# Interactive Simulations And Games As An Aid To The Learning Process For Engineers

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**Abstract**: As engineers are increasingly required to gain competencies that require practical knowledge in certain areas, computer-aided software is becoming an essential part of the learning process for university students. With a practical application of one software for the development of failure mode analysis, we want to present a paper on the teaching and learning advantages linked to the employment of interactive simulation and games proposed to students of the third year of mechanical engineering in the course of maintenance and safety of industrial plants. After a synthetic literature analysis on the advantages of the employment of software in the courses of engineering universities, we focused on the description of the proposed case, its solution, and the student's results. With this assignment, students were required to learn how their decisions could influence a complex system (such as an industrial plant to produce orange juice) and how their choices would have brought to conclusions that needed to be justified to guarantee a profit in five years. The students have introduced adequately to the employed software, TARAS, and lessons were held to answer all the student's questions on the simulation software.

**Keywords**: Simulation; Game; Cccc; Dddd; Eeee.

## I. INTRODUCTION

During the last two decades, society has become greatly influenced by technology, relying extensively on computers and advanced technology, which, year by year, become available for everyone. Companies and educational institutions find themselves in a privileged position. As competent people work for such institutions, it is advantageous to use simulation tools and games to improve the competencies of employees and students, reducing management factors such as the cost and the time of teaching and learning. With a rising awareness to attention to the single element of a group, a teaching approach based on digital technologies may result in a more tailored experience for the person, possibly positively affecting the student's growth [1-3].

The advent of computer technologies such as applications, virtual laboratories, and E-learning has ushered in new and practical teaching methods. These methods enable students not only to memorise but also to understand the theory practically. Studies have shown [4] that interactive multimedia learning is an effective method of imparting knowledge quickly. To manage cognitive load, students must be able to think, understand, and memorise as per established guidelines. Simulation games (SG) are ideal for conveying theoretical concepts and checking if students have grasped practical concepts.

The challenge of the teaching process, in this way, moved from the educator, being the expert on the subject, to the ability of the developers to deliver software up to the expectations requested.

The choice of focusing this paper on interactive simulations and games as tools for the learning process was driven by the interest in analysing how the new generation of future engineers could be evaluated on the study of the fault tree analysis (FTA) method. The availability of tools, such as TARAS, has significantly increased in the last decades, and a significant factor of interest is the

inclination of engineers to appreciate simulation tools.

Among the multitude of ways in which simulation and games have been defined, we chose the following one:

- "Simulation": the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within limits imposed by a criterion or set of criteria) for the operation of the system [5];
- "Game": the definition of "Game" can be assessed as a simulation where a real-world environment is simulated, and it is possible to display elements such as score or advancement, bringing the player to predetermined objectives [6].

In general, these two concepts are very interesting for young engineers because they allow two different stimulating approaches for the students: the simulation allows the student to modify specific parameters and study how the taken choices influence the output results, which are not predetermined; the game stimulates the student to achieve a goal, to obtain a reward with an interactive interface.

The aim of this paper is an analysis of the applicability of interactive simulations and games to engineering courses, with a focus on the simulation aspect and the study of three main objectives:

- Students should learn how to manage complex systems, such as industrial plants;
- Students should understand the complexity of interacting elements;
- Students should learn how to justify the results of a project adequately.

The considered students will be undergraduate students of the Maintenance and Safety of Industrial Plants, a course in the third year of the bachelor's degree in mechanical engineering at the University of Genoa. For this assignment, the students were taught how the software for the development of the FMEA analysis work, giving them time to ask us questions during the lessons. The 45 students were provided with a limit of time of 50 days to complete the assignment.

## II. LITERATURE REVIEW

Digitalisation allows the development of new tools for the digital representation of physical components. The possibility of developing business games, and proposing them through university courses, enables the students to improve mainly their independent learning skills. Another type of learning game is serious games. According to Connolly et al. [7], the critical distinction between SG and traditional games lies in their primary objectives. While conventional games aim to provide entertainment, serious games prioritise educational purposes. Combined with engineering education, serious games were studied as tools with a double effect: make students participate in the proposed scenario and bring out their functional skills through a practical application [8-11].

Several dimensions distinguish SG [12], including uncertainty, the pressure to act or make decisions, and openness to the future, allowing players to decide and act differently and encounter and change situations. Additionally, SG provides development options wherein decisions have a perceptible effect. The actions taken in SG are also interconnected, such that they can affect other roles. Finally, SG are characterised by dynamics, which can create a spiral of emotions in motion.

Albert et al. [13] have identified digital SG (DSGs) as practical tools for enhancing safety training and education. These games incorporate various forms of simulation technology, including simulated game-based learning and serious games. DSGs are particularly effective in motivating learners by providing a competitive and risk-oriented environment, encouraging them to complete their learning tasks and achieve their desired learning outcomes [14]. DSGs offer a significant advantage over traditional lectures by simulating visuals and interaction.

A literature review [15] compared trends in the video gaming industry and their potential application to Serious Games in Engineering Education. The study analysed 28 relevant studies published in the last ten years, which reported games for teaching engineering courses. Results showed that computer engineering and mechanical engineering disciplines were the most used in SG in engineering education. However, the authors noted that engineering fields are unique in that they require specific problem-solving skills and are very hands-on. This poses a gap in the literature, as few studies have investigated the effectiveness of immersive Serious Games in teaching these hands-on skills. The manufacturing industry has adopted

virtual reality technologies to train their personnel and operators, while the medical field has experimented with Simulators to relay psychomotor skills to surgeons. However, the authors noted significant differences between Simulators and Serious Games formats. While SG exist, they have yet to be extensively studied and developed. The authors recommend experimenting with the capability of SG to relay hands-on skills. In their opinion, the game engines used to create SG in recent years are outdated and lag behind the graphical capability of more modern game engines.

In work [16], the development of a comprehensive, authentic learning framework (EALF) was carried out to create a digital simulation game (DSG) to teach workplace safety and health (WSH) education. The resulting game, SafeSim Hazards, was designed to enable students to identify hazards and good practices related to tools, equipment, materials, machines, processes or activities, workplace conditions, environment, and at-risk behaviour in a construction site. The study found that guidance was the most influential factor in authentic learning, while authenticity was the least important. The most effective game design factor was game interaction, followed by game objectives and user-friendliness, and game interaction was the most influential game design feature in operationalising an authentic learning framework in DSG. Game objectives were the least important design factor. Participants rated SafeSim Hazards as highly effective for their learning, with an average rating of 3.36 out of 4. The authors recommended that future construction hazard identification DSG for inexpert-ended trainees should emphasise guidance and game interactions. Digital SG, including variants of DSGs such as simulated game-based learning and serious games, have been identified as technologies that can help improve safety training and education. DSGs provide a more significant edge to traditional lectures by simulating visuals and interaction, motivating learners by providing a sense of competition and risk and encouraging them to complete their learning tasks and achieve learning outcomes.

An interesting classification of this type of learning is described by Breuer and Bente [17], who propose labels for nine categories with which these types of activities can be classified. In our case, we would be able to organise our assignment as a Monte Carlo-based simulation (4;9) developed for academic purposes (7), where groups of undergraduate engineering students (5) will create a Failure Mode and Effect Analysis (2) aimed at improving their functional skills through objectives to achieve (3). The development choice has been the students interfacing as groups with the software (6), which has been installed on their personal computers after the download of the JAVA plugin (1), in which they have to insert data in the software, build the fault tree and discuss the results of their choices (8).

In the courses held by our laboratory, it is nearly ten years that interactive simulations and games have been used on different occasions: courses held in bachelor's and master's courses of engineering as part of the final evaluation; conferences organised for PhD and young researchers to improve skills such as transversal thinking and teamwork; and with students for their final projects. This framework could also address the aspect of poor organisation under certain elements during the COVID-19 pandemic. We concluded by observing the engineering students who have been forced behind screens for more than one semester, severely impacting those courses with laboratory activities included. In these situations, using games and interactive simulations could have resulted in positive feedback from students [18-23], with fewer psychological disorders due to anxiety, depression or stress [24-27]. From these studies, the perception of the teachers of their lessons and the opinion of the students, it was acquired the opportunity of changing the teaching approach, with the possibility of improvements during the pandemic situation, but also by giving important suggestions for carrying on certain aspects also once the emergency was passed [28-39].

The authors [40] created and tested a digital simulation game for media education in teacher training. The game was designed to simulate school decision-making processes for implementing hybrid teaching during the pandemic. The primary objective was to determine whether participation in digital SG could initiate reflection processes that change or deepen students' attitudes towards hybrid learning concepts. Using a questionnaire, the study used a pre-post design and surveyed N=300 students participating in 12 SG. The researchers employed quantitative questioning to determine the extent to which the perception of multiple perspectives, digital inequality, and the planning of hybrid teaching caused reflection processes among the students. The SG were evaluated using questionnaires in a pre-post design, and the results indicated that more than 80% of the students had a positive view of the process and results of the game.

With this knowledge, in a critical situation, such as the COVID-19 pandemic, or as it could be, online

lessons due to natural calamities, it has been possible to implement the assessment of the course's knowledge through assignments. Given the possibility of interacting with each other, the students were motivated to give positive feedback at the end of the courses. These types of activities always resulted in full participation in the classes. However, these assignments were not mandatory for passing the course, only for improving the mark obtained by the written exam.

The study [41] examines the impact of interactive and portable applications on student engagement and learning over four years. The aim is to help students identify weaknesses and develop strategies to address them. The applications provide theoretical concepts review and gamification elements to enhance the appeal and practical instruction using computer technologies. An interactive method has successfully supported students, increasing approved students from 15% to 38%. 89% of students expressed satisfaction in surveys, and 96% wanted more interactive applications to enhance learning. These methods are highly appreciated during COVID-19 confinement and should be expanded to support a broader range of subjects.

The assignments have always been proposed to learn several aspects of industrial engineering. This paper focused on the Failure Mode and Effect Analysis, a topic faced during the seminars. It has been proposed to the students the scenario of an event with different requests at increasing difficulty, challenging the students without demotivating them. Nowadays, great attention is given to the mental state of the students, and certain pedagogical aspects cannot be avoided [42-44]. This conclusion is brought by the role of new technologies, critical in teaching young engineers, such as augmented Reality, Virtual Reality or virtual simulation tools [45-52].

## III. Method

Forty-five students in the third year of mechanical engineering were asked to perform an assignment on evaluating the availability of an industrial plant to produce orange juice.

We realised that the limited number of students is the main factor of the current research. Given the importance of the course and the presence of other courses held by industrial engineering professors, which essential part of the evaluation is the development of simulation-based assignments, we are confident that the limited number of elements of our set could still assess the general tendency of the student's behaviour towards interactive simulations and games.

The analysed system consists of an orange processing plant to produce concentrated juice. The following diagram represents the production process sequence in a simplified manner. All the information in Figure 1 can also be found in each component's failure rates and eventual capacity.

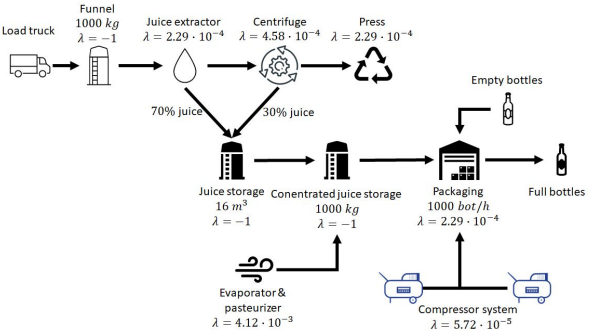


Figure 1. Orange juice production process

## IV. Discussion

To learn about the impact of a SG on students, we decided to use an annual report that contains a survey of their opinions on the quality of teaching for each subject at the University of Genoa. The survey is conducted among both direct students of the course and those who have chosen it as an elective or part of other educational programs, like Erasmus. Students can anonymously and voluntarily offer their suggestions for course improvement and evaluate the educational process according to specific criteria:

a) Was your prior knowledge sufficient for understanding the topics on the examination syllabus?

b) Is the teaching load proportionate to the credits allocated?

c) Are the teaching materials (indicated and available) adequate for the study of the subject?

d) Are the examination procedures clearly defined?

e) Are the timetables for lectures, tutorials and any other teaching activities adhered to?

f) Does the teacher motivate interest in the discipline?

g) Does the lecturer present the topics clearly?

h) Are the supplementary teaching activities (exercises, tutorials, workshops, etc.) useful for learning the subject?

i) Has the teaching been carried out in a manner consistent with what is stated on the course website?

j) Is the lecturer available for clarification and explanation?

k) Are you interested in the topics covered in the teaching?

To evaluate the game, we chose the criteria of c), f), h), j) and k) because they most closely reflect the impact of the SG on student assessment. Next, we compared the results of this academic year (2022/23) with the previous one (2021/22) on the criteria that are important to us. The available answers to the students were the following:

A. Definitely No

B. More No than Yes

C. More Yes than No

D. Definitely Yes

E. Does not answer

Overall, the assignment resulted in significant participation by the students. During the semester, the students took advantage of the professor's and the assistant's availability by asking questions pertinent to the assignment, asking about meetings outside the lecture hours and bringing updated versions of the assignment for final comments. Overall, we gathered positive feedback on this type of activity, where the students could deliver a Fault Tree Analysis (FTA) scheme, which by comparison were all more or less the same, assessing that the students well understood the theory behind this type of assessment. A precious commentary delivered by a minority of the students has been the definition of the optimal duration of the simulation run, with personal insights on their decisions. An essential part of the assignment was the determination of the critical elements of the system and the personal suggestions on how to improve the system's output in one year and five years, also justifying the possible changes by showing the positive benefits of the investments.

TABLE I. COMPARISON BETWEEN THE 2021-22 (29 PARTICIPANTS) AND 2022-23 (45) ACADEMIC YEARS SURVEY RESULTS IN PERCENTAGE

| | 2021<br>2022 | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| **c)** | 0 | 3.45 | 44.83 | 31.03 | 20.69 |
| **f)** | 3.45 | 27.59 | 31.03 | 13.79 | 24.14 |
| **h)** | 3.45 | 17.24 | 31.03 | 13.79 | 34.48 |
| **j)** | 3.45 | 10.34 | 37.93 | 24.14 | 24.14 |
| **k)** | 6.9 | 17.24 | 44.83 | 10.34 | 20.69 |

## V. CONCLUSION

Interactive multimedia learning has emerged as an effective approach for the rapid dissemination of knowledge. By employing simulations, students can manipulate specific parameters and observe the impact of their decisions on the resulting outcomes. Unlike predetermined scenarios, these outcomes are not predetermined, adding an element of unpredictability. Additionally, gamified elements within the learning process incentivize students to strive for goals and rewards through interactive interfaces. Integrating business games into university courses enhances students' ability to cultivate independent learning skills. Although simulation games (SG) are widely used in mechanical and computer engineering within the realm of engineering education, there is still room for growth and development in these disciplines, as they require specialized problem-solving skills.

Another notable aspect of Digital Simulation Games (DSGs) is their applicability to students who lack practical experience in their respective fields. However, evaluating the tangible benefits of using SGs can be challenging for users who have yet to encounter real-world situations in their future workplaces. Studies suggest that students are more inclined to evaluate the interface, graphics, and learning potential of SGs rather than their practicality and goals. It is worth highlighting that both simulation and serious games can enhance students' motivation by fostering a competitive environment among their peers.

The focus of this paper is the analysis of a simulation assignment that was introduced as a mandatory component for evaluating the Maintenance and Safety course in industrial plants. This course is offered in the third year of the

Bachelor of Mechanical Engineering program. The aim of the paper was to examine the applicability of interactive simulations and games in engineering courses, specifically their impact on teaching students how to manage complex systems, understand the interplay of elements within such systems, and effectively justify project outcomes. This assignment carries a maximum of seven bonus points towards the final evaluation, totaling 31 points.

During the course, students displayed a keen interest in the subject matter and provided valuable insights and observations. Their feedback included suggestions for implementing additional features in the assignment, which were covered during the lessons. Lower scores on the assignments were primarily observed among foreign students who did not request explanations in English (since the course is primarily taught in Italian) and students who did not attend the explanatory classes. This highlights the importance of two key aspects for engineers: effective communication and the responsibility of attending lectures.

In conclusion, it is noteworthy that students expressed a genuine interest in innovative teaching methods and demonstrated competence in critically analysing their work by providing explanations for their choices. Furthermore, they developed proficiency in working with new software that could be applied to their final theses. Future studies could explore how students approach assignments in the upcoming years, particularly considering the ongoing dynamics resulting from the COVID-19 pandemic. In other words, it would be beneficial to examine the relationship between didactic practices and the diminishing impact of the pandemic.

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