluating the consequences of alternative actions.

The CC dimensions exhibited a different pattern. Learning (L) showed substantially larger gains than TS and IS. This outcome is consistent with the structure of the simulation, where collaborative mechanisms were available but not mandatory. Participants encountered repeated opportunities to collaborate, yet they retained autonomy regarding whether cooperation would be pursued. Consequently, the intervention may have contributed more strongly to participants' understanding of collaborative decision-making than to their perceptions of routine teamwork behaviors.

This distinction is consistent with observations made by Schürmann et al. [17], who note that collaboration encompasses multiple dimensions that do not necessarily develop simultaneously. Likewise, Braathen [11] conceptualize collaboration as a multidimensional construct in which learning from others, supporting others, and exchanging information represent related but distinct competencies. The larger gains observed in L therefore suggest that the simulation primarily strengthened participants' capacity to recognize and

evaluate collaborative opportunities rather than altering all dimensions of collaboration to the same degree.

Taken together, the findings suggest that the Tequila Game was particularly effective at helping students recognize when sustainability-oriented and collaborative actions become relevant within operational settings. Rather than treating sustainability and collaboration as normative ideals, participants were required to evaluate when such actions were appropriate, beneficial, and feasible under realistic decision constraints. This outcome is consistent with calls from sustainability-education scholars for learning environments that move beyond awareness-building and expose students to the complexities of real-world decision making [13,16].

4.4. Behavioral Evidence from Gameplay Data

Beyond the pre–post survey results, gameplay logs were analyzed to examine how participants translated sustainability and collaboration concepts into operational decisions. Throughout the Tequila Game, students assumed the role of independent retailers competing for market share while simultaneously facing opportunities to collaborate through inventory sharing, transportation consolidation, and proportional supply-allocation mechanisms. Consequently, the gameplay data provide a behavioral perspective that complements the self-reported learning outcomes presented in the previous sections.

4.4.1. Inventory Sharing Behavior

Inventory sharing represented a voluntary mechanism through which retailers could offer part of their available inventory to competitors experiencing shortages. Figure 3 presents the relationship between inventory availability and the proportion of inventory offered to competing retailers.



Figure 3. Inventory availability and willingness to offer stock to competing retailers.

A strongly nonlinear relationship emerges. Inventory sharing remained very limited when available inventory was close to expected demand and increased substantially only after retailers accumulated sizeable inventory surpluses. Thus, collaboration was not observed as an unconditional behavior. Instead, retailers appeared willing to support competitors only after securing their own operational requirements.

This finding is particularly interesting from an educational perspective. Collaboration is frequently presented in management education as a desirable organizational capability; however, real-world decisions rarely occur in the absence of operational constraints. Within the Tequila Game, students assumed the role of competing retailers and were therefore required to balance potential collective benefits against the possibility of compromising their own service performance. The observed pattern suggests that participants did not approach collaboration as an abstract principle, but rather as a decision requiring judgment under uncertainty.

This interpretation is consistent with the view of CC as a multidimensional construct that extends beyond positive attitudes toward teamwork. Sargeant et al. [20] argue that effective collaboration involves evaluating alternative courses of action while balancing individual and collective responsibilities. Likewise, Schürmann et al. [17] emphasize that collaboration is best understood through behaviors exhibited in authentic contexts rather than through perceptions alone. The gameplay data therefore provide a useful complement to the questionnaire results by revealing how participants behaved when collaborative opportunities carried potential operational consequences.

The results also help contextualize the larger gains observed in the L dimension of CC relative to TS and IS. According to Braathen [11], collaboration competence involves several distinct dimensions that do not necessarily develop at the same rate. In the present study, students were repeatedly exposed to situations requiring them to evaluate whether collaboration was advantageous, but they were not required to collaborate. Consequently, the simulation may have strengthened participants' understanding of collaborative decision-making more than their perceptions of routine teamwork behaviors.

From a learning perspective, the most interesting result may be that participants did not simply learn that collaboration can be beneficial. Rather, they experienced that collaborative actions are often conditional on context. Inventory sharing became increasingly common only when perceived operational risk was sufficiently low. This distinction reflects an important reality of managerial decision making, where collaborative initiatives frequently compete with local performance objectives. The simulation therefore appears to have helped students move beyond normative notions of collaboration toward a more nuanced understanding of the circumstances under which collaborative behavior becomes feasible.

4.4.2. Transportation Collaboration

Transportation sharing allowed retailers to consolidate shipments and jointly utilize transportation assets. Figure 4 compares vehicle-capacity utilization under shared and non-shared transportation arrangements.

Across all vehicle categories, transportation sharing was associated with higher capacity utilization. The effect was particularly pronounced for medium and large vehicles, where shared transportation frequently approached full utilization levels, whereas non-shared transportation exhibited lower median utilization and substantially greater variability.

From an operational perspective, these results indicate that participants were able to identify opportunities for shipment consolidation when collaborative mechanisms were available. Because transportation emissions are closely related to vehicle utilization, the decisions adopted by participants simultaneously improved logistics efficiency and environmental performance. Transportation sharing therefore represented a situation in which sustainability objectives and operational objectives were aligned rather than competing.

This finding is educationally relevant because it exposed students to a form of sustainability decision making that differs from the trade-off narratives commonly emphasized

in classroom discussions. Rather than being required to sacrifice operational performance to improve sustainability outcomes, participants encountered situations in which collaborative decisions generated benefits on both dimensions simultaneously. As argued by Wiek et al. [1], sustainability competence develops most effectively when learners engage with authentic decision contexts that reveal the interconnected nature of social, environmental, and economic outcomes. The transportation-sharing mechanism created precisely this type of learning situation by linking collaboration, logistics performance, and environmental consequences within a single decision.

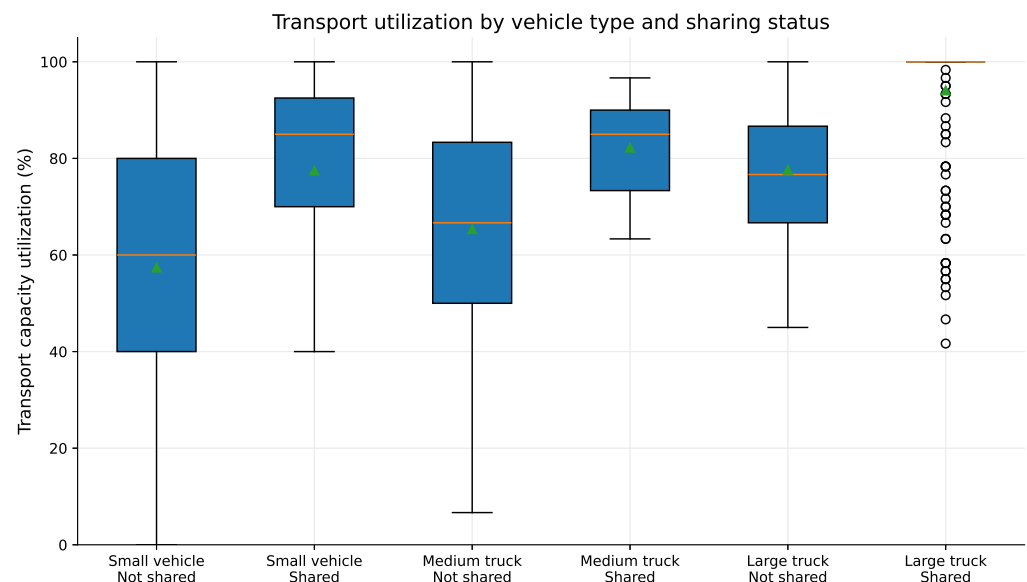


Figure 4. Transport capacity utilization by vehicle type and sharing status. The horizontal line within each box indicates the median, green triangles denote the mean, and open circles represent outliers.

The behavioral results are also informative when interpreted alongside the SAC outcomes. Among the SAC dimensions, some of the largest gains were observed in COI and WTA. According to Olsson et al. [10], these dimensions reflect individuals' beliefs that their actions can contribute to sustainability outcomes and their readiness to engage in such actions. Within the simulation, participants repeatedly faced decisions regarding whether transportation resources should be used individually or collaboratively, allowing them to observe how alternative choices influenced system performance. Consequently, sustainability was experienced as something that could be shaped through managerial decisions rather than as an external constraint imposed on the supply chain.

This interpretation is consistent with the action-competence perspective advanced by Jensen and Schnack [14] and Mogensen and Schnack [15], which emphasize learners' perceived capacity to influence sustainability outcomes through informed action. The observed improvements in COI and WTA therefore appear compatible with a learning environment that allowed participants to experiment with alternative decisions and observe their consequences within a realistic operational setting.

More broadly, the transportation-sharing results strengthen the interpretation of the survey findings because they provide behavioral evidence that complements the self-reported outcomes. Many sustainability-education studies rely exclusively on questionnaire-based measures of knowledge, attitudes, or intentions. In contrast, the Tequila Game generated observable behavioral traces showing that participants voluntarily adopted collaborative transportation arrangements associated with higher resource utilization and lower environmental impact. The convergence between these behavioral patterns and the observed improvements in SAC suggests that the intervention influenced not only

participants' perceptions, but also the way they approached sustainability-related decisions during gameplay.

4.4.3. Collaboration Failures and Lone Defectors

To better understand why proportional allocation occasionally failed, gameplay rounds characterized by a single dissenting retailer were examined. These “lone-defector” rounds are particularly informative because collaboration failed despite overwhelming support from the remaining participants.

Figure 5 presents the distribution of relative inventory positions observed during lone-defector rounds.

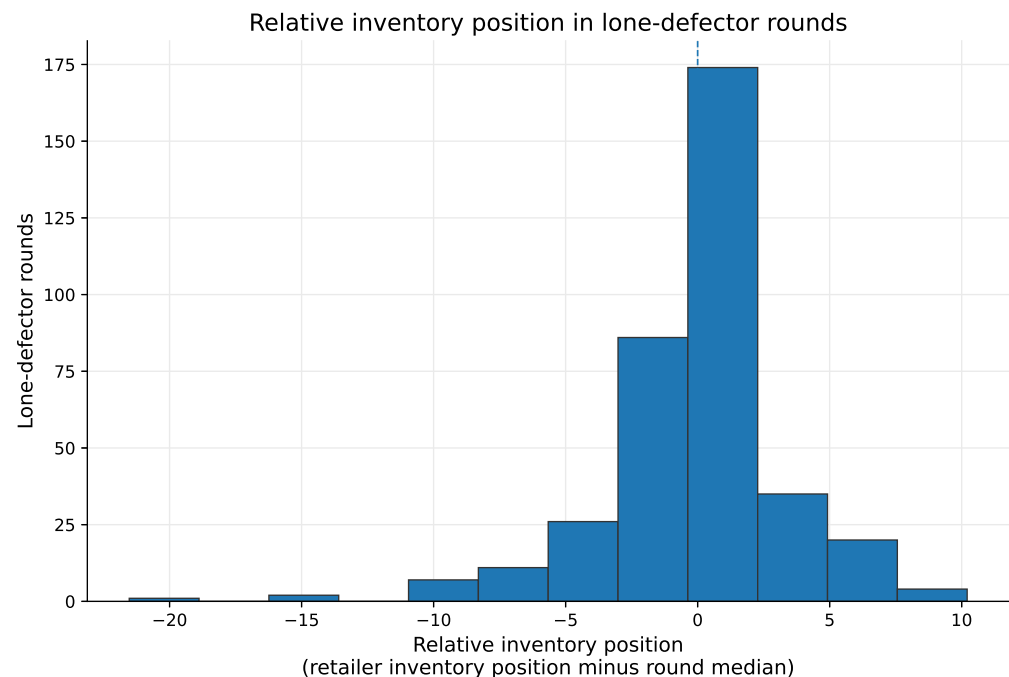


Figure 5. Distribution of relative inventory positions during lone-defector rounds. Positive values indicate that the retailer possessed a more favorable inventory position than the median retailer in the same round.

If opposition to proportional allocation were driven primarily by operational self-interest, one would expect lone defectors to possess systematically superior inventory positions. However, the distribution is centered near zero and includes both positive and negative values. Formal analysis confirms this interpretation, as relative inventory position was not significantly associated with opposition to proportional allocation ($r = 0.026$, $p = 0.396$).

A second analysis examined whether lone defectors expected to receive a larger share of available supply by rejecting proportional allocation.

Once again, the evidence provides little support for a purely economic explanation. Figure 6 shows the distribution of expected allocation advantages during lone-defector rounds. Allocation advantage exhibited no meaningful relationship with opposition to collaboration ($r = -0.010$, $p = 0.756$), and the distribution remains centered near zero.

Perhaps the most interesting finding of the gameplay analysis is therefore not why collaboration succeeded, but why it failed. Neither inventory advantages nor expected allocation benefits explain lone-defector behavior. Retailers who blocked proportional allocation were not systematically better positioned than their competitors, nor were they consistently more likely to gain from rejecting the mechanism.

This result contributes to a growing body of literature suggesting that collaborative failures cannot always be explained through objective incentives alone. While supply-chain models often assume that actors respond rationally to operational conditions, the present findings indicate that behavioral factors may play an equally important role. Although the current study cannot identify the precise causes of defection, possible explanations include perceptions of fairness, distrust of collective solutions, competitive instincts, or individual risk preferences.

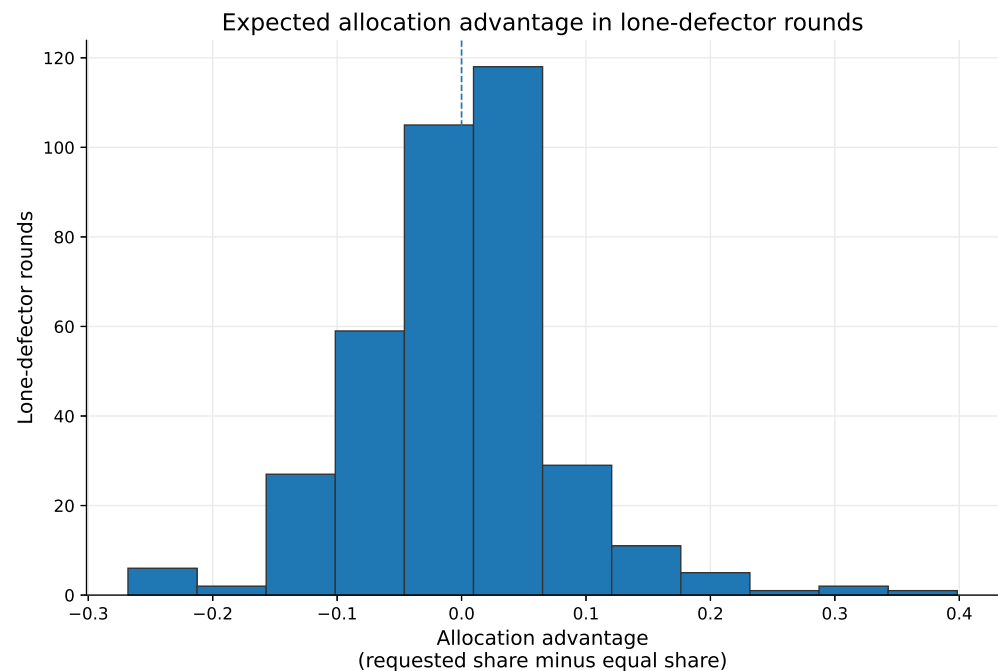


Figure 6. Distribution of expected allocation advantages during lone-defector rounds.

From an educational perspective, this finding may represent one of the most valuable aspects of the simulation. Participants did not simply learn that collaboration is beneficial; they experienced first-hand that collaboration can fail even when operational conditions appear favorable and collective benefits are widely recognized.

5. Conclusions

This study examined differences in SAC and CC associated with participation in the Tequila Game, a multiplayer supply chain simulation, among undergraduate engineering students. Using a quasi-experimental pretest–posttest control-group design, students who participated in the simulation exhibited significantly larger pre–post gains across both competency domains than students who completed alternative learning activities. Although these findings are consistent with a positive contribution of the intervention, they should be interpreted in light of the non-randomized design and the self-reported nature of the competency measures.

The first contribution of this study is empirical. The findings provide evidence that simulation-based learning can support the development of sustainability-related competencies in higher education. Students who participated in the Tequila Game exhibited significantly larger gains than those in the control condition across all SAC dimensions, including KAP, COI, and WTA. These results suggest that engaging students in realistic supply chain decision-making scenarios involving environmental trade-offs and collaboration may strengthen not only their understanding of sustainability challenges, but also their perceived capacity and willingness to contribute to addressing them. In this way, the

study extends the application of action-oriented sustainability education to supply chain and engineering contexts.

The second contribution concerns collaboration competence. Students who participated in the Tequila Game exhibited significantly larger improvements than the control group across the collaboration dimensions evaluated in this study, with the largest gain observed in the Learning dimension. These findings suggest that immersive decision-making environments requiring coordination under uncertainty can complement traditional instructional approaches for developing collaborative capabilities. Given the increasing importance of collaboration in addressing contemporary supply chain and sustainability challenges [27,38], the results reinforce the value of serious games as educational tools that combine technical decision making with collaborative capability development.

The third contribution emerges from the analysis of gameplay behavior. Whereas the survey results captured changes in students' perceived sustainability and collaboration competencies, the gameplay logs provided complementary evidence of how these competencies were expressed during operational decision making. Rather than collaborating indiscriminately, participants adapted their collaborative behavior according to operational conditions, resource availability, and perceived risks. These behavioral patterns complement the questionnaire findings by showing how sustainability and collaboration principles were translated into context-dependent managerial decisions within the simulated supply chain.

The fourth contribution is methodological. Research on serious games frequently relies on self-reported measures such as engagement, satisfaction, or perceived learning. In contrast, this study illustrates how integrating validated competency instruments with automatically recorded behavioral data can provide a richer evaluation of educational interventions. Combining perception-based measures with behavioral learning analytics allowed changes in students' perceived competencies to be interpreted alongside their operational decisions, providing complementary perspectives on learning that neither source of evidence could capture independently.

Taken together, the findings suggest that serious games can provide learning environments in which sustainability and collaboration are experienced as interconnected managerial challenges rather than isolated theoretical concepts. By requiring students to balance economic performance, environmental impacts, uncertainty, and voluntary collaboration within a common operational setting, the Tequila Game complements traditional instructional approaches with authentic decision-making experiences. The study also illustrates the value of integrating validated competency measures with behavioral evidence to better understand how sustainability- and collaboration-related capabilities are expressed during learning.

Several limitations should be acknowledged. First, the study was conducted within a single institutional context using intact class sections rather than randomly assigned participants. In addition, age was not collected, limiting the demographic characterization of the sample. Consequently, the findings should be interpreted with caution when generalizing to other educational settings or student populations, and the quasi-experimental design cannot completely eliminate the possibility of selection bias. Second, learning outcomes were measured immediately after the intervention. Although significant improvements were observed, the persistence of these competency gains over time remains unknown. In addition, while the inclusion of gameplay data strengthened the interpretation of the learning process, the study cannot determine whether the observed competency gains and behavioral patterns translate into long-term educational or professional practice. Finally, the IS dimension of the CC instrument demonstrated lower internal consistency than the remaining dimensions. This dimension consists of only two items, and Cronbach's alpha is

known to be influenced by the number of items in a scale. Similar findings have been reported in an independent validation of the SACS instrument, where lower reliability for the IS dimension was likewise observed and discussed in relation to its two-item structure [11]. Accordingly, results for this dimension should be interpreted with caution, whereas the principal conclusions of this study are based on the overall CC construct.

Future research should evaluate the durability of the observed competency gains through longitudinal designs and examine the effectiveness of simulation-based interventions across multiple institutions, disciplines, and cultural contexts. Building on the methodological approach adopted in this study, future work could further integrate perception-based instruments with objective behavioral evidence—such as gameplay logs, decision trajectories, and collaboration patterns—to better understand how sustainability and collaboration competencies develop over time. Qualitative approaches may also help explain how learners interpret sustainability challenges, negotiate collaborative decisions, and why some participants consistently embrace collaborative strategies whereas others remain reluctant to do so.

Ultimately, the value of the Tequila Game extends beyond its digital implementation or gameplay mechanics. Its contribution lies in creating a learning environment where sustainability and collaboration are no longer discussed as desirable principles but experienced as operational choices with tangible consequences. By confronting students with realistic trade-offs among economic performance, environmental impact, and collaboration, the simulation provides opportunities to connect classroom concepts with the complexities of contemporary supply chain management.

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Institutional Review Board Statement: Ethical review and approval were waived for this study since at the Institution this project is classified as a “Research without risk”, i.e., these are studies that use retrospective documentary research techniques and methods and those in which no intentional intervention or modification is carried out in the physiological, psychological and social variables of the individuals participating in the study, among which the following are considered: questionnaires, interviews, review of clinical files and others, in which they are not identified or sensitive aspects of their conduct are not addressed.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: <https://tinyurl.com/TequilaGameMDPI>, accessed on 20 June 2026.

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Abbreviations

The following abbreviations are used in this manuscript:

SAC	Sustainability Action Competence
CC	Collaboration Competence
SPACS-Q	Self-Perceived Action Competence for Sustainability Questionnaire
SACS	Self-Assessment of Collaboration Skills
KAP	Knowledge of Action Possibilities

COI	Confidence in One's Own Influence
WTA	Willingness to Act
L	Learning
TS	Team Support
IS	Information Sharing

Appendix A. Default Game Configuration

Unless otherwise indicated, all experimental sessions were conducted using the software's default configuration summarized in Tables A1 and A2. These parameters remained constant across all treatment sessions and define the operational environment experienced by participants throughout the study.

Table A1. Game configuration used in all experimental sessions.

Parameter	Value	Description
Number of players	4	Retailers participating in each simulation game.
Decision rounds	20	Decision periods per simulation game.
Supplier capacity	50–80 units	Supplier availability generated each round.
Customer demand	8–20 units	Customer demand generated independently for each retailer and round.
Procurement cost	20	Purchase cost per unit ordered.
Inventory holding cost	1	Holding cost per unit remaining in inventory.
Backlog penalty	5	Penalty per unit of unmet customer demand.
Initial budget	\$1000	Initial budget assigned to each retailer.
Initial inventory	20 units	Initial inventory assigned to each retailer.
Supplier hazard probability (α_{event})	0.10	Probability of a supplier hazard event.
Transportation hazard probability ($\alpha_{\text{transport}}$)	0.10	Probability of a transportation hazard event.
Transportation loss	50%	Fraction of transported units lost during a transportation hazard.
Cost leadership multiplier	1.15	Reward multiplier for the retailer with the lowest round operating cost.
Cost leadership threshold	Round 10	Round after which the cost leadership reward becomes active.
AI-generated feedback	Disabled	AI feedback of previous round decisions.
3D warehouse visualization	Disabled	Standard two-dimension or three-dimension visualization.

Table A2. Transportation alternatives available during gameplay.

Vehicle	Capacity	Fixed Cost	Variable Cost	Fixed Emissions	Variable Emissions
Van	10	100	2.0	1.0	0.20
Truck	30	250	1.0	2.5	0.15
Thorton	60	400	0.8	4.0	0.10

Appendix B. Statistical Assumption Diagnostics and Sensitivity Analyses

This appendix summarizes the statistical assumption diagnostics and sensitivity analyses supporting the parametric analyses reported in the manuscript. Table A3 presents the normality and homogeneity-of-variance diagnostics, whereas Table A4 compares the corresponding parametric and nonparametric analyses.

Table A3. Assumption diagnostics for the parametric analyses.

Construct	Outcome	Control		Treatment		Gain Comparison	
		Shapiro–Wilk	<i>p</i>	Shapiro–Wilk	<i>p</i>	Brown–Forsythe	<i>p</i>
Sustainability	KAP	0.980	0.124	0.981	0.254	0.416	0.520
	COI	0.985	0.278	0.989	0.670	2.893	0.091
	WTA	0.966	0.010	0.974	0.078	3.410	0.066
	Overall	0.990	0.627	0.988	0.618	22.165	< 0.001
Collaboration	L	0.984	0.273	0.984	0.382	1.340	0.249
	TS	0.981	0.155	0.952	0.003	0.134	0.715
	IS	0.966	0.009	0.958	0.008	2.126	0.146
	Overall	0.990	0.683	0.986	0.474	0.003	0.957

Shapiro–Wilk tests were performed on the paired pre–post difference scores within each experimental condition. Homogeneity of gain-score variances between the treatment and control groups was assessed using the Brown–Forsythe version of Levene’s test (centered on the median).

Table A4. Sensitivity analyses comparing the parametric and nonparametric results.

Construct	Outcome	Control		Treatment		Gain Comparison	
		<i>t</i> -Test <i>p</i>	Wilcoxon <i>p</i>	<i>t</i> -Test <i>p</i>	Wilcoxon <i>p</i>	Welch <i>p</i>	Mann–Whitney <i>p</i>
Sustainability	KAP	0.330	0.201	<0.001	<0.001	0.003	0.006
	COI	0.668	0.649	<0.001	<0.001	<0.001	<0.001
	WTA	0.254	0.454	<0.001	<0.001	<0.001	<0.001
	Overall	0.275	0.319	<0.001	<0.001	<0.001	<0.001
Collaboration	L	0.369	0.393	<0.001	<0.001	<0.001	<0.001
	TS	0.836	0.995	0.002	0.007	0.032	0.044
	IS	0.666	0.788	0.054	0.057	0.107	0.170
	Overall	0.497	0.409	<0.001	<0.001	<0.001	<0.001

Wilcoxon signed-rank tests were used as nonparametric counterparts of the paired-samples *t*-tests. Mann–Whitney *U* tests on gain scores were used as nonparametric counterparts of the Welch independent-samples *t*-tests. For every outcome, the corresponding parametric and nonparametric analyses produced the same inferential conclusions.

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