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ScienceDirect

Procedia CIRP 69 (2018) 621 – 626

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

Teaching sustainability leadership in manufacturing: a reflection on the educational benefits of the board game Factory Heroes

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Abstract

Sustainability is a complex and interdisciplinary topic which can be challenging to teach. We need to adopt a student-centred and participative approach to invite learners to reflect on societal challenges and their role as individuals to tackle them. Therefore, we need appropriate educational tools to encourage creativity, an open mind and broad thinking to raise awareness and teach about sustainability. Gamification and serious games have recently emerged as promising tools to engage students by immersing them in various complex situations and giving them an opportunity to play an active role in decision-making. Gamification lends itself particularly well to sustainability education as it provides a safe and fun environment for students to experiment, to take complex decisions and to reflect on the impact of their actions. It can deliver the necessary skills to address today's global challenges: envisioning, critical thinking and reflection, systemic thinking, collaboration and decision-making in uncertain conditions. This paper introduces a board game, *Factory Heroes*, and discusses its potential in raising awareness and fostering the skills and knowledge for sustainability leadership in manufacturing. Early findings from 8 pilot sessions are presented along with some of the benefits and pitfalls of gamification.

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference

Keywords: Sustainability leadership; Eco-efficiency; Resource efficiency; Manufacturing; Gamification.

1. Introduction

1.1. Sustainability in education

Environmental education started to be recognised as an important topic from the early 90s [1]. However, topics such as Education for Sustainable Development and Global Citizenship Education gained momentum only in the past decade or so [2]. They adopt a practical and learner-centred approach [3-4] to develop student's moral sense of responsibility to humanity [5] from a future-oriented and global perspective [6]. This new learning culture follows a much more open-minded and participative process in which students are invited to reflect on the complexity of societal challenges [6]. It is a clear departure from the traditional role of academia in which competences are developed in formal learning settings.

1.2. Paradox thinking

Sustainability is a complex and paradoxical topic due to the interdisciplinary and ambiguous nature of the concepts it encompasses [7]. For students to learn about and respond to this challenge, they need to be equipped with the right knowledge and to critically analyse today's society and industrial systems which involve multiple stakeholders. This imply a need for an open mind and broad thinking in decision-making. Several scholars [8] emphasise that managing decision-making in such multi-stakeholder processes requires paradox thinking. Instead of a single "best solution", decision-makers are left with the paradox of enacting conflicting strategies simultaneously. In contrast to trade-offs and compromises, a paradox perspective recognises that conflicts cannot always be solved and offers an alternative approach [9].

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference
doi:10.1016/j.procir.2017.11.130

1.3. Gamification

Serious games have emerged as a promising educational tool to engage students by immersing them in various complex situations and giving them an opportunity to play an active role in decision-making [8,10]. Gamification lends itself particularly well to sustainability education as it provides a safe and fun environment for students to experiment, to take complex decisions and to reflect on the impact of their actions. It can deliver the necessary skills to address today's global challenges [11].

1.4. Scope and objectives

Sustainability as a topic spans across multiple disciplines and perspectives [12]. Thus it is crucial to exploit diverse teaching methods to improve the learners' experience and to provide them with the knowledge and skills required to meet new industry needs in the face of growing sustainability challenges. These skills include envisioning, systemic and critical thinking, reflection, innovation, creativity, collaboration, dialogue, negotiation and decision-making in uncertain conditions [11,13].

While resource efficiency and industrial sustainability are best taught in an industrial environment (e.g., company-based projects or robot lab) [14], this is not always possible due to lack of time or access to facilities. Traditional teaching methods in classroom environments are limited in their ability to stimulate and engage students with the topic of sustainability [15], thus new, more interactive methods are being developed [4,16].

In this paper, a board game is proposed as an educational tool to address the need for more experiential and participatory methods in the classroom to teach sustainability in science and engineering programmes. It focuses on the specific challenges in implementing sustainability principles in manufacturing. It provides a stimulating learning environment for students to take on an active role in implementing sustainability in a manufacturing and experience some of the challenges in doing so.

The board game is part of a wider toolkit developed to engage students (in higher education) and trainees (in professional courses) in learning about eco-efficiency and sustainable manufacturing [17]. The toolkit aims to simplify and gamify various sustainability concepts and activities. It encourages learners to adopt a positive and innovative mindset to see sustainability as a creative constraint and an opportunity [18], rather than an oppressing and limiting factor.

This paper reports on the game development process and initial findings from a series of pilot sessions conducted with companies, students and researchers to gain feedback on and improve the game design. The intended learning outcomes were partially tested and further work is suggested to validate the overall effectiveness of the board game as an educational tool.

2. Methods

2.1. Game development

The board game presented in this paper is called *Factory Heroes*. It is part of the eco-efficiency toolkit developed in a previous research project [17], and integrates the five activities recommended to implement eco-efficiency in manufacturing: (1) see waste and inefficiency with examples of bad practices; (2) find solutions; (3) set targets and (4) assess current performance; (5) systematise and create good habits.

Factory Heroes was developed as a non-commercial educational tool to actively engage learners with the topic of eco-efficiency in manufacturing. It is a follow-up activity after the successful reception of a simpler card game which focused on good practices for energy efficiency in manufacturing operations [19]. Given the positive response and overall recommendations to increase the game complexity, a more advanced version was developed as a collaborative, strategic board game.

The game is a stand-alone educational tool and does not require prior knowledge or expertise to be used; although prior knowledge on manufacturing and/or sustainability makes the content easier to assimilate and allows learners to go deeper in their reflection. For instance, its intended use with engineering students would focus on the practices, while management students would focus on strategic planning. The game can also be used with a lay audience to raise awareness on sustainable production in a fun and engaging manner.

The rules are largely based on an existing cooperative board game, *Pandemic*, developed by Matt Leacock [20]. This popular board game provides adapted mechanics to capture the complexity and randomness of real-world phenomena with relatively simple rules. This was a decisive aspect as players should be able to learn how to play quickly so they can focus on the educational content. Besides keeping the rules as simple as possible, it is critical to provide sufficient context to make the learning experience as effortless, intuitive and fun as possible.

2.2. Testing and validation

A total of 29 persons participated in eight pilot sessions to consolidate the game design, and to articulate and partially test the intended learning outcomes. The first session was done in a workshop with companies from the STIM consortium [21]. The following five sessions were conducted with students and researchers at the University of Cambridge, and the last two with students and researchers at Chalmers University of Technology.

The sessions started with a short lecture on eco-efficiency and industrial sustainability (5 to 10 minutes). Some sessions did not include this introduction as participants were already knowledgeable on the topic. Then the rules were shortly explained (10 to 15 minutes) with a strong emphasis on the relevance of the game mechanics in a real-world context. This is to encourage players to reflect on their actions (subsection 3.6) and the examples of good/bad practices (subsection 3.4) during the game to provide a meaningful learning experience.

The level of difficulty was adjusted between sessions to find an appropriate balance between the difficulty level and the chances of success. Participants found the game setup too easy in the first 3 sessions, and thus it was modified in subsequent pilot sessions. In addition, some rules were softened as they put too much stress on the players and caused some teams to lose too quickly (or almost lose despite having a robust strategy).

At the end of each session, the experience was discussed to check whether participants understood the aim of the game and the learning objectives, whether they felt like they actually learnt about eco-efficiency as a concept and a set of practices, and whether they had fun and would be keen to play again. Participants also filled in a short survey to capture their recommendations on to improve the game design, the purpose and context introduction, and the facilitation process during the game.

3. Game Design

3.1. Intended learning outcomes

The intended learning outcomes of the game were formulated and improved based on feedback from the pilot sessions. They are focused on three practical aspects of sustainability leadership in manufacturing:

- Describe examples of eco-efficiency practices;
- Recognise some of the challenges in implementing eco-efficiency (improving and maintaining performance);
- Appreciate the need for cross-functional collaboration (teamwork) to implement eco-efficiency.

3.2. Context and scenario

Factory Heroes is a cooperative board game in which players are taking on the role of highly skilled members of a manufacturing company. The company has been very successful over the past century and the production has increased over time, along with the negative environmental and social impact of its activities. However, the clock is ticking as the poor sustainability performance has put the company in the spotlight. Authorities have issued their last warning: they will shut the factory down if the company has not complied with the latest environmental, health and safety regulations by the end of the year. The company is now fighting against its own inefficiency and pollution to meet minimum legal requirements, improve their brand image and remain competitive on the market.

The players must work together to develop knowledge and good practices to improve the sustainability performance of the factory. They must identify sources of waste and pollution, and implement quick fixes. But they must also learn from each other to develop systematic and long-term solutions for eco-efficiency. Each player is one of the factory heroes: he or she is given a unique role with a special ability called "superpower". The players must collaborate and combine their individual abilities to eliminate bad practices and to achieve sustainability leadership.

3.3. Aim of the game (end game conditions)

Factory Heroes is a purely collaborative game: there is no competition between players. There is only one winning condition: the team wins when all four management **systems** for sustainability leadership are in place. The four systems are:
Performance analysis and communication (**information**);
Environmental awareness and training (**people**);
Efficient use of process technology (**technology**);
And physical resource management (**resource**).

Although the four systems are distinct categories in the game, there is a strong overlap in the technical and managerial practices associated with each system. For instance, practices around the topics of education and training cover both ***people*** and ***information*** themes, and measuring energy use covers both ***information*** and ***resource***. This overlap aims to capture the multidisciplinary nature of sustainability leadership through the strong relationship between these four themes.

The team loses if any of the following conditions is met:

1. Running out of solution cards as the deck represent one year (the team runs out of time to comply with regulations);
2. Running out of problem tokens of one type on the side board (the team has cumulated too many problems of this type);
3. The incident counter on the side board reaches the maximum value (at the 7th incident, authorities shut down the factory immediately as it is too unsafe to operate); or
4. The Key Performance Indicators (or KPIs) reach the lowest value on the side board (the company is clearly not putting enough effort to improve).

3.4. Game components

The game includes two boards, two decks of cards, 12 roles, 6 pawns, and 64 tokens. The **main board** is composed of 16 locations representing a typical manufacturing site: assembly, break room, car park, finishing, forecourt, IT, logistics, machining, office, packaging, quality control, restaurant, showroom, utility area, warehouse and waste station. All locations are connected in such a way as to ensure that all areas of the main board can be accessed within five moves.

The team's performance is measured using a series of indicators on the **side board**. It is composed of three sections to keep track progress and failures (see section 3.3 for end game conditions). At the top, the four management systems (people, information, technology and resource) are represented by colourful symbols and act as placeholders for problem tokens. In the middle, a second indicator represents the number of incidents that occurred this year. Finally, the indicator at the bottom represents the current performance level. It is a simplified representation of the production KPIs and represents the number of problems each player gets on their turn. The performance indicator is updated when a player picks up an **audit** card. The better the performance, the fewer problems will occur. Conversely, players will get more problems when performance goes down.

The most important components of the game are the cards providing examples of technical and managerial practices for eco-efficiency and sustainability leadership in manufacturing:

Solution cards, examples of good practices (and the deck represents time limit of one year), events and audits;

Problem cards, examples of bad practices which are also represented by colourful tokens on the board (when a location gets three problem tokens, an incident occurs).

For both solutions and problems, there are four types of cards matching the four systems the team must develop: information, technology, people, and resources. In addition, there are special solution cards for internal and external **audits** (to update the KPIs), and **events** (temporary advantage).

Each card is structured as follows: at the top, the type of **system** associated with the practice; then the **location** associated with the practice; in the middle, the good or bad **practice** itself (this must be read out loud during the game); at the bottom, the **subtext** to give an example of what people may say to reflect this good or bad practice (it is optional to read the subtext, instead players are encouraged to make up their own story).

3.5. Players' role

There are 12 role cards describing the "factory heroes" which can be played with, and 6 colourful pawns to represent them on the main board:

- The factory director has authority and enables employees to do their best (moves other players with their consent);
- The production engineer has ingenuity and thinks outside the box (draws solution cards earlier than other players);
- The health and safety officer does prevention (gets fewer problems than other players);
- The chief sustainability officer has expert knowledge on sustainability (needs fewer cards to develop a system).
- The building technician has access the company archive (picks up discarded solution cards);
- The shopfloor worker is good at learning (easily takes solution cards from other players);
- The academic collaborator disseminates ideas (easily gives solution cards to other players);
- The assembly line manager does planning and control (can reorder the top 4 solution cards);
- The IT officer has data access to see where problems may occur (can reorder the top 6 problem cards);
- The site maintenance function does maintenance and housekeeping (remotely removes problems).
- The catering supervisor is good at dialogue and listening (can hold an unlimited number of solution cards).
- The company mascot has a proactive behaviour (takes one additional action compared to other players).

The six roles available for a basic game are: factory director, chief sustainability officer, production engineer, health and safety officer, shopfloor worker and building technician. The academic collaborator, assembly line manager and IT officer are more advanced roles and thus only used when the facilitator can continuously supervise the game (sessions with only one team). In addition, the assembly line manager and IT officer are only available for game with three players or more.

3.6. Players' turn sequence and actions

On their turn, players can take up to 5 actions and then draw 2 solution cards. If players have more than 6 solution cards (hand limit), they must discard excess cards. Finally, they must draw the number of problem cards as indicated by the performance indicator and place problem tokens on the main board accordingly (the lower the performance, the more problems they pick up). When a third token is placed in a given location, an incident occurs. If no player is present to deal with this incident, an overflow occurs: problem tokens are placed in each connected location. This can trigger a chain reaction if there are many connected locations with 2 or 3 problem tokens.

On their turn, players have the following options as actions:

Factory walkthrough. Move to a connected location.

Emergency intervention. Discard a solution card to move directly to the location indicated on the card.

Quick fix. Remove 1 problem token in their current location.

Big fix. Discard a solution card to remove all problem tokens of the matching type in their current location.

Knowledge exchange. Give a solution card to another player OR take a solution card from another player. Both players must be in the location mentioned on the card exchanged.

New system development. If a player has 4 solution cards of the same type and is in his/her starting location with at least half of the players, then he/she must read out loud and discard these 4 cards to develop the matching system. From now on, the players can ignore the problem cards of this type as they now have a systematic approach to solve such problems. But the problem tokens still on the board remain there until they are dealt with (this will not cost an action anymore).

3.7. Winning strategies

The game is an action economy. Actions represent the valuable time available for individuals to get the work done each week or month. The game is designed to slowly push the team towards losing (through accumulation of problems spreading in various areas the company). The team must use the following strategies to change the balance towards winning:

- Combine their superpowers (teamwork) to save actions—not just considering their own turn, but planning the course of actions in a holistic and strategic manner for all players;
- Identify critical areas before problems spiral out of control—an element of luck is involved here as cards are shuffled randomly, so the hotspots are not fixed but they become predictable as the game progresses;
- Develop the systems as a team while solving problems on the way ("think global, act local")— purely focusing on developing systems will lead to daily problems spiralling out of control;
- Develop at least one system mid-game or earlier—as soon as a system is in place, fewer problems will occur and thus a virtuous cycle can start with an increased focus on collaboration and long-term strategy;
- And (optionally) use one-time events in an effective and timely manner— they are temporary advantages enabling radical improvements if combined with the right actions.

4. Results from the pilot sessions

A total of 29 persons participated in the pilot sessions. The post-game discussions covered the following questions:

- Was the aim of the game clear?
- Was it easy to learn the rules?
- Did you learn about concepts for industrial sustainability?
- Did you learn about eco-efficiency as a set of practices?
- Did the game raise your interest/awareness on these topics?

Most players fully understood the aim of the game. Only four had a mixed response due to unclear links between the aim of the game and specific learning objectives. This was addressed by reformulating the intended learning outcomes and improving the game introduction lecture.

Although the game is initially perceived as complex, some participants were able to play autonomously from the beginning. This was particularly the case for people with prior gaming experience. But it usually took one or two rounds for the majority of players to fully understand and get used to the playing sequence and more advanced types of actions. In one of the pilot sessions, a player was unable to play autonomously and required assistance by the facilitator or another player for the whole game, but this participant still reported some positive learning outcomes. Thus it is critical that at least half of the players learn the rules quickly so they can help others overcome

this difficulty and focus on the learning content for the remainder of the game.

The learning outcomes on both concepts and practices were reported as partly or fully achieved for all but one participant. It must be noted that most participants were PhD students and researchers with expertise in or close to the area of industrial sustainability, thus the questions about learning and awareness were of limited relevance and further testing with non-experts is required to validate the intended learning outcomes.

The response for "learning about practices" was lower than "learning about concepts". Many participants commented on the design of the cards used for the prototype versions tested in the first 6 sessions at the University of Cambridge. The text on the cards was often criticised: some practices were considered too technical, too long, or in a font too small. This was considered as the main barrier for the practices to be read systematically. This weakness was remedied for the final version of the game used in the last two pilot sessions at Chalmers. The facilitator occasionally needed to remind players to read the cards out loud as this rule is still easily forgotten; ignoring the text on the cards means practices are overlooked and thus not learnt, but it does not affect the ability to play. However, there were no more comment on the cards in those last two sessions.

One participant was particularly negative about the game itself. A more in-depth discussion revealed possible causes: a strong scepticism about the ability to learn from such a game (not serious enough) and mismatching expectations about what the "game" was (did not expect an actual game). A second negative response for "Interest and awareness" was due to a stronger motivation to play than to learn (the participant asked to play again but without reading the cards).

The comments about the overall learning experience were mainly focused on suggestions to allocate more time for the introduction of the eco-efficiency concept and the game. This issue was anticipated as the time available for the pilot sessions was constrained to 90 minutes (often overrunning to 120 minutes or longer). The game will be introduced in a lecture providing a more in-depth explanation of the context to better scope the exercise and clarify the links with the learning objectives.

A trend was also observed for teams who lost the game. The comments were initially purely on the gameplay (what the players should have done differently or on how the game should be changed in order to make the team win). It was difficult to steer the participants towards a more constructive discussion about what they learnt and the meaning of what happened in a real-world context. They focused strongly on small mistakes made or details of the rules that caused them to lose. This highlights that the frustration of losing the game can also be in the way of the learning experience.

Finally, some participants suggested that more time is needed to "absorb" and "make sense" of the experience when the level of excitement was lower, for instance the next day. This highlights the importance of reflection to capitalise on the learning outcomes.

5. Discussion

5.1. The learning experience

Implementing sustainability requires a broad sets skills and capabilities as it encompasses multiple disciplines. Factory Heroes attempts to foster the development of those skills using various game mechanics, such as role playing and an immersive learning environment. Players are placed in a challenging situation and asked to work as a team towards a common goal. They also get a specific role with a "superpower", encouraging them to consider their own strengths in combination with other players' before taking actions. Thus it teaches them about teamwork/collaboration, gain a deeper understanding of others' perspective, dialogue and negotiation.

One of the most difficult actions in the game is "knowledge exchange": players must meet in the specific location associated with the card they want to give or take. This indicates that knowledge is not easy to transfer and that it requires time commitment from both the teacher and the learner to be successful.

Players are also limited in the number of actions they can take on their turn: the 5 actions represent the 5 days we have every week to get our work done. It teaches that time is a valuable resource and thus prioritisation is a key skill to make the most of the time (actions) available. In this manner, movement is also quickly recognised as the weakest type of action, thus a waste, as well as action not taken. While staying still (wasting actions) or moving around the site, players do not add value. This captures the idea of waste in motion and waiting (two of the seven *mudas* of lean manufacturing). The factory director has the ability to move other players so they can be where they will be the most impactful on their turn. This highlights the role of good leadership in enabling people to do their best.

Challenges in implementing eco-efficiency and sustainability in manufacturing are captured with typical examples of good and bad practices (solution and problem cards). They are categorised into four "systems" to cover both technical and managerial practices (winning conditions). As long as the team has not developed a system of a certain type, they keep having the same problems coming back, illustrating that they need to get to the root cause of an issue to truly solve it.

In the game, solving a problem in the short-term is relatively easy (quick fix in one action). But developing a system takes more actions and commitment from many players, thus requires a longer-term strategy. However, sticking to the long-term strategy while neglecting mounting daily problems will result in catastrophic consequences. This teaches the players the importance of strategically planning for long-term success while remaining flexible in daily operations. The randomness of the problems also forces players to take decisions under uncertain conditions. They must envision scenarios in order to inform their decisions and actions.

In the post-game discussions, players also are asked to consider the gaming experience in relation to their knowledge about industrial sustainability. This provides opportunities for players to reflect on their personal role, behaviour, responsibilities and individual actions to contribute towards the sustainability goals of the team.

5.2. Limitations of the game

A major limitation of games and other simulation-based activities is in their oversimplification of the real world. Most notably in Factory Heroes, the definition of sustainability leadership is simplified into four management systems. This is partially remedied through the post-game review, discussions and reflections. But it remains an issue as some participants may still limit themselves to those four themes when reflecting on what sustainability leadership is in manufacturing.

Another limitation is the observed difference in the quality of reflections between winning and losing teams. Losing the game creates a sense of frustration which can prevent the participants' reflection to go beyond the game mechanics or what they would like to change. In the worst case scenario, it may turn into a blame game which spoils the experience for all involved which would further reduce the chances to generate constructive reflections towards the intended learning outcomes.

Although the overall response to the game was highly positive, the results also revealed that prejudice against games (e.g., too childish), struggling to learn the rules (still unable to play unaided by the end of the session) or mismatching expectations (e.g., expecting a different exercise) can prevented the participants to fully engage with the game and achieve all the intended learning outcomes.

Finally, too high excitement levels can also be a barrier to learning as players get carried away by the game. Supervision and facilitation is often required to ensure that the participants pay attention to the learning content and reflect on the meaning of their actions in relation to real-world sustainability challenges in manufacturing.

6. Conclusions

Factory Heroes aims to develop the learners' skills for collaboration, dialogue, strategic thinking, envisioning scenarios, decision-making in uncertain conditions, and reflection on the impact of one's actions. It encourages players to carefully plan their course of action based on individual strengths and weaknesses, and to enact conflicting strategies to ensure both the short-term survival and long-term sustainability of a company. Despite some shortcomings, the overall learning experience are highly positive and the biggest barriers to learning were recognised and potential ways to remedy them were identified.

Further work includes full deployment of the game to teach engineering students of the Production Engineering masters' programme at Chalmers (and potentially other courses). The learning outcomes will be evaluated using a questionnaire at the end of the game session. In addition, students will write a reflective account of their experience based on a few guiding questions to steer them towards a constructive reflection.

Acknowledgements

The author would like to thank all participants of the pilot sessions at the Institute for Manufacturing (University of Cambridge) and Industrial and Materials Science department (Chalmers University of Technology): Martin, Jingchen, Ettore, Yan, Dominik, George, Bang, Sudhir, Kirsten, Ola, Serena, Nitish, Anthony, Karen, Simon, Miriam, Nick, Angus, Lloyd, Steve, Dee Dee, Davor, Chris, Sarah, Dan, Mats, Daniel, Sandra, Mukund, Mahesh, Cecilia, Jonatan, Maria and Ilaria. The author wishes to express her gratitude to Ghita Lauritzen for the enlightening discussions on paradox thinking, and Dr Rob Phaal and the STIM consortium 2016 for the feedback on early prototypes and the funding for producing the final version.

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