A STUDY ON THE POTENTIAL OF GAME BASED LEARNING FOR SUSTAINABILITY EDUCATION

Scurati, Giulia Wally (1);
Kwok, Sze Yin (2);
Ferrise, Francesco (3);
Bertoni, Marco (1)

1: Blekinge Tekniska Högskola, Department of Mechanical Engineering;
2: Blekinge Tekniska Högskola, Department of Strategic Sustainable Development;
3: Politecnico di Milano, Department of Mechanical Engineering

ABSTRACT

Academic institutions are increasingly required to prepare future practitioners to face complex sustainability challenges. The need to foster the development of different skills, attitudes, and multidisciplinary collaboration raised the interest in alternative learning approaches. Game-based learning can be a tool to achieve a variety of desirable learning outcomes, including sustainability and collaborative attitudes change. We present a pilot study investigating the potential of a board game on sustainability risks and opportunities in product development and life cycle, performing a test with different student audiences. The paper discusses our results of the experiment, including a survey following the game, qualitative analysis of students' feedback, and observations during the game sessions. Additionally, we relate insights from students' reflections to CDIO learning objectives. We then illustrate lessons learned and the potential advantages of using the game compared to other teaching approaches and as a complementary tool. Finally, we propose future directions and recommendations for the use of the board game and game-based learning in sustainability education with different student audiences.

Keywords: Sustainability, Education, Early design phases, Serious Game, Game Based Learning

Contact:
Scurati, Giulia Wally
Blekinge Tekniska Högskola
Sweden
giulia.wally.scurati@bth.se

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1 INTRODUCTION

Contributing to reaching Sustainable Development Goals (SDGs) is now on the agenda of every enterprise and organization. Governments, industries, and the whole labor market demand practitioners that are more informed and attentive to sustainability matters, able to consider social, environmental, and economic aspects when making strategic and operational decisions, and to communicate in multi-stakeholder settings (Leal Filho et al., 2016). Academic institutions are in charge of preparing future citizens and professionals to solve sustainability problems, however, integrating sustainability into educational and industrial contexts is not simple. The concept of sustainable development itself is not trivial to apply: the conflict between "sustainable" and "development" emerges especially at operational levels (Jabareen, 2004). Moreover, when different sustainability targets are in contrast, bringing together multiple perspectives can generate disagreement on how such problems should be addressed and prioritized. At the same time, there is a need for multidisciplinary and collaborative approaches to deal with the complexity of sustainability challenges (Guerra, 2017, Williams et al., 2017) and positive attitudes towards sustainability (Bielefeldt, 2013). Achieving these objectives in higher education requires cooperation across different departments and programs, to provide students - but also researchers and teachers - with occasions to better understand other disciplines and how they could impact their own field (Guerra, 2017). Moreover, this interdisciplinary collaboration should be supported by shared educational strategies, methods, and tools. In this regard, Serious Games (SGs) represent an opportunity to face these challenges in various ways. SGs are games whose aim goes beyond pure entertainment, including learning and training goals (Alvarez and Djaouti, 2011). In fact, a similar concept is one of game-based learning, referring to types of gameplay with defined learning outcomes (Plass et al., 2015, Despeisse, 2018). SGs are now considered an established educational tool to develop hard and soft skills, as well as transfer knowledge and attitudes (Backlund and Hendrix, 2013). Moreover, a game can work as a "boundary object" (Whalen et al., 2018), supporting connections between different practices. In this light, the use of an SG could help students, educators and researchers, professionals, and future ones from different areas to share knowledge and build common views, strategies, and approaches. Importantly, game-based learning can be an alternative teaching method to support CDIO (Conceive – Design – Implement – Operate) objectives (Despeisse, 2018, CDIO, 2023).
This paper presents the results of a study assessing the potential educational use of a previously developed serious game (Authors' paper) with two different student audiences: MSc in Mechanical Engineering and MSc in Strategic Leadership towards Sustainability (MSLS). Four learning areas were identified and related to CDIO learning objectives (Crawley et al., 2011) and compared to the game features to evaluate the game's suitability for the study's purpose. Then a questionnaire was designed to assess the students' experience and the potential of the game to reach the desired objectives. The main aim was to investigate the game's suitability in an educational context and learning outcomes for students from different programs. We discuss the results of an online survey, qualitative feedback from students, and observations during the game sessions. Then, we identify potential advantages of using the game and opportunities to adapt and use the game for educational purposes. This study also aims at exploring the game's potential to foster cross-programs and departmental collaboration in sustainability education.

2 SERIOUS GAMES ON SUSTAINABILITY IN EDUCATION

SGs have been experimented with as a tool for sustainability education at various levels, for different topics and learning targets. They have been developed for primary school children (e.g., Rossano et al., 2017), high school (e.g., Toprac, 2011, Mesquita et al., 2013) and university students (e.g., Whalen et al., 2018, Peña et al., 2020). Hereafter we discuss the role of SGs in learning approaches, different SGs categories, and assessment methods.

2.1 Game-based learning

Game-based learning consists of the full implementation of an SG towards predetermined learning outcomes (Plass et al., 2015, Despeisse, 2018). Game-based learning can support problem-based learning (PBL), as games can be tools to present complex challenges to players, working as problem solvers in small groups, while teachers act as facilitators (Toprac, 2011). Games can engage students in active learning by supporting discussions and concept exploration (Plump and LaRosa, 2017). Therefore, games

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have the potential to enhance social interactions, supporting the development of argumentation skills (Noroozi et al, 2020) and collaborative learning (Wang and Huang, 2021), contributing to enhancing creative problem-solving (Chen et al., 2021). However, on the one hand, real-time feedback from digital games can facilitate teaching by creating occasions for the teachers to provide explanations (Plump and LaRosa, 2017). On the other hand, it can also lead to minor conversations compared to traditional PBL, possibly affecting students' motivation (Toprac, 2011). The case of analog games could be different, also depending on the game category and specific design: some SGs are specifically proposed to foster conversations (Scurati et al., 2020). However, the concept of game-based learning has mostly been discussed in the context of digital games (e.g., Toprac, 2011, Tobias, 2014, Noroozi et al, 2020). Despite many works investigate analog games (e.g., Whalen et al, 2018, Chen et al., 2021), similar reflections on game-based and how it relates to other learning approaches represent a research gap. Moreover, despite the potential of game-based learning to support CDIO objectives (Despeisse, 2018, CDIO, 2023), there is a lack of work discussing and assessing SGs considering the CDIO syllabus.

2.2 Serious games categories

SGs and gamification categories in technical education are described in (Scurati et al., 2020). Categories of SGs include:

- Simulation game: reproducing/analysing a real situation which is the object of learning (e.g., product, development);
- Metaphor: reproducing/analysing a situation which is different from the object of learning, but has some learning transfers towards it (e.g., similar mechanisms, logic);
- Role play: a simulation where users have to act the part of a specific role;
- Board game: a traditional table game (using both simulation/metaphors);

These categories take advantage of different structures and mechanisms to reach a variety of objectives and learning outcomes, which may differ depending on the case study's needs.

For instance, realistic simulations support procedural knowledge and experience of how to perform a specific task. A metaphor can be used when the need is to simplify a difficult concept. Role play allows impersonating actors and situations that are far from the player's everyday ones, allowing perspective change. Board games can represent an overview of complex systems, relate multiple factors, and enhance the social dimension. Importantly, these games' typologies and advantages can be combined together depending on the audience and context's needs. Noticeably, games are used to improve the learning experience and boost students' and trainees' motivation, helping them to reach better results in a time-efficient way. However, this potential can be focused on one or more objectives, ranging from learning specific information or task execution to understanding the general picture and managing complexity. For instance, an exploration experience with simple game mechanics, based on visualization, can educate on complex scientific facts and phenomena (e.g., Jang et al., 2022). Another possibility is to focus on the characters' roles and stories, to facilitate perspective change and raise empathy (e.g., Nilsen et al., 2011). A game could instead depict dynamics and interrelation between multiple factors, providing an overview of a complex system (e.g., Whalen et al, 2018).

2.3 Assessing serious games in education

When testing SGs both educational and entertainment aspects should be assessed (Bellotti et al, 2013). Considering the former, quantitative assessment is used to measure and compare learning outcomes, this can be done through various student performance assessment methods (Bellotti et al, 2013). They can differ depending on their aim and implementation, they can be for instance in-game (e.g., right answers, targets achieved) and out-game assessments (tests following the gameplay) (Caballero-Hernández et al., 2017). Qualitative assessment can include post-game debriefing sessions (Taillandier and Adam, 2018), focus groups (Wang et al, 2016) and collecting written reflections after the game (Whalen et al, 2018). These methods are used to investigate the games' potential and possible improvements. Quantitative methods can be also used to evaluate the game experience, for instance, Likert scales can be used and combined with open questions to gain insights into the motivation behind answers (Plump and LaRosa, 2017). Likert scales are also used to measure users' attitudes (Nilsen et al., 2011), and self-assessed learning outcomes (Bakhuys Roozeboom et al., 2017). Finally, the game type can affect the assessment choice: in-game assessment is easier in digital games (Caballero-Hernández et al., 2017), while in strategy/board games it can be hard due to increasing complexity and fewer right/wrong answers.

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3 MATERIAL AND LEARNING OBJECTIVES

The aim of this study was to assess the use of a previously developed SG to support sustainability education with different student audiences (Authors' paper). The board game typology fosters collaboration due to the social setting, involving role-play and simulation features. Players impersonate a company and proceed across different product life-cycle phases, proposing a simulation to acquire general knowledge and an overview of the decisions and aspects involved. While the aim is maximizing profit, players' strategic and operational choices have economic, social, and environmental impacts represented by three different kinds of coins. Depending on their decisions, they face the effects of unexpected events related to economic, social-politic, and legislative dimensions (getting penalties/rewards). The game was originally designed for the industrial context, targeting a company's employees. However, the content was designed for a multidisciplinary audience, targeting any role (e.g., material procurement, designers) and level (e.g., new employees, managers). In fact, it highlights fundamental concepts and their interrelation and does not include complex technical information. Additionally, the game had previously been tested at the company, involving a variety of audiences, including master thesis students. For this reason, we considered it interesting to assess the game's suitability and potential in an educational context. We identified four learning areas for sustainability in education in the literature that the game could support:

Knowledge regarding fundamental concepts within specific fields. Knowledge from different fields is necessary to build multidisciplinary expertise (Remington-Doucette et al., 2013);

Systems thinking supports the development of a holistic lens to understand the relationships between economic, political, social and ecological aspects considering temporal and spatial dimensions (Williams et al., 2017);

Sustainability awareness and attitudes are related to concern and willingness to act to face sustainability challenges, they help ensure that students will apply their sustainability knowledge professionally (Bielefeldt, 2013);

Collaboration and openness are necessary to solve complex sustainability problems, requiring a desire to cooperate, adopt perspective change, welcome new knowledge, and learn from experts and peers from different domains (Guerra, 2017).

These learning areas are related to CDIO objectives (Crawley et al., 2011) 2 Personal and professional skills and attitudes, 3 Interpersonal skills: teamwork and communication, and 4 - conceiving systems in the enterprise, societal and environmental contexts. Table 1 describes how the game features can satisfy the defined learning areas and CDIO sub-objectives.

Table 1. Learning areas, related CDIO learning objectives and game features

Learning areas	CDIO learning objectives	Game features
Knowledge	4.1.2 The Impact of Engineering on Society and the Environment, 4.1.3 Society's Regulation of Engineering	The game provides simple knowledge on the basic elements of product development (phases and decisions) and sustainability (triple bottom line concept) and possible related events. This area is more focused on the knowledge of the single elements rather than the interaction between them.
Systems thinking	2.3.1-Thinking holistically; 2.3.2-Emergence and Interactions in Systems; 2.3.4-Trade-offs, Judgment & Balance in Resolution; 2.4.1-Initiative and Willingness to Make Decisions in the Face of Uncertainty	The game relates product life cycle decision-making at the company to economic, social-politic, and legislative systems. It considers local/global and short/long-time dimensions and depicts uncertainty related to risks and opportunities.
Sustainability awareness and attitudes	4.1.7 Sustainability and the Need for Sustainable Development, 4.3.1-Understanding Needs and Setting Goals	The game illustrates in which way and how seriously each decision and phase affects and is affected by local and global actors, improving, or worsening environmental, social, and economic conditions.

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Openness and collaboration	3.2.7-Inquiries, Listening and Dialogue; 3.2.8-Negotiation, Compromise, & Conflict resolution; 3.2.9-Advocacy	The game relates multiple company roles and external stakeholders, showing the importance of integrating different perspectives to reach the game's objective.

4 EXPERIMENT SET UP AND EXECUTION

We conducted a pilot test to evaluate the potential of playing the game and its suitability in the educational context. The test's aim was to evaluate students' experience and perception of the game, their self-assessed learning outcomes and impact on attitudes, a similar method is used by Bakhuys Roozeboom et al. (2017).

Twenty questions related to five areas were designed to evaluate the overall experience, as well as learning outcomes and attitudes (Figure 1). For the latter, the students were asked to report their thoughts after playing the game. These five areas and included measures were related to the four game's objectives plus the gaming experience. We used quantitative feedback to identify and compare different student audiences, and qualitative feedback to have more insight into opportunities to improve the game design and experience and relate the game to possible pedagogic strategies. Therefore, the items were measured on 1-5 Likert scales (1-strongly disagree to 5-strongly agree). Each area was followed by an open question asking for additional comments, a similar approach was used by Plump and LaRosa (2017).

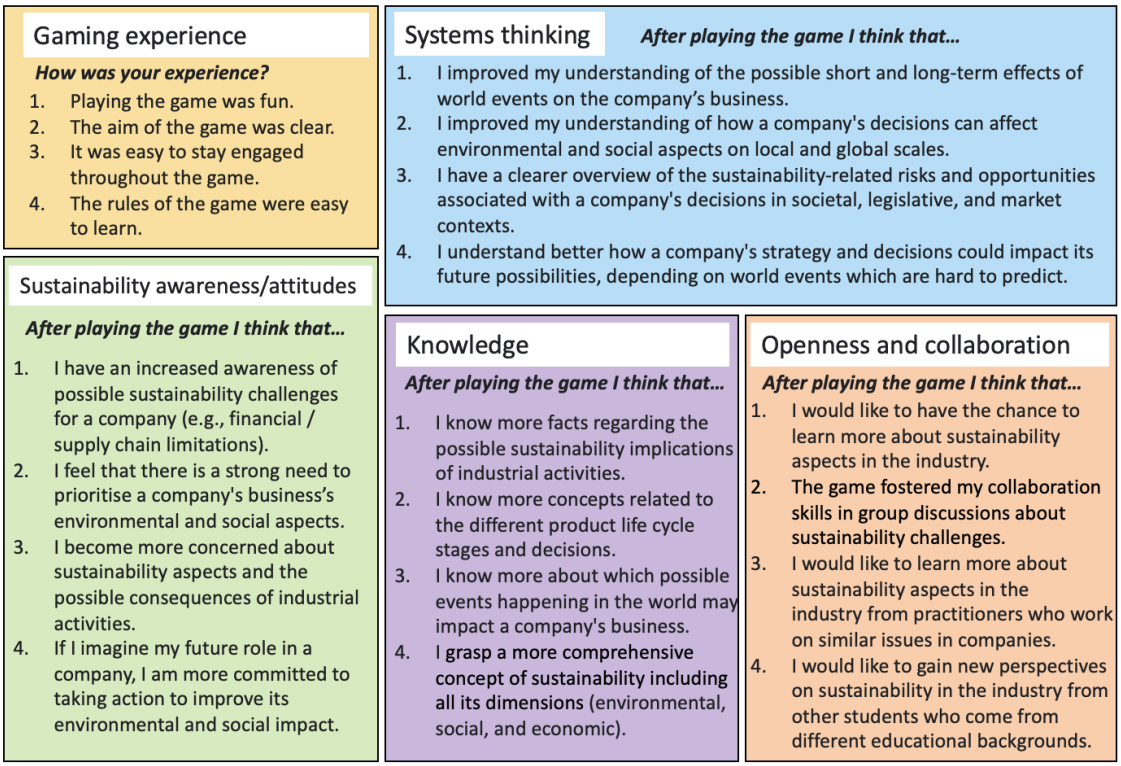

Figure 1. Questionnaire learning areas and questions.

The study involved students from two MSc programs. One is the MSc in Mechanical Engineering - structural mechanics. The program includes 7.5 course credits on sustainability. The other is the MSc Strategic Leadership towards Sustainability (MSLS) program which focuses on two core themes: Strategic Sustainable Development (SSD) and Leading in Complexity (LiC). Students from diverse educational backgrounds are admitted to this program. The students from the two programs may have different levels of expertise and perspectives on sustainability, how to prioritize different factors, and how to implement practices. The participants from Mechanical Engineering (Group 1) and MSLS (Group 2) programs took part in the study in different sessions with one or two tables playing depending on the number of participants. Each table had two or three teams (2-3 participants per team). Two experimenters (one for each table) were moderating the game (Figure 2).

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Figure 2. Pictures from the game session. A team is investing in a product development decision and delivers money to the moderator.

5 RESULTS AND DISCUSSION

5.1 Survey results

Nine students from Group 1 and eleven from Group 2 answered the survey. Figure 3 shows that most of them rated the game as fun and engaging (Q1 and Q3). Q2 and Q4 scored lower, in particular, the rules were harder to understand for Group 1. In the comments, many asked for more detailed instructions prior to the sessions. This result was expected since the game's complexity was known from previous sessions with academic and industrial audiences.

Considering Knowledge and Systems Thinking (Figure 4), Group 1 scored slightly higher than the MSLS group (Group 2). This was expected since the MSLS program focuses on sustainability education, so students in Group 2 may have higher expertise in general. However, in both groups, there was disagreement, with higher polarization in Group 2. Group 2 was however less homogeneous than Group 1 considering participants' age, background, and working experience.

Considering sustainability awareness and attitudes (Figure 5), the game had higher scores for Group 1 students, while Group 2 was more neutral, especially for Q1. This was also expected since all Group 2 students are highly committed to sustainable development as documented work experience in the field

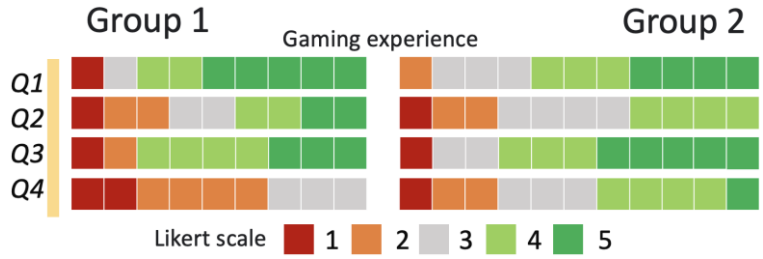

Figure 3. Survey answers for the gaming experience

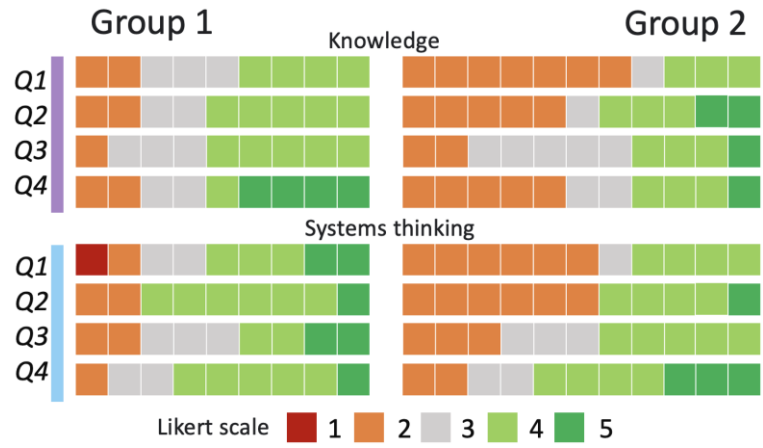

Figure 4. Survey answers for knowledge and systems thinking

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is a requirement for admission to the program. Group 1 had a high score for Q2, regarding the need to prioritize social and environmental aspects. The two groups both scored higher in Q4 on their commitment as future professionals. Finally, the questions regarding openness and collaboration reached generally high scores for both groups (Figure 6). However, Q2, regarding the ability of the game to foster collaboration skills in group discussions, had lower scores. Overall, the survey

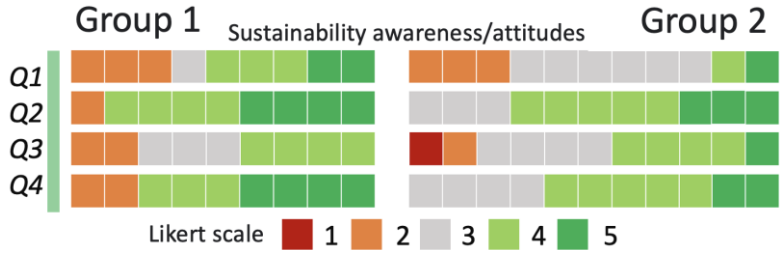

Figure 5. Survey answers for sustainability awareness and attitudes

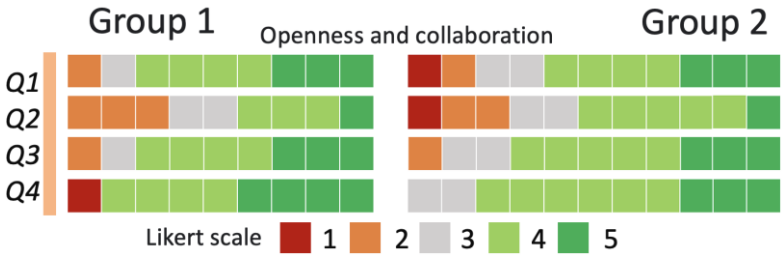

Figure 6. Survey answers for openness and collaboration

highlighted the game's potential in the areas of openness and collaboration, partially for sustainability awareness and attitudes and for specific items., also depending on the audience. The results regarding knowledge and system thinking had a higher disagreement. A possibility is that the presentation and contextualization of the game before the session, along with the aim and rules, could improve these outcomes. Providing the opportunity to discuss and apply lessons learned after the game (e.g., through group tasks) could also be beneficial.

5.2 Qualitative analysis

The comments collected from the survey and during the game session are summarized and mapped in Figure 7 according to the learning areas and CDIO objectives described in Table 1. We related the statements to the CDIO objectives, sub-objectives and descriptions described by Crawley et al. (2011). Considering personal and professional skills and attitudes, the students' statements show an understanding of the importance to deliver solutions that balance various factors, resolve tensions and optimize the product design considering the whole life cycle. In particular, the students had to discuss if it was a better choice to select the optimal solution, or the one allowing for more flexibility in the later phases (e.g., due to budget availability). Moreover, the results of their actions were often uncertain, as shown by the comment regarding R&D investments. Understanding the need for compromising also supports interpersonal skills, teamwork, and communication objectives. In fact, the students had to reach an agreement, by trying not to compromise fundamental sustainability principles (Broman & Robèrt, 2017), also involving the practice of advocacy. At the same time, the decisions had to be acceptable from many perspectives, including the customer and market ones. The need for coherence with the initial strategy led to an understanding that it is important to prioritize sustainability from the beginning. This aspect is central for conceiving systems in the enterprise, societal and environmental contexts. The students understood that not only do possible decisions (and sustainability aspects) attract different investors but they affect the goals that a business can set in the long run. While a fundamental role in setting such goals is played by the customer and market, the other is set by other influences (e.g., social, environmental, regulatory). In this regard, students could observe which possible events in legal and political systems (e.g., a carbon tax, an incentive, a conflict) could affect engineering decisions and how an engineering choice can impact society and knowledge (e.g., employees' satisfaction and safety, ability to invest in R&D).

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5.3 Observations during the sessions

During the game sessions, some students were "playing safe", meaning that the choices they made throughout the product life cycle were coherent with the initial business strategy. However, many of them took high risks by making contrasting choices, especially those starting with low-cost and unsustainable strategies. At a point, the risks associated with low sustainability (presented by legislative, social-political, and economic events) made them realize that they needed a change of paradigm. Hence, they went for more sustainable decisions, even though this was risky from a financial perspective. This

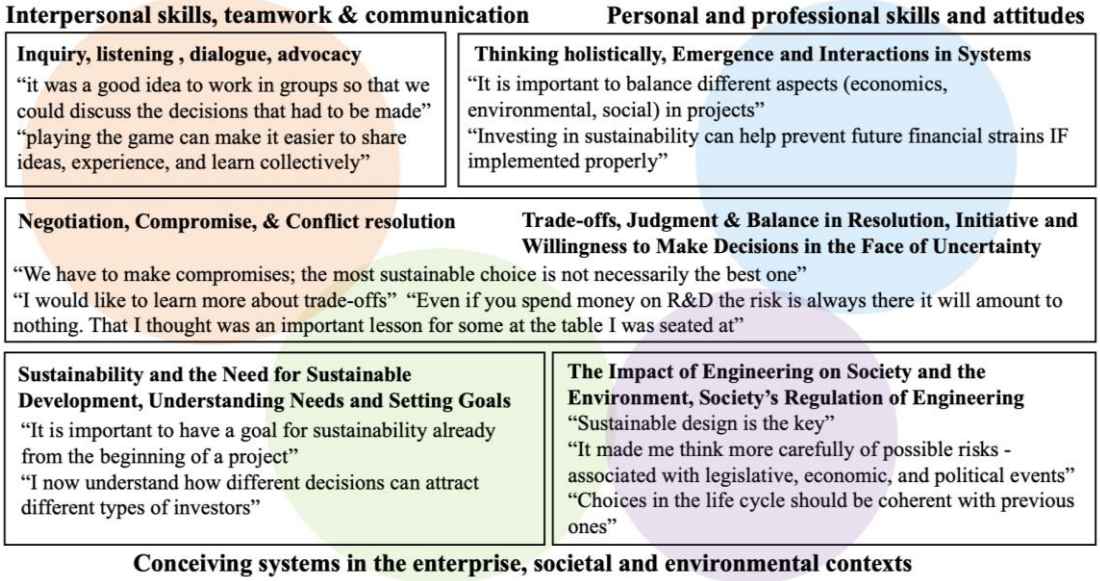

Figure 7. Students' comments mapped to learning areas and CDIO learning objectives

could explain how they understood and commented that sustainability is important, but also coherence with the business strategy, and then it is important to set sustainability goals from the beginning. For some students, especially those in Group 2, the game did not prioritize sustainability enough: "While the game IS an accurate facsimile of the world as it is, I'm not sure it does much in the way of teaching the need for a shift in paradigm". This highlights the need to balance the understanding of the current challenges and motivation for sustainable change. However, even in Group 2, when a more sustainable choice did not provide any advantage or protection from risks (e.g., the end-of-life decision, since it was the last one) some teams preferred a less expensive and less sustainable option to make more money - to win the game. This could raise reflections during debriefing discussions since it can happen in decision-making processes within businesses in the real world. In this regard, students proposed and imagined new rules, sometimes to make the game more realistic, sometimes to push sustainability goals. Finally, not only did students discuss within their own group, but could listen to the conversations within the other groups' decision-making process, and this affected their subsequent discussions throughout the game. This is also a positive outcome compared to other game-based learning approaches using digital games, where there can be a lack of communication between players (see Section 2.1). More students proposed to have reflection time and discussions after the game sessions.

From these observations, compared to traditional PBL approaches (e.g., workshops) the game might:

- Speed up the understanding of the need of changing strategy and decisions during the session by foreseeing the possible consequences;
- Induce students to take more risks and explore a wider variety of possible scenarios;
- Raise more reflections on the ethical perspective and stimulate critical thinking;
- Bring up more arguments and affect decisions through discussions within and across groups.

The students were sometimes disappointed when they missed rewards or got penalties despite they had made more sustainable choices than the competing teams. However, this might have led to the insight that compromises are needed, sustainable strategies should be implemented correctly, and awareness of uncertainty. Moreover, other PBL approaches would allow more design and implementation activities. The game could then be a complementary tool (as it supports the "conceiving" aspects) for CDIO objective 4 (Crawley et al., 2011).

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6 CONCLUSION AND FUTURE WORKS

In this study, we investigated the use of an SG on sustainability in the product life cycle to support risks and opportunities awareness in decision-making. This pilot study highlights the potential use of the game in education for different programs as a tool to boost students' interest and collaborative learning in sustainability. However, the results from the survey showed disagreement within each group, highlighting the current limitations of the game. Nevertheless, positive and interesting insights emerged from the students' reflections and were discussed in relation to CDIO learning objectives. We also identified possible advantages of playing the game deriving from insights from observations during the sessions. Hence, we suggest that the game could be an effective tool if contextualized and integrated with additional information and activities prior to and after sessions, as well as different teaching approaches. However, future work is needed to confirm this hypothesis. For the students who are less familiar with the sustainability field, learning about sustainability aspects in industrial strategic and operational decision-making before the game session could be beneficial to better understand the objectives and mechanisms. For students in sustainability, it could be an occasion to learn about the potential use of SGs to introduce sustainability concepts to non-expert audiences and lead sustainable change in enterprises. Hence, having different introductory lectures according to the audience could help overcome the current limitations that emerged from the survey results. Moreover, this work did not involve mixed groups to assess how the game could support discussions, especially regarding trade-offs. Here we summarize the lessons learned and future directions:

- Before the sessions, the game should be contextualized according to the audience;
- After the sessions, debriefing and discussions would help clarify and improve learning outcomes;
- Future tests to assess how the game experience and learning outcomes relate to the players' success in the session and how they may change after playing multiple times;
- Future works involving mixed audiences in the same game session to investigate further the collaborative potential of the game;
- A comparison with a traditional PBL approach (e.g., a workshop) /non game-based education to further investigate the potential, limitations and complementary aspects of game-based learning;
- A PBL group task following the game session to assess its impact on collaborative skills;
- Future tests to assess learning objectives prior to and after the game session;
- Future tests to assess the impact of the gaming experience on the learning outcomes by comparing different player teams;
- Future works using other assessment methods, including summative and teacher assessments, involving more students;
- The game can be improved based on the evaluations and feedbacks from the study participants.

Finally, this experience could raise questions for teachers on how to identify, balance, and prioritize the desired learning outcomes on sustainability education through games. These aspects should be discussed across programs and departments to understand how game-based learning tools could be shared and at the same time differentiated. For instance, while playing the game can be an occasion for collaborative learning, its aim could also be adapted (e.g., setting different goals). This opens to possible collaborative game re-design sessions involving teachers and students. A common effort would also help to maximize the tools' effectiveness and prevent negative outcomes.

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