Design and Evaluation of an Educational Escape Room to Teach Quality Management in Engineering Education

Prof. Christine Tessele Nodari, Universidade Federal Do Rio Grande Do Sul

Full Professor at the Federal University of Rio Grande do Sul (UFRGS) and recipient of a CNPq Research Productivity Fellowship (Category C), with expertise in Transportation Engineering and Road Safety. She holds a B.Sc. in Civil Engineering (1992), an M.Sc. (1996), and a Ph.D. (2003) in Production Engineering from UFRGS, including a study period at the University of British Columbia (Canada). Her work focuses primarily on road safety, active mobility, and engineering education. She has been dedicated to promoting the internationalization of research and academic training through partnerships and collaborative projects with foreign institutions. Currently, she serves as Associate Thematic Coordinator for the Education in Transportation area of ANPET — the National Association for Research and Education in Transport — and as Deputy Coordinator of the Undergraduate Committee of the Department of Production and Transportation Engineering (DEPROT) at UFRGS. Throughout her career, she has participated in numerous university extension projects focused on traffic safety and sustainable transport, aiming to integrate academia with society and local needs.

Maria Auxiliadora Cannarozzo Tinoco, Universidade Federal Do Rio Grande Do Sul

Maria A. Cannarozzo Tinoco is a professor in Industrial Engineering Program at the Federal University of Rio Grande do Sul (UFRGS) in Brazil. She currently coordinates the Institutional Modernization Proposal for the modernization of the Industrial Engineering Undergraduate Program, managed by the School of Engineering at UFRGS, under the Graduation Modernization Program (PMG) promoted by CAPES (Brazilian funding agency) and the Fulbright Commission since 2019.

Italo Rodeghiero Neto, Federal University of Rio Grande do Sul

Post doctoral researcher in Industrial Engineering from the Federal University of Rio Grande do Sul (UFRGS), Brazil. Temporary professor at the same university. Doctor and Master of Industrial Engineering from UFRGS (2020). His research mainly spans engineering education, ergonomics, human factors, and accessibility.

Paula Kvitko de Moura, Federal University of Rio Grande do Sul

Paula Kvitko de Moura, PhD, is a Postdoctoral Researcher in Industrial Engineering at the Federal University of Rio Grande do Sul (UFRGS), Brazil, and a Deep Tech Specialist at the UFRGS Science and Technology Park. She also serves as a Professor and as an Analyst in the Undergraduate Modernization Program, where she supports pedagogical innovation, stakeholder engagement, and strategic development across the School of Engineering. Her research focuses on innovation ecosystems, startup innovation, digital transformation, and active learning in engineering education. She is also an International Research Partner at the Technical University of Munich (TUM), collaborating on initiatives related to innovation and technology-driven education.

Kelly Cristina Ferreira Dias, Universidade Federal Do Rio Grande Do Sul

Kelly Cristina Ferreira Dias is a Ph.D. candidate in Industrial Engineering at the Federal University of Rio Grande do Sul (UFRGS), Brazil. Her research focuses on competency-based education, technology foresight, and digital transformation in engineering education. She has experience in innovation management and applied research in collaboration with industry, working on projects related to educational technology, data analytics, and strategic intelligence. Kelly is also involved in initiatives that connect academia and industry to promote continuous improvement and the development of adaptive learning ecosystems.

Design and Evaluation of an Educational Escape Room to Teach Quality Management in Engineering Education

Abstract

The empirical full paper presents the design, implementation, and evaluation of an educational escape room developed to teach Quality Management in an undergraduate Industrial Engineering program using the DMAIC framework (Define, Measure, Analyze, Improve, Control). An educational escape room is defined as a timed, puzzle-based, collaborative learning activity in which students apply disciplinary knowledge to achieve a structured instructional objective. Guided by the Design Science Research (DSR) methodology, the study employed a mixed-methods evaluation combining a rubric-based pre- and post-test of conceptual understanding with a post-activity perception questionnaire. Learning gains were operationalized as changes in aggregated scores by DMAIC stage. Results indicate substantial improvements in Define and Measure, moderate gains in Improve and Control, and limited progress in Analyze, reflecting persistent difficulty in distinguishing graphical tools from root cause techniques. Perception-based findings show high engagement, collaboration, and professional relevance. Limitations include a restricted sample size and a single institutional context, constraining generalizability.

Keywords: Engineering Education; Educational Escape Room; Quality Management; Design Science Research; Active Learning.

Introduction

Engineering education has progressively shifted from a predominantly technical orientation toward the development of integrated graduate profiles that combine knowledge, skills, and attitudes required to address complex, systemic, and interdisciplinary challenges [1], [2]. This transformation is closely associated with the growing adoption of competency-based education, which emphasizes not only content mastery but also the ability to apply methods, tools, and professional judgment in dynamic and uncertain contexts. At the same time, recent studies report increasing difficulties in sustaining student concentration, engagement, and active participation in higher education [3], [4]. These challenges have intensified the search for pedagogical strategies capable of promoting meaningful learning and producing observable evidence of competency development. In this context, active learning methodologies have gained prominence in engineering programs due to their potential to enhance student engagement, improve knowledge retention, and strengthen the connection between theory and professional practice when compared to traditional lecture-based instruction [5], [6]. Active learning is commonly understood as a set of pedagogical approaches that position students as active agents in the learning process, requiring cognitive involvement, collaboration, decision-making, and reflection on the application of knowledge, rather than passive reception of information [3]. Empirical evidence suggests that such approaches support experiential learning and contribute to the development of both technical and transversal competencies, including communication, teamwork, and structured problem-solving [7], [8].

Recent studies on educational escape rooms in engineering education further refine what is known about the design of effective active learning interventions. Prior implementations emphasize the importance of aligning puzzles with explicit learning objectives, structuring interdependent tasks that require collaborative problem-solving, and incorporating time constraints to simulate authentic professional pressure [5], [9] Research also highlights that puzzle architecture (linear, open, or multi-linear formats) influences cognitive flow and teamwork dynamics, affecting how students distribute responsibilities and integrate conceptual knowledge during the activity [10]. Among the strategies associated with active and game-based learning, educational escape rooms have emerged as an immersive format that integrates narrative, puzzles, time constraints, and team-based challenges within simulated professional scenarios [11], [12]. Within the literature, this format is frequently positioned within game-based learning and experiential approaches, where knowledge is constructed through active engagement with contextualized problems rather than passive exposition [5]. The experience-based nature of escape rooms aligns with collaborative constructivist perspectives, as students negotiate meaning, test hypotheses, receive feedback from peers, and iteratively refine solutions under constraints [9]. In this sense, learning occurs through situated problem-solving and social interaction, offering insights into how students integrate conceptual understanding with procedural reasoning during the activity.

However, recent reviews indicate that many studies emphasize affective outcomes, such as engagement and satisfaction, while providing limited articulation of theoretical foundations or systematic measurement of conceptual gains [6], [13]. In addition, prior analyses highlight design principles associated with more robust educational implementations, including: constructive alignment between puzzles and targeted competencies, explicit rules and coherent narrative structures, calibrated levels of difficulty to balance challenge and ability, structured collaboration among participants, and post-activity debriefing to consolidate learning [13], [14]. Collectively, these findings suggest that escape rooms are most effective when intentionally designed as pedagogical artifacts grounded in learning objectives and assessment strategies, rather than implemented primarily as engagement-driven activities.

Addressing this gap, the present study develops and evaluates an educational escape room designed to support the teaching of Quality Management in engineering programs, using the DMAIC (Define, Measure, Analyze, Improve, Control) framework as the organizing structure for the narrative and challenges. DMAIC is a structured, data-driven framework widely adopted in quality management and industrial engineering curricula to support systematic problem solving and continuous improvement. The design of the escape room intentionally incorporated the best practices identified in prior research: puzzles were constructively aligned with each DMAIC stage; tasks were structured in an interdependent sequence to reflect the logical progression of the framework; collaborative decision-making was embedded in the challenges; time constraints simulated professional urgency; and a structured debriefing phase was implemented to promote conceptual consolidation [9], [10], [13]. By grounding the intervention in these documented design principles and situating it within experiential and collaborative learning perspectives, this study advances the literature by explicitly connecting theoretical foundations, best-practice design strategies, and systematic evaluation of conceptual learning outcomes. Grounded in the Design Science Research (DSR) methodology, the study applies the artifact in undergraduate Industrial Engineering classes at a Brazilian university and examines its contribution to student engagement, perceived learning, and conceptual understanding through a mixed-methods evaluation. From this perspective, the problem addressed in this study can be defined as the need for instructional approaches that not only increase student engagement but also provide structured and measurable evidence of conceptual learning in Quality Management, particularly in the application of the DMAIC framework.

Methodology

This study adopts a mixed-methods approach, combining qualitative and quantitative data to examine learning outcomes and student perceptions associated with an educational escape room intervention [17]. The research is framed within the DSR methodology, which supports the development and evaluation of instructional artifacts designed to address practical problems [18], [19]. Although DSR is commonly described as a six-stage framework (problem identification, objective definition, artifact design and development, demonstration, evaluation, and communication), this study reports in detail only the stages directly related to artifact design and empirical evaluation. Specifically, the focus is on Stage 3, which concerns the design and development of the artifact, and Stage 5, which addresses its evaluation. The remaining stages form part of the broader research process but are not described extensively, as they do not involve direct empirical data collection or analysis.

Artifact Design and Development

The artifact developed in this study is an educational escape room designed to support the teaching of Quality Management using the DMAIC framework in an undergraduate Industrial Engineering course. The escape room was structured as a game-based learning activity in which students work in small teams to solve a sequence of challenges aligned with the stages of DMAIC. The instructional design was informed by active learning and experiential learning principles, including constructive alignment between tasks and learning objectives, collaborative problem-solving, contextualized application of knowledge, and iterative feedback through challenge progression. These principles were introduced in the literature review and were operationalized in the design of the escape room challenges. Students were positioned as active participants who needed to interpret information, make decisions collaboratively, and apply quality tools under time constraints. The challenges were embedded in a simulated professional context, aiming to approximate the conditions of real-world quality improvement projects. Each challenge was intentionally mapped to one or more stages of the DMAIC method. This mapping reflects an instructional design choice intended to support conceptual coherence and procedural learning.

Participants and Educational Context

The study was conducted with undergraduate students enrolled in the Quality Management course of an Industrial Engineering program at a Brazilian public university. The escape room activity was implemented during the regular academic semester as part of the course curriculum. A total of 47 students participated in the evaluation stage of the study. The activity took place in the middle of the semester, after students had received prior theoretical instruction on Quality Management concepts and an introduction to the DMAIC methodology through lectures and traditional coursework. Most participants had basic familiarity with DMAIC terminology and tools, but limited prior experience applying the method in integrated, practice-oriented, or game-based learning settings. Participation in the evaluation instruments was voluntary, and responses were collected anonymously. The escape room activity was implemented as part of regular course instruction, and the evaluation instruments were used exclusively for research and pedagogical improvement purposes.

Evaluation Instruments

The evaluation of the artifact employed two main instruments. The first was a pre- and post-test questionnaire designed to assess students' conceptual understanding of the DMAIC method. The second was a post-activity perception questionnaire focusing on engagement, collaboration, and perceived learning outcomes. The conceptual questionnaire consisted of open-ended questions addressing the overall purpose of DMAIC, the objectives of specific stages, and the identification of documents, tools, and techniques associated with the Define, Measure, Analyze, Improve, and Control phases. The instrument was developed based on Quality Management and Six Sigma literature and was designed to capture not only correct answers but also partial understanding and common conceptual confusions. The same questionnaire was administered before and after the escape room activity to allow comparison of learning outcomes. The perception questionnaire included Likert-type items using a 0–10 numerical scale, as well as open-ended questions for qualitative feedback. Items addressed aspects such as student engagement, teamwork, information search and analysis skills, perceived relevance to professional practice, and overall evaluation of the activity. The complete set of questionnaire items is provided in the appendices.

Data Analysis

Data analysis followed both qualitative and quantitative procedures and was conducted as part of the Methods section. Responses to the conceptual pre- and post-tests were evaluated using an analytic scoring rubric with three levels: correct, partially correct, and incorrect, corresponding to scores of 1.0, 0.5, and 0.0, respectively. Expected answers were defined in advance based on established DMAIC and Quality Management references. All responses were independently assessed by two evaluators with expertise in the DMAIC methodology.

Differences in scoring were discussed until consensus was reached, increasing the reliability of the evaluation process. Scores were then aggregated by question and compared between pre- and post-test administrations to identify learning gains associated with the escape room intervention. For the perception questionnaire, descriptive statistics were calculated for all Likert-type items. Qualitative responses from the open-ended questions were analyzed thematically to identify recurring patterns related to engagement, collaboration, perceived learning, and challenges experienced during the activity.

Results

The results of this study are presented in two ways: (i) the artifact developed in the third stage, showing how the escape room approach was used to design a session for teaching DMAIC; and (ii) the evaluation of the artifact developed in the fifth stage, based on its application with 47 students.

Artifact Developed

After defining the objectives related to student interaction and problem-solving in the Quality Management course, the DMAIC method was selected as the core instructional framework. The escape room was designed to be conducted in teams of three to five members. Each team is positioned in a scenario created by the instructor, simulating the desk of the former production manager of a fictional energy drink factory called **ENERGEPiti**. The synopsis presented to students is shown in Table 1, which contextualizes the activity and introduces the narrative that guides the escape room development.

Table 1. Escape Room Synopsis

Escape Room Synopsis
The production manager of the fictional energy drink factory ENERGEPiti has won the lottery and decided it was time to take a one-year sabbatical. Before leaving on a cruise around the world, he warned that the factory is facing serious production problems. If not resolved, these issues will cause major delays in scheduled deliveries. Importantly, ENERGEPiti is the exclusive supplier of CarnaPROD, a traditional off-season Carnival event. Any delay in delivery will directly impact the success of the event. The “former production manager” left a note explaining his sudden departure and informing that all the material he had already worked on regarding the production line problem is on his desk. Students in the Quality Management course are now hired as consultants to identify and solve the problem preventing the company from meeting the delivery deadline. Only by completing this mission will the energy drink shipment be delivered and CarnaPROD become a success. To accomplish this, students must solve a series of challenges related to Quality Management concepts using the DMAIC method.

After reading the synopsis and becoming familiar with the scenario of the activity, students are presented with the rules that govern the game and assume the role of newly hired employees at the energy drink factory ENERGEPiti, tasked with solving the problems the company is facing following the sudden departure of its Production Manager. Each team is positioned within the scenario and, using the available materials, must progress through the game by applying the knowledge developed in the course. If necessary, teams may request hints during the challenge, provided that a minimum waiting time is respected, 10 minutes after the start of the game for the first hint and 5 minutes between successive hints. All information required to complete the challenge and resolve the company's problems is embedded in the scenario that reproduces the former Production Manager's desk; therefore, students are encouraged to solve the tasks as efficiently as possible, emphasizing that, as in professional environments, time is a scarce resource. The game begins when the envelope containing the "Note left by the former Production Manager" is opened, which may only occur once the game timer displayed on the classroom projector has started. When a team completes the escape room puzzle, a member must approach the instructor's desk and ring a bell, signaling the end of the team's game time. As the escape room is structured as a competitive activity, information exchange between teams is strongly discouraged, and no hints should be shared with students from other classes or semesters to preserve the educational value of the approach. Once the rules are explained, the game begins, and teams must complete four consecutive challenges aligned with the stages of the DMAIC method to finish the escape room. The alignment between challenges and DMAIC stages reflects instructional design mapping rather than statistical correlation between variables. This structure was intended to support both conceptual coherence and procedural learning by situating each activity within a recognizable quality management logic.

Challenge 1 corresponds to the Define stage of the DMAIC method. In this phase, students focus on problem identification, goal definition, and project scope delimitation, while being introduced to DMAIC as a structured problem-solving approach and to the Project Charter as a tool to formalize these elements. During the escape room, the team locates and analyzes the Project Charter on the former Production Manager's clipboard, which outlines the problem, targets, and scope of improvement. A concluding message signals completion of the challenge and instructs the team to request an envelope containing the task needed to obtain the code for Challenge 2. To reveal the code, students correctly sequence cards with excerpts from the Project Charter definition; once properly arranged, a numerical code appears, unlocking the next folder. Upon completion, the team accesses the folder labeled Measurements, which contains production documents and datasets, including check sheets on breakage rates and filling parameters, run charts, scatter diagrams, and process instructions for analysis.

Challenge 2 corresponds to the Measure stage, in which students collect data on the current process and quantify the defined problem. Emphasis is placed on the use of the Check Sheet and graphical tools such as run charts and scatter diagrams. Teams analyze the materials in the Measurements folder to identify the improvement target. They calculate the current average can breakage rate (17.8%) and apply the Project Charter goal of an 80% reduction, resulting in a target rate of 3.56%, which serves as the code to unlock the next challenge.

Challenge 3 covers the Analyze and Improve stages, aiming to identify the causes of the quantified problem and propose actions for its elimination. Students apply quality tools for data analysis and process improvement, including the run chart, cause-and-effect diagram, 5 Whys, 5W2H, and a prioritization matrix. Teams open the box titled *Completed Analyses and Proposed Improvements* using the previous code and complete tasks involving interpretation of process data, identification of out-of-specification parameters, analysis of correlations, and evaluation of structured action plans. Correct completion of these tasks yields the final code to unlock the last compartment of the escape room.

Challenge 4 corresponds to the Control stage, focusing on establishing process controls to monitor performance and sustain low defect rates. Students are introduced to Statistical

Process Control (SPC) as a method for monitoring process stability. Using the final code, teams access the last compartment, where a note indicates that SPC will be covered in greater depth in a subsequent course. This final step marks the conclusion of the game and reinforces the DMAIC sequence.

Evaluation of the Escape Room

The fifth stage corresponds to the evaluation of the artifact, whose purpose is to analyze how its application contributes to addressing the identified problem. A pre- and post-test evaluation strategy was adopted through the administration of a questionnaire designed to measure the knowledge developed throughout the activity. Learning gains were operationalized as changes in aggregated rubric-based scores between pre- and post-test administrations (Table 2), complemented by descriptive statistics from the post-activity perception instrument.

Evaluation Questionnaire

The questionnaire used in the artifact evaluation stage was structured with open-ended questions and aimed to assess students' conceptual understanding of the DMAIC method, considering both its overall logic and the specific elements of each stage. The instrument included questions related to the purpose of DMAIC, the objectives of the Define, Measure, and Control stages, as well as the identification of documents, tools, and techniques associated with the Measure, Analyze, and Improve stages. In this way, the questionnaire sought to capture different dimensions of the knowledge required to apply the method in process improvement contexts. The questions were designed to require not only nominal recognition of concepts but also differentiation among objectives, tools, and techniques, particularly in more conceptually complex stages such as Analyze. The use of open-ended questions made it possible to capture nuances in participants' reasoning, identify partial understandings, and reveal recurring conceptual confusions, such as the distinction between graphical tools for cause identification and techniques for root cause investigation. This format contributed to a more in-depth assessment of the learning promoted by the active practice, going beyond a superficial verification of term memorization.

Scoring and Score Calculation Procedure

Given the qualitative nature of the conceptual understanding questions, a combined approach of content analysis and score assignment was adopted to transform qualitative responses into quantitative learning indicators. For each question, an expected conceptual answer was first defined based on the Six Sigma and process improvement literature. Based on this reference, an analytic scoring rubric was developed with three performance levels: correct, partially correct, and incorrect responses. Each response was assigned a score of 1.0, 0.5, or 0.0, respectively, according to its degree of conceptual alignment with the expected answer (Table 3). Student responses were evaluated individually, and scores were subsequently aggregated by question for the pre- and post-test administrations. This procedure enabled the comparison of aggregated performance before and after the escape room implementation, as well as the identification of variations in students' levels of understanding across the different content areas addressed in the questionnaire. Scoring was conducted independently by two evaluators with expertise in Quality Management and the DMAIC method. Each evaluator assessed student responses using the predefined rubric, after which results were compared, and discrepancies resolved by consensus to establish a final classification for each response. This process enhanced evaluation reliability and reduced potential individual bias.

Table 2. Scoring Rubric for Conceptual Understanding of DMAIC

	Stage / Focus	Score 1.0 (Correct)	Score 0.5 (Partially Correct)	Score 0.0 (Incorrect)
Q1	**DMAIC – Purpose**	Defines DMAIC as a structured method for process improvement or problem solving	Mentions improvement or problem solving in a generic way	Reduces DMAIC to a single stage or tool, or does not respond adequately
Q2	**Measure – Objective**	Identifies data collection, performance measurement, and/or baseline definition	Mentions data collection or measurement in a vague manner	Confuses Measure with Analyze, Improve, or Control
Q3	**Control – Objective**	Refers to sustaining gains and preventing recurrence	Mentions monitoring or continuity in a generic way	Focuses on data collection, analysis, or implementation
Q4	**Define – Document**	Correctly identifies the Project Charter or equivalent	Mentions defining documents partially	Mentions tools from other stages
Q5	**Measure – Tool**	Identifies structured data collection tools (e.g., check sheet)	Mentions generic data sources or collection methods	Mentions analysis or visualization tools
Q6	**Analyze – Graphical Tool**	Identifies the Pareto Diagram for identifying the main causes	Identifies Ishikawa (fishbone), 6Ms, or tree diagram	Mentions generic charts or unrelated tools
Q7	**Analyze – Technique**	Identifies the **5 Whys** as a root cause investigation technique	Mentions tools for organizing causes	Mentions planning tools or does not respond
Q8	**Improve – Prioritization**	Identifies a prioritization matrix or equivalent tool	Mentions tools without a clear prioritization structure	Mentions tools from other stages
Q9	**Improve – 5W2H**	Indicates the use of **5W2H** to plan and detail improvement implementation	Mentions planning in a generic way	Associates **5W2H** with problem analysis

Comparison of Pre- and Post-Test Scores

Pre- and post-test scores for each questionnaire item (Table 3) were compared using side-by-side bars to visualize performance changes associated with the escape room implementation. The analysis of Table 3 indicates overall learning gains following the active practice, although improvements were not uniform across all assessed content. Post-test scores increased for most items, suggesting that the escape room contributed positively to students' conceptual understanding of the DMAIC method. The most substantial gains were observed in the **Define** and **Measure** stages, particularly in identifying the key project document and using structured data collection tools. These results suggest that the activity supported the assimilation of formal and procedural elements of the method, which are often perceived as more abstract in traditional instruction. Moderate gains were also observed in the **Improve** and **Control** stages, indicating progress in understanding improvement prioritization, action planning, and the sustainability of gains over time. In contrast, items related to the **Analyze** stage did not show improvement and, in some cases, exhibited slight declines. These items required students to distinguish between graphical tools for cause identification and techniques for root cause investigation, pointing to a persistent conceptual difficulty in differentiating these analytical approaches. Overall, the findings highlight the effectiveness of the escape room for learning in the Define, Measure, and Improve stages, while underscoring the need for additional pedagogical strategies to support higher-order cognitive demands in the Analyze stage.

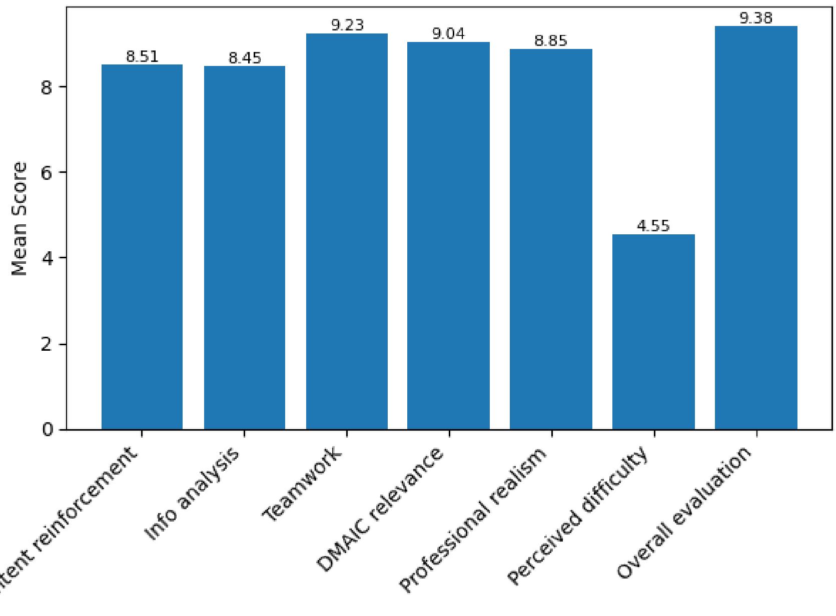
Table 3. Consolidated Scores by Item – Pre- and Post-Escape Room

	Stage / Focus	**Pre**	**Post**	**Difference (Δ = Post − Pre)**
Q1	**DMAIC – Purpose**	26.0	30.5	+4.5
Q2	**Measure – Objective**	31.5	32.0	+0.5
Q3	**Control – Objective**	31.0	34.0	+3.0
Q4	**Define – Key Document (Project Charter)**	28.0	42.0	+14.0
Q5	**Measure – Data Collection Tool**	24.5	36.0	+11.5
Q6	**Analyze – Graphical Tool (Causes)**	39.0	37.0	−2.0
Q7	**Analyze – Root Cause Technique**	26.0	25.0	−1.0
Q8	**Improve – Improvement Prioritization**	32.0	36.0	+4.0
Q9	**Improve – Use of 5W2H**	22.5	24.5	+2.0

Evaluation of the Escape Room Practice

In addition to assessing conceptual learning through the pre and post-tests, student perceptions of the escape room were evaluated to examine engagement, collaboration, simulated professional experience, and contributions to the teaching–learning process. This stage complements the DSR-based artifact evaluation by incorporating the perspective of end users. A post-activity questionnaire was administered, consisting of statements rated on a 0–10 numerical scale and an open-ended field for comments and suggestions. Items addressed content reinforcement, information search and analysis skills, teamwork, the perceived importance of the DMAIC method, professional relevance, and overall evaluation of the activity. Transversal competencies were assessed through student self-reports and qualitative feedback rather than direct behavioral observation or performance-based assessment. The results indicate a highly positive assessment (Figure 1). Students reported strong contributions to content reinforcement (M = 8.51) and to the use of information search and analysis skills in decision-making (M = 8.45). Teamwork received the highest rating (M = 9.23), highlighting the collaborative nature of the activity, while the perceived reinforcement of structured problem-solving through DMAIC was also high (M = 9.04). The approximation to professional practice, characterized by incomplete information and time pressure, was positively evaluated (M = 8.85). The item stating that the challenges were “too easy” received a low mean score (M = 4.55), indicating that the activity was perceived as appropriately challenging. The overall evaluation was very high (M = 9.38). Qualitative comments reinforced these findings, emphasizing the dynamic and engaging nature of the escape room compared to traditional instruction, the central role of communication and collaboration, and the more concrete understanding of DMAIC achieved through the integrated application of concepts and tools in an unstructured, realistic context. These insights corroborate the quantitative results and suggest that the activity supported both conceptual learning and the development of professional competencies.

Figure 1 – Perception results



Discussion

This study contributes to the engineering education literature in two main ways. First, it presents a DSR-based educational artifact that systematically integrates active learning principles with the DMAIC framework in a structured escape room format. Second, it provides empirical evidence that learning gains are not uniform across DMAIC stages, revealing that different types of content respond differently to escape-room-based interventions. These contributions are reflected in the empirical results, which show that the impact of the escape room varied across DMAIC stages. More specifically, the most substantial gains occurred in the Define and Measure stages, particularly in understanding key documents and structured data collection tools. This suggests that the experiential and contextualized nature of the escape room supported the comprehension of procedural elements often perceived as abstract in traditional instruction, aligning with studies emphasizing the value of simulated, practice-oriented contexts. Moderate gains in Improve and Control reflect progress in understanding implementation logic and the sustainability of improvements, competencies central to Industrial Engineering practice. In contrast, results related to the Analyze stage did not improve and, in some cases, slightly declined. This pattern helps explain the second contribution of this study, as it suggests that escape-room-based learning does not affect all types of knowledge equally. Procedural and structured elements, such as those found in Define and Measure, appear to benefit more from contextualized and task-oriented activities. In contrast, the Analyze stage requires higher-order cognitive processes, including abstraction and differentiation between tools and techniques, which may not be fully supported by time-constrained, puzzle-based environments alone. These findings lead to important implications for the design of educational escape rooms. Rather than assuming uniform effectiveness across all learning objectives, instructors should align challenge design, scaffolding, and debriefing strategies with the cognitive demands of each stage. In particular, analytically demanding stages may require additional instructional support beyond the game-based activity. In addition, high student ratings for teamwork and perceived relevance to professional practice reinforce the role of the escape room as a structured environment for the application and consolidation of transversal competencies such as collaboration, communication, and decision-making.

These findings are consistent with prior research in engineering education showing that active learning approaches can enhance student engagement, participation, and conceptual understanding [3], [5], [6]. The positive student perceptions observed in this study, particularly regarding teamwork and professional relevance, further corroborate existing literature on the benefits of game-based learning in higher education [15], [16]. In this context, the escape room functioned not only as a mechanism for reinforcing conceptual knowledge, but also as a structured environment for the development and application of transversal competencies such as collaboration, communication, and decision-making. From a Design Science Research perspective, the evaluation indicates that the artifact effectively addressed the identified educational problem while generating insights for iterative refinement. In particular, the limitations observed in the Analyze stage highlight the need for targeted design adjustments, reinforcing the iterative and improvement-oriented nature of the DSR approach.

Conclusion

This study developed, implemented, and evaluated an educational escape room for teaching Quality Management in engineering courses, using DMAIC as the organizing framework and Design Science Research as the methodological foundation. The results indicate positive contributions to the teaching–learning process, with learning gains across most assessed content and high student acceptance. Improvements were most pronounced in Define and Measure, with moderate gains in Improve and Control, suggesting that the activity supported the understanding of structural and procedural elements of the method. Perception-based results further indicate strong engagement, collaboration, and a positive approximation to professional practice, highlighting the potential of educational escape rooms to integrate technical knowledge with transversal competencies. However, the lack of gains in Analyze underscores the need for complementary strategies, such as guided reflection or structured comparison activities, to support more abstract conceptual differentiation. From a DSR standpoint, the artifact met its intended objectives while revealing avenues for enhancement in subsequent iterations. Study limitations include the restricted number of course sections and a single institutional context. Future research should examine replication across programs and institutions and explore combinations with complementary instructional strategies to strengthen learning in analytically demanding stages of DMAIC. Findings should therefore be interpreted as context-sensitive rather than statistically generalizable.

References

[1] K. E. McKone and J. A. Bozewicz, "The ISM simulation: Teaching integrated management concepts," *Journal of Management Education*, vol. 27, no. 3, pp. 388–406, 2003, doi: 10.1177/1052562903027003006.

[2] C. Pacher, A. Ghezzi, A. Cavallo, and M. N. Cortimiglia, "Engineering Education 5.0: A systematic literature review on competence-based education in industrial engineering and management," *Education Sciences*, vol. 14, no. 2, pp. 1–24, 2024, doi: 10.3390/educsci14020123.

[3] L. F. Rodrigues, "Gamification in engineering education in Canada: A systematic review," *Education Sciences*, vol. 10, no. 9, pp. 1–20, 2020, doi: 10.3390/educsci10090215.

[4] M. A. Tinoco, M. N. Cortimiglia, A. Ghezzi, and A. G. Frank, "Proposition of a method to monitor higher education students' competence development through assessment rubrics," *Studies in Higher Education*, vol. 48, no. 9, pp. 1550–1566, 2023, doi: 10.1080/03075079.2022.2108203.

[5] J. Ross and A. de Souza-Daw, "Educational escape rooms as an active learning tool for teaching telecommunications engineering," *Education Sciences*, vol. 11, no. 4, pp. 155–170, 2021, doi: 10.3390/educsci11040155.

[6] A. Gordillo and D. López-Fernández, "Are educational escape rooms more effective than traditional lectures for teaching software engineering? A randomized controlled trial," *IEEE Transactions on Education*, vol. 67, no. 1, pp. 1–10, 2024, doi: 10.1109/TE.2023.333XXXX.

[7] L. R. Goldberg, E. Rich, and S. J. Korth, "Active learning through service-learning," *Communications of the ACM*, vol. 49, no. 9, pp. 50–55, 2006, doi: 10.1145/1151030.1151037.

[8] I. Rodeghiero Neto and F. G. Amaral, "Teaching occupational health and safety in engineering using active learning: A systematic review," *Safety Science*, vol. 171, p. 106391, 2024, doi: 10.1016/j.ssci.2023.106391.

[9] A. M. Peleg, L. A. Eason, and J. L. Hennessy, "A Lab-Based Chemical Escape Room: Instructional Design and Implementation," *Journal of Chemical Education*, vol. 96, no. 5, pp. 985–991, 2019, doi: 10.1021/acs.jchemed.8b00714.

[10] B. Rocha, K. F. McMullen, and M. Rocha, "Say Yes to the Stress: Escape Rooms in Civil Engineering Classrooms," in Proceedings of the 2023 American Society for Engineering Education Annual Conference & Exposition, Baltimore, MD, USA, 2023.

[11] H. N. Eukel, J. E. Frenzel, and D. Cernusca, "Educational gaming for pharmacy students—Design and evaluation of a lab-based chemical escape room," *Journal of Chemical Education*, vol. 96, no. 5, pp. 985–991, 2019, doi: 10.1021/acs.jchemed.8b00406.

[12] R. Peleg, M. Yayon, D. Katchevich, M. Moria-Shipony, and R. Blonder, "Teachers' views on implementing educational escape rooms," *Journal of Chemical Education*, vol. 96, no. 5, pp. 955–962, 2019, doi: 10.1021/acs.jchemed.8b00645.

[13] A. Torres-Velasco and A. Juneja, "Escape Rooms as an Educational Tool for Engineering Education: Implementation of an Educational Chemical Engineering Escape Room," in Proceedings of the 2024 ASEE Midwest Section Conference, American Society for Engineering Education, 2024.

[14] A. Cunha, M. J. Campos, M. C. Ferreira, and C. S. Fernandes, "Prototyping an escape room to enhance interprofessional collaboration in healthcare: Pilot study," Teaching and Learning in Nursing, vol. 20, pp. e920–e927, 2025, doi: 10.1016/j.teln.2025.03.022.

[15] J. L. Gómez-Urquiza, J. Gómez-Salgado, L. Albendín-García, M. Correa-Rodríguez, E. González-Jiménez, and G. A. Cañadas-De la Fuente, "Application of escape room-based learning in undergraduate education: A systematic review," *Nurse Education Today*, vol. 85, p. 104109, 2020, doi: 10.1016/j.nedt.2019.104109.

[16] J. Rocha, J. Oliveira, and R. Silva, "Say yes to the stress: Escape rooms in civil engineering classrooms," in *Proc. American Society for Engineering Education (ASEE) Annual Conf.*, 2023.

[17] A. C. Gil, *Methods and Techniques of Social Research*, 6th ed. São Paulo, Brazil: Atlas, 2017.

[18] D. P. Lacerda, C. S. Dresch, A. L. M. Proença, and J. A. Antunes Jr., "Design Science Research: A research method for advancing science and technology in production engineering," *Gestão & Produção*, vol. 20, no. 4, pp. 741–761, 2013, doi: 10.1590/S0104-530X2013000400001.

[19] S. Guths, *Design Science Research in Engineering Education: Developing and Evaluating Instructional Artifacts*, Berlin, Germany: Springer, 2016.