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Scalable Modeling for a Shirt Supply Chain

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Abstract

Scalable Modeling is a 1:32 scale physical representation of a supply chain that integrates key logistics operations and links. For pedagogical purposes, it was linked to shirts and implemented in a course for two groups of fourth-semester Industrial Engineering students. The objective was to enhance their competency in quality, productivity and optimization methodologies, ensuring they develop a deeper understanding of supply chain dynamics. The implementation focused on three key learning objectives. Increasing motivation, improving learning, and developing competency. A qualitative approach was adopted utilizing surveys, questionnaires, and grade analysis to assess the impact of the activity. While no statistically significant differences were found between groups, students exhibited greater motivation, improved comprehension and enhanced mastery of key concepts. This initiative reinforced experiential learning, allowing students to engage with real-world supply chain scenarios, strengthening both their analytical skills and practical application of methodologies.

Keywords: *Scalable Modeling, Supply Chain, educative innovation, Optimization, Experiential Learning and Mastery.*

1. Introduction

University teaching practices aim to connect students with their professional fields. However, Industrial Engineering education requires urgent improvements to foster participation and collaboration in modeling real-life scenarios relevant to their careers. Given the limited time to master key topics—such as optimization, operations management, logistics, and supply chain management—enhancing student learning experiences is crucial for developing competitive advantages. A key approach is making learning experiences authentic, closely mirroring real-world challenges. Scaled modeling provides a quick and effective understanding of key relationships, particularly in supply chains.

In the scale physical representation of a supply chain is possible to observe its links or workstations with elements to execute operations. An approximate description is as follows. In the supplier station there are pallets, forklifts, wood and metal blocks to represent the load of products and cargo trucks. Trucks are moved using a conveyor belt. For storing, there is a set of shelves. For order preparation there is a wrapping machine. For the distribution and redistribution processes, the students can use a whiteboard to record information, and origami is used for manufacturing shirts. Figure 1 shows some pictures of the operations of the supply chain. Our innovation is divided in the main links in aimed to improve student mastery of the competency: "*Enhancing the competitiveness of key systems and processes in organizations through quality, productivity, and optimization methodologies*". This competency is part of the fourth-semester course "*Process Improvement in Organizations*" at TEC de Monterrey Campus CEM (March 2024). The objectives of the innovation were: (1) evaluate increased student motivation in operations management through scaled modeling, (2) assess improvements in learning, and (3) determine its contribution to competency development. A qualitative methodology was used, emphasizing a human-centered and contextualized approach. The process included diagnostics, objective formulation, activity design, implementation and result analysis. Findings confirmed the achievement of objectives, with students reaching the highest level of competency. The paper presents the theoretical framework, methodology, development, results, and concludes with key insights and future perspectives.

Figure 1. Some operations in the shirt supply chain – scale representation -

2. Theoretical framework

According to Gándara (2022), authentic learning activities must include relevant and meaningful tasks that motivate students and spark interest. Scalable modeling and game-based teaching are essential tools in Industrial Engineering education, enabling students to engage in complex, realistic situations through active learning. These methods provide a safe environment for experimentation, fostering autonomy, problem-solving and the practical application of theoretical concepts. Naumann *et al.* (2018) define scalable modeling as creating simplified representations of complex systems that can be expanded or reduced with minimal effort and risk. It allows inferences about system behavior while optimizing resources before real-world implementation. However, its use in universities remains limited, mainly for testing, simulations and prototyping (Chung *et al.,* 2024).

Game-based learning promotes exploration, discovery and engagement, enhancing knowledge retention and key skills such as critical thinking, decision-making, and teamwork (Huotari & Hamari, 2017). Kapp (2012) highlights how games create a learning environment where students can experiment with different approaches and consequences, fostering informed decision-making. Similarly, Sitzmann (2011) found that games improve cognitive, motor and social skills, enhancing competency development. Developing an innovation project using game-based teaching and scalable modeling in Industrial Engineering provides significant benefits. Games are intrinsically motivating, engaging, and challenging (Skibski *et al.,* 2022). They also help the students develop essential skills for real-world challenges (Nieveen *et al.,* 2024). Emphasizing these methods promotes active, practical learning, leading to higher student engagement and stronger professional competencies.

3. Methodology and development

The methodological approach was qualitative, consisting of five stages: diagnosis, objective formulation, activity design, implementation and result analysis. The diagnosis identified the need for methodologies connecting students to real-world contexts, as traditional methods hindered topic comprehension. Objectives were based on key reflections: How can student motivation and learning be enhanced? How does innovation improve learning? How can outcomes be evaluated? Assessment tools included a questionnaire, a survey (20 perception questions on motivation and learning) and an evaluation rubric. The questionnaire introduced supply chain links, an origami shirt-making video, and questions on competency achievement, positive aspects and improvement opportunities. Student engagement was evaluated through participation, interest, interaction, and reduced distractions. Key questions included: Did participation increase? Did students show more interest and ask more questions? Was there greater collaboration? Positive student feedback confirmed the effectiveness of innovation.

The questions of the survey were: Q_1) Do you think this activity makes learning more interesting or motivating? Q_2) Do you feel more engaged or active in your learning process? Q_3) Does the activity adapt to your individual needs as a student? Q_4) Does the activity encourage more participation than a traditional one? Q_5) Do you think this activity helped you enjoy the learning process more? Q_6) Did you notice a stronger connection with your classmates during the activity? Q_7) Do you feel that this activity gave you more confidence to participate in class? Q_8) Did this activity inspire you to better appreciate the importance of your training as an Industrial Engineer? Q_9) Do you feel more motivated to learn with this method compared to traditional ones? Q_{10}) Do you find this approach more appealing for learning? Q_{11}) Do you feel that this activity can improve your problem-solving skills compared to traditional lectures? Q_{12}) Does the implementation of this activity enhance your learning ability? Q_{13}) Can you transfer the knowledge acquired to practical or real-life situations more easily? Q_{14}) Does this activity allow you to explore topics of interest more deeply compared to traditional lectures? Q_{15}) Is it easier for you to understand the situation being scaled for a real-life supply chain? Q_{16}) Did this activity help you understand the concepts of this module more easily? Q_{17}) Do you think this activity helped clarify your doubts? Q_{18}) Did the activity make the topics seem easier to learn? Q_{19}) Do you think you learned faster with this methodology compared to traditional methods? Q_{20}) Did the activity allow you to express your doubts and receive clear answers more quickly?

The competency has two sub-competencies (S_1 and S_2), which were evaluated using a mastery scale with four hierarchical levels (55, 75, 88 and 100 points). In S_1, the student analyzes key factors influencing competitiveness within the context of an organization. This includes identifying fundamental aspects of quality, productivity and optimization, understanding performance indicators, and viewing the organization as a system. In S_2, the student designs improvement solutions for organizational processes by selecting appropriate industrial engineering methodologies and tools. This involves proposing solutions to enhance productivity and quality, evaluating their impact on indicators and assessing the strengths and limitations of these methodologies. The responses were recorded, contributing to the rubric and validating the results. Student Evaluations of Teaching "SET" provided further insights into the impact of innovation. The implementation involved two groups (Group 1: 23 students and Group 2: 27 students) in a 90-minute Industrial Engineering lab session. Students received instructions, completed the activity and provided feedback, which was highly positive. Data analysis was conducted using Microsoft Excel and Minitab software.

4. Results

The results are illustrated according to the achievement of objectives collectively in each of the groups. For the first two objectives, the percentage of positive perception per question was determined by counting the number of times students recognized an increase in motivation and the advantages at implementing the activity. Subsequently, it was assessed whether there were significant differences in responses between groups through a hypothesis test for proportions (p) for two samples with a confidence level of 95% ($\alpha = 0.05$), defining the null hypothesis as the difference being zero (H_0: $p_1 - p_2 = 0$) and the alternative hypothesis as them being different from zero (H_a: $p_1 - p_2 \neq 0$). Additionally, it was verified whether the difference obtained per question was included in the confidence interval. Figure 2 presents a table with the proportions per question per group, the difference between proportions ($p_1 – p_2$), the confidence interval (CI), and the p-value for the hypothesis test at not rejecting H_0. Additionally, a comparative bar graph of the proportions of the two groups is illustrated.

Concerning the first objective, it is evident that the percentages of positive perception reached 100% in both groups for questions Q_1 and Q_4. For the rest of the questions, both groups scored above 90%, except for Q_6 with 87.5% and 85.2% respectively. While these percentages could be considered favorable, they indicate that future practices should focus on improving student communication. At analyzing columns Difference, CI and p-value, in Q_1 and Q_4, there is no difference between groups, and thus, the recorded asterisk validates them. For the remaining questions, the differences in proportions are not significant, considering the confidence interval and p-value. Regarding the CI, the difference belongs to it. For instance, in Q_2, the difference is -0.03241, which is included within (-0.094674, 0.159489). Related to the p-value, none is lower than 0.05, leading to the conclusion that there is no evidence to reject H_0. For example, for Q_2 (p-value= 0.617). It might be considered that the difference is different from zero for Q_5, Q_7, Q_8, and Q_{10}. However, this suspicion was rejected despite a p-value of 0.142 for Q_7 and Q_{10}. This finding supports the implementation of practices to improve communication, which would boost student confidence and engagement.

Question	Proportion		Difference	CI	p-value
	Group 1	Group 2			
Q_1	1.000	1.000	0.000	*	*
Q_2	0.958	0.926	0.032	(-0.094674, 0.159489)	0.617
Q_3	0.917	0.926	-0.009	(-0.157533, 0.139015)	0.903
Q_4	1.000	1.000	0.000	*	*
Q_5	0.958	1.000	-0.042	(-0.121612, 0.038279)	0.307
Q_6	0.875	0.852	0.023	(-0.165165, 0.211462)	0.810
Q_7	1.000	0.926	0.074	(-0.024710, 0.172858)	0.142
Q_8	0.917	0.963	-0.046	(-0.177830, 0.085238)	0.490
Q_9	1.000	0.963	0.037	(-0.034197, 0.108271)	0.308
Q_{10}	1.000	0.926	0.074	(-0.024710, 0.172858)	0.142
Q_{11}	1.000	0.889	0.111	(-0.007430, 0.229652)	0.066
Q_{12}	0.958	0.926	0.032	(-0.094674, 0.159489)	0.617
Q_{13}	0.917	0.926	-0.009	(-0.157533, 0.139015)	0.903
Q_{14}	1.000	0.963	0.037	(-0.034197, 0.108271)	0.308
Q_{15}	1.000	0.926	0.074	(-0.024710, 0.172858)	0.142
Q_{16}	0.958	0.889	0.069	(-0.073536, 0.212424)	0.341
Q_{17}	0.875	1.000	-0.125	(-0.257313, 0.007313)	0.064
Q_{18}	0.875	0.852	0.023	(-0.165165, 0.211462)	0.810
Q_{19}	0.917	0.926	-0.009	(-0.157533, 0.139015)	0.903
Q_{20}	0.958	0.963	-0.005	(-0.111707, 0.102448)	0.932

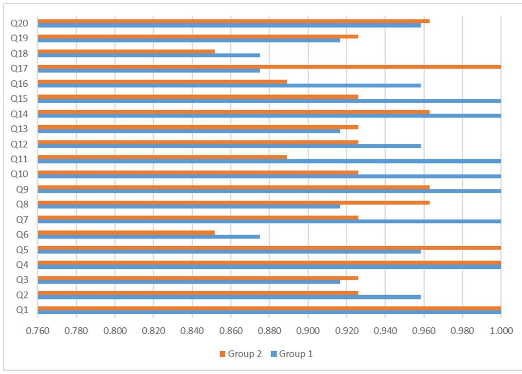

Figure 2. Results for Positive perception in motivation and learning

To validate the achievement of Objective 2 and considering the same Figure, it is observed that for most questions, the percentage of positive perception exceeds 90%. However, for three questions, it falls between 85% and 90%. This occurs in Q_{16} for Group 2, Q_{17} for Group 1, and Q_{18} for both groups. This finding highlights the need to refine the instruction text and provide additional explanations to facilitate learning. Analyzing both groups in the table (Figure 2), it can be stated that there are no significant differences in responses between groups. However, questions Q_{11}, Q15 and Q_{17} suggest the need to develop strategies adaptable to different student group sizes and skill diversity, as their p-values are closest to 0.05 (0.066, 0.142 and 0.064, respectively). The evaluation questionnaire provided insights into Objectives 1 and 2, with students highlighting the activity's engaging, didactic, and real-world relevance. They valued their own role in knowledge retention, concept reinforcement, and motivation to learn. Improvement opportunities included group size, laboratory infrastructure, environmental conditions, supply chain component quality and execution training. The impact of the activity was evident in SET comments. Group 1 emphasized improved learning, lab usage, and professional development. While, Group 2 highlighted the experience of new practices, particularly in the Supply Chain Simulation of shirt production.

For Objective 3, the student responses allowed to determine the highest level of mastery achieved. Regarding S_1, students identified key aspects such as defining a production line, recognizing bottlenecks, and proposing mitigation strategies. They also acknowledged the importance of communication, teamwork, and collaboration for process success, as well as strategies for supply chain synchronization, quality assurance, operator training and preventive maintenance. Additionally, students developed strategies to optimize logistics operations, including storage within distribution vehicles and pallet combinations for transportation, all while recognizing the value for the final customer. For S_2, the students demonstrated an understanding of pull and push approaches to supply chain management, resource calculation based on capacity and its alteration considering efficiency and workforce numbers.

Based on the findings above, it is possible to approximate the fulfillment of the objective by validating whether innovation led students to achieve average scores approaching the highest mastery level—specifically, statistically validating that the final grade average exceeds 88 points with a normal distribution model at a 95% confidence level (α=0.05). For this purpose, the analysis considered the grade frequency histogram, the Anderson-Darling normality test (AD), the box plot, the confidence interval, and the hypothesis test for the mean. It can be seen in Figure 3 for both groups. Figure 3(a) presents the results report for Group 1. In this figure, the normal distribution curve is modeled over the grade frequency histogram, with a mean of 93.603 and a CI of (92.633, 94.573). The box plot reveals a higher concentration of grades to the right of the mean. Regarding the AD (p-value= 0.502), which suggests that the grades follow a normal distribution. Additionally, the hypothesis test highlighted in the rectangle at the bottom right (p-value = 0.00) confirms that the mean grade is greater than 88. In Figure 3(b) illustrates the results report for Group 2. The normal distribution curve is modeled over the grade frequency histogram, with a mean of 91.558 and a CI (89.664, 93.452). The box plot shows a higher concentration of grades to the left of the mean. The p-value in the AD is 0.12, supporting the assumption of normality and confirming that the mean is greater than 88. The analyses derived validated both the normality and the mean scores exceeding 88 points. Next, the statistical significance of the difference between the mean grades of both groups was evaluated through a hypothesis test with $\alpha = 0.05$ (see Figure 4).

At the top of Figure 4, it is observed that in the test the difference of means equal variances were not assumed, resulting in a p-value of 0.055. Consequently, there is no sufficient evidence to conclude that the means are different (as the null hypothesis was not rejected). However, the proximity to 0.05 suggests the need for strategies that accommodate different group sizes and the diversity skill levels. Additionally, the difference of 2.04 is included in (-0.05, 4.14). In the bottom right of the same Figure, the diagram of individual observations reveals greater dispersion in Group 2, while the box plot on the right highlights the concentration of observations and the gap between the means. The illustrated results demonstrated the achievement of the objectives. Moreover, their analysis provides opportunities to enhance student learning through continuous improvement and encourages teachers to reflect on their role in considering modern educational scenarios.

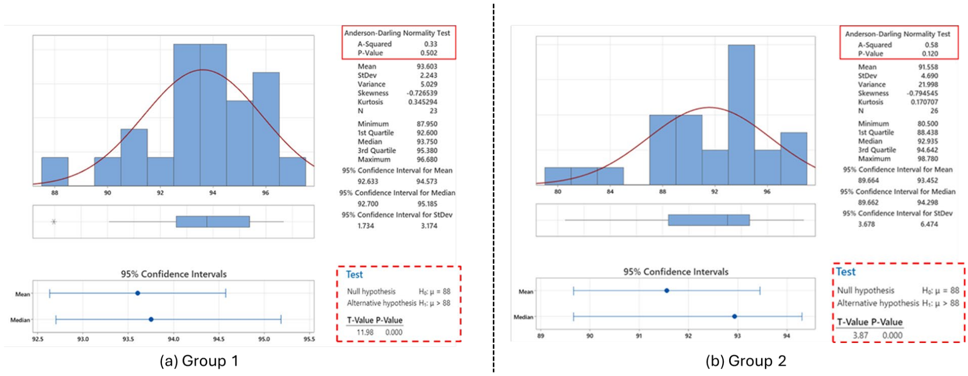

Figure 3. Final grade report for the groups

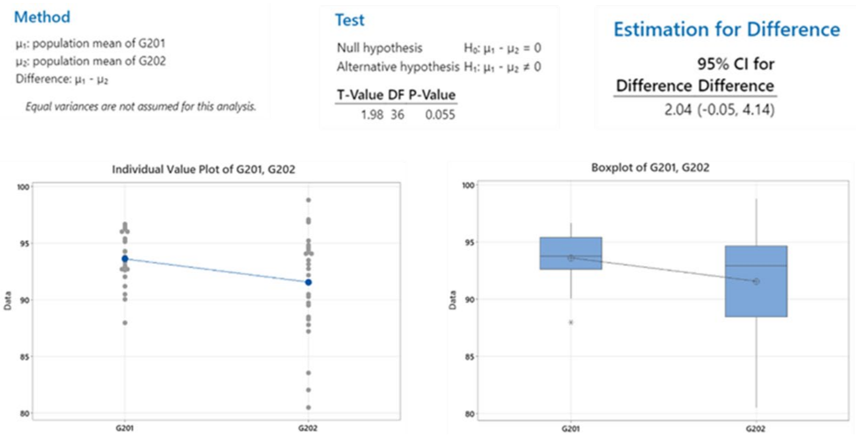

Figure 4. Report on the difference of means in the final grade between Groups 1 and 2

5. Conclusions and perspectives

This document presents the educational innovation Scalable Modeling for a Shirt Supply Chain, implemented in Improvement of an Organizational Process as part of the Industrial and Systems Engineering curriculum at TEC de Monterrey (2024). The objective was to enhance students' proficiency in the competency: “Improves the competitiveness of key systems and processes in organizations through quality, productivity, and optimization methodologies”. The innovation focused on increasing student motivation, improving learning through scalable supply chain modeling and assessing its contribution to competency development. Results confirmed that students achieved the highest proficiency level. The methodology positively influenced motivation and learning, helping students develop skills for a globalized industrial landscape. The findings highlighted opportunities for improving instruction, fostering teamwork, utilizing laboratories, and designing activities aligned with industry trends such as additive manufacturing and virtual reality. In fact, the results contributed to develop the educative innovation ID 844307 “Digital Twins” recorded in the registration-I belonging to the TEC de Monterrey.

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