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GAMES AND SIMULATIONS IN INDUSTRIAL ENGINEERING EDUCATION: A REVIEW OF THE COGNITIVE AND AFFECTIVE LEARNING OUTCOMES

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ABSTRACT

Gamification and experiential learning are increasingly used in education as they create an immersive environment to stimulate students and promote deeper learning. In industrial engineering education, computer simulations and digital games are commonly used to teach technical skills in supply chain management and production planning. Used alongside other teaching methods, they allow students to apply theories learnt and reflect on the impact of their decisions. Other "hands-on" games can also foster the development of professional skills such as leadership, teamwork and communication. Focusing on serious games and game-based learning in industrial engineering, this paper reviews examples to discuss games' benefits and drawbacks as educational tools. Finally, the author suggests ways for game developer to consider how game aspects align with learning outcomes in the cognitive and affective domains.

1 INTRODUCTION

Engineering education traditionally focused on technical skills and knowledge. However, modern curricula go beyond core engineering topics to deliver up-to-date knowledge in a fast-changing world as well as broader professional skills (Buyurgan and Kiassat 2017). According to the Institute of Industrial & Systems Engineers (IISE) definition, industrial and systems engineering aims to design, analyze, improve and install systems integrating people, materials, information, equipment and energy. It brings together the fields of mathematical, physical, and social sciences to specify, predict, and evaluate the systems' performance (IISE 2018). In addition, the international CDIO Initiative (which stand for Conceive – Design – Implement – Operate) stresses that the engineering curriculum should be rich with design-build-test projects, integrate professional skills such as teamwork and communication, feature active and experiential learning, and constantly improve (CDIO 2018). With these definitions in the background, it is clear that production engineering education is faced with the challenging task to equip the new generation of engineers with skills and knowledge going beyond the traditional focus on technical subjects.

New technology developments in industry (such as automation and digitalization) and societal challenges (such as climate change, urbanization, and population growth) have obvious implications on educational programs' content. This is particularly the case in science, technology, engineering and management (STEM) education which must keep the pace to ensure that the next generation of engineers can meet future industry needs. The fourth industrial revolution presents new challenges such as skill obsolescence and skill deficit. In Europe, unemployment rates are increasing while 4 in 10 companies have difficulties in recruiting due to a rising skill mismatch (Cedefop 2018). But technological advances in information and communication technology are also transforming education in a positive manner. Most notably, computers and mobile devices have increased accessibility to course material outside the traditional classroom (Bustos Andreu and Nussbaum 2009) as well as increased student autonomy in their own learning—which is particularly the case with massive open online courses (Jordan 2014). Thus it gives the student the opportunity to be more active and engaged. Many universities use an online learning management system to facilitate course preparation and delivery (Romero et al. 2008). Such a system provides a platform for tailoring teaching and learning activities to meet individual student's needs. While creating possibilities to work at anytime, anywhere, new technology enables communication and collaboration remotely thereby bringing students and teachers closer together.

Teaching facilities and course design are also evolving. Classrooms in the developed world are often equipped with audiovisual systems (such as screens, projectors and speakers) and, in rarer cases, interactive technologies (such as touchscreens) (Hughes 2013). Most universities also have computer labs, design studios, workshops, robot labs and other such high-tech facilities to offer a more applied learning experience (such as problem-based learning or industry projects). In addition to these technology-driven changes, research in higher education and psychology provides educators with new frameworks to adapt teaching activity and instruction methods to deliver intended learning outcomes more efficiently.

In line with the CDIO Initiative guidelines (CDIO 2018), this study explores alternative teaching methods, such as active and experiential learning to deliver the technical and professional skills needed by the current and future generations of engineers. The next subsections present some of fundamental ideas used in this study and provides the theoretical foundations for using gamification in engineering education.

1.1 Theory of Learning

This study adopts a constructivist approach and makes use of active and experiential learning theories. Active learning is based on constructivism whereby knowledge is built by developing meaning through social interaction and language (Piaget 1972; Biggs 1996). The students are therefore active in the learning process and the teacher facilitates this process. Accordingly, the purpose of teaching is to develop deeper levels of understanding or expand it to new areas by building on learner's prior knowledge (Biggs 1999). Active learning is often contrasted to traditional instruction methods such as lecturing whereby knowledge is transferred from the teacher to the learners (Prince 2004). Active learning has proven to be a superior teaching practice across a broad range of STEM disciplines, assessment types and class sizes (Freeman et al. 2004). However, active learning also has additional requirements for the teaching activities to be truly effective: meaningful context should be provided so the learner sees the purpose of what is being learnt and connects it to the real world (Prince 2004).

Another important theory for this study is experiential learning (Kolb 1976). It advocates that learning must be experienced concretely and actively as well as abstractly and reflectively in order to be internalized. In other words, the experience with no personal reflection on outcomes does not enhance learning (Kiili 2016). While active learning and experiential learning share many commonalities, a notable difference is the responsibility allocation for the learning: in active learning, students are responsible for their own learning; but in experiential learning, more emphasis is given to the teacher's role to provide support in the directions and experiences to the learners (Garris et al. 2002). This is done by directing the learning not just through visual and verbal information, but also kinesthetically.

Finally, the assumption that students are partly or fully responsible for the learning process does not exclude that teachers are responsible for providing the right environment and guidance to ensure that learners achieve the intended learning outcomes. By making learners active and responsible for their own learning, both active and experiential learning also follow a developmental process (Piaget 1972) whereby the teaching activities should be designed to match the learners' current development level. The appropriate level of complexity or difficulty must be carefully considered based on students' prior knowledge and skills.

1.2 Gamification in Education

While gamification as a topic of research has gained significant interest from educators and researchers in the past decade or so (Connolly et al. 2012; Dichev and Dicheva 2017), games and simulations have been used in education long before (Showers 1977; Smith and Pollard 1986; Crookall 1990) and the trend is accelerating (Deshpande and Huang 2011). This new surge in education research allowed the concept of gamification to develop and gain popularity. Two broadly accepted definitions of gamification are "the use of game elements in non-game contexts" (Deterding et al. 2011) and "the process of making activities more game-like" (Werbach 2014). It is important to note that these definitions also allow for subjectivity: one person may perceive a learning activity to be "game-like" while another may not. Deterding et al. (2011) also proposed two dimensions to contrast playing and gaming, and gamification through parts and whole, and placing their definition of gamification in the quadrant of "gaming" and "parts". Deterding et al. (2011) and Werbach (2014) both address what can be called "superficial" gamification, but also include some game mechanics in line with "deeper" gamification aspects as discussed below.

In this paper, gamification is considered as a broad umbrella concept encompassing superficial gamification, deeper gamification and game-based learning, with a special focus on the use of gaming for educational purpose. It is important to note that, while it is useful to differentiate between these three levels of gamification, the threshold between levels is not clear-cut.

Superficial gamification. The first level of gamification includes simple game elements—e.g. avatars, points, badges and leaderboards—in order to increase students' interest and motivation in engaging with the course content (Holmes and Gee 2016). An extensive review and critic of educational benefits of this type of gamification was conducted by Dichev and Dicheva (2017). The game elements are usually in a digital form and implemented via the learning management system. It focuses on gamifying aspects of the user interface to create more playful interactions, sometimes creating competition between students by making performance visible using leaderboards and rewards. The students' interaction with the learning content will generate changes in the game elements through well-defined game mechanics, e.g. completing a task to earn more points and increase the student's total score, resulting in rewards, badges or level-ups. In some rare cases, some game elements are non-digital, e.g. medals, chocolates and other physical rewards. However, the learning content itself remains largely ungamified and is not directly affected by the game mechanics. While there is no consensus on the real benefits of superficial gamification, it has proven useful to motivate and engage students (Holmes and Gee 2016; Sailer et al. 2017). In a study by Landers and Landers (2015), the use of a leaderboard to track and display performance level relative to all other students resulted in increased time spent on project work, and thus in better student performance.

Deeper gamification. The second level involves similar game elements but also more complex game mechanics and dynamics embedded in the learning activities. This time, the gamified content is used as a tool to facilitate the learning process. However, the game aspects in both superficial and deeper gamification may not be explicit, i.e. the activities are not presented as games or do not necessarily feel like a game. The aim of deeper gamification is to give more autonomy to the students with their own learning. It can motivate them to deepen their approach to learning by encouraging curiosity—e.g. discussions, narratives, experiments, trial-and-error—and by providing direct input to improve performance—e.g. visualization, quizzes, direct feedback. This type of gamification can be implemented both digital and non-digital forms.

Game-based learning. Finally, the third level is the full implementation of a game or simulation, also called "serious game", towards predetermined learning outcomes. It encompasses all the game elements, mechanics and dynamics of the previous two levels as well as other explicit game aspects—e.g. role-play, scenarios, cards and board games. The learning activity is often presented as a game to the learners and playful behavior is encouraged. The aim is to create an immersive environment for the students to fully engage in the learning activity, also known as a flow experience (Kiili 2005). Such games and simulations create a safe environment for students to explore their own behavior and experiment with new ideas. When carefully designed, such games can provide a meaningful personal and emotional experience with the topic. Importantly, post-game reflection is required to translate this experience into learning outcomes.

From a learner's perspective, the following benefits can be realized for each gamification level:

- *Superficial gamification* focuses on game elements and mechanics to enhance student engagement: it makes the learning activity more attractive and enjoyable, thereby increasing time spent with the course material and resulting in higher grades;

- *Deeper gamification* focuses on game dynamics and students' behavior to increase motivation to go further: it encourages curiosity and intensifies the learner's efforts to explore the topic proactively, thereby generating deeper learning;
- *Game-based learning* for student's long-term performance: achieve flow experience followed by reflection and abstract conceptualization, resulting in personal/emotional connection with the topic and knowledge retention in the long-term.

Superficial gamification has been researched and reviewed in more depth than the other two levels (e.g. Dichev and Dicheva 2017). This paper attempts to address this deficiency in the literature by reviewing games and simulations for game-based learning in industrial engineering.

2 EDUCATIONAL GAMES IN INDUSTRIAL ENGINEERING

2.1 Examples

Focusing on the third level of gamification introduced earlier (game-based learning), this subsection provides examples of games and simulations used in industrial engineering education. The examples cover a broad range of methods—digital, tabletop and mixed media. They are presented in chronological order to illustrate different ways serious games and game-based learning have been implemented and their evolution over the years. The games are shortly described and references to publications dedicated to each game is provided if the reader wishes to get more detailed information.

One of the earliest and most popular serious game to teach about supply chain management is the MIT Beer Game (Croson et al. 2014). It was originally developed in the 1950s as a tabletop game and was later digitalized to ease facilitation and enable more time-efficient delivery. As teams of students engage in a participative simulation model of a beer distribution system, they experience the bullwhip effect. The game has been criticized for its unrealistic representation of demand-supply dynamics. Thus, various "upgrades" were proposed to remedy some of the game deficiencies (e.g. Holweg and Bicheno 2002). However the original Beer Game remains a solid platform to teach dynamic decision-making in supply chains.

Besides the Beer Game, computer simulations and digital games have long been used to teach technical skills in logistics, production planning and process control. For instance, as early as 1977, Showers presented a discrete-event simulation of material flows to teach and illustrate inventory management concepts: the learner takes a series of decisions to control the flow of products through the system and gets feedback on the financial impact of their decisions (Showers 1977). A few years later, Cullingford et al. (1979) reported their experience using computer simulations to cover similar topics in civil engineering (planning and control of construction projects, and transport planning). Such computer-based simulations provide an ideal platform for students to experiment with various parameters controlling material and financial flows, and learn about the impact of their decision on performance.

More recent games have picked up these technical topic and further developed simulation models based on more mature understandings of performance drivers in logistics and production flows. A good example was reported by Lambrecht et al. (2012) with a dice game as a computer-based learning exercise focusing on production flow and line balancing. The game simulates workstations in a production line characterized by a wide range of variation coefficients. Students learn about the impact of variability and dependency on production inventory, throughput and work-in-process, and wider supply chain implications.

Going back to early computer simulations, Wu (1980) introduced a pioneering tool to teach energy awareness by demonstrating how oil reserves could be depleted by the year 2099 if no conservation measures are taken. The simulation used computer graphics to raise awareness on the limits of global energy resources as well as stimulate interest in the field of energy efficiency and conservation. Despite rudimentary simulation due to limited computing power, positive acclaim from the students was reported along with better understanding of energy trends (Wu 1980).

The Fishbanks simulation is another notable game commonly used to teach resource management in the early development of sustainability as a topic in scientific education (Meadows et al. 1993; Crookall

1990). Fishbanks was initially developed as a tabletop game (and it is still frequently used in this format), but is also available web-based. It is a multi-player simulation played in teams competing for natural resources. Each team represent a fishing company and must maximize their profit by buying, selling, and exploiting ships. As the simulation progresses, the fish stock gradually decreases until fully depleted if the teams do not take the necessary measures to preserve fish stocks. Fishbanks thereby demonstrated that the rate of exploitation cannot exceed the regeneration rate of a given natural resource, and highlights the importance of sustainable resource management.

With progress in computing technology and the democratization of the computer, more advanced simulations were developed and their use in education also increased. As computer games and simulations gained more complexity, tutoring is increasingly needed. The effectiveness of these teaching methods heavily relies on the quality of instruction and facilitation. Angelides and Paul (1993) proposed Intelligent Tutoring Systems for gaming-simulation environment. Such systems provide instructions to ensure that the intended learning outcomes are achieved (Siemer and Angelides 1994).

Since the late 1990s, many more games, simulations and computer-based simulations emerged to tackle new topics such as real-time process control, environmental impact analysis and automation. Most notably, learning factories have been recognized as ideal teaching environments as they are identical or close to real-world industrial settings (Lamancusa et al. 1997; Lamancusa et al. 2008). For instance, Bruzzone et al. (2000) proposed a system integrating a simulation model and a statistical analysis module for production control. The system enables the training of both operators and managers through a portable and scalable system to analyze process performance in (near) real-time and in a distributed environment via internet connection (Bruzzone et al. 2000). Another example is OperEx-Power which used to teach business and operations management in a typical factory environment for the electronics industry (Haapasalo and Hyvönen 2001). A more recent example of learning factory is "Die Lernfabrik" which puts a strong emphasis on energy and resource efficiency, digitalization and sustainable production (Blume et al. 2015). However, not all universities have the financial resources to be equipped with such facilities as they require high-cost equipment and experts to be exploited effectively. Therefore, computer-based simulations remain a popular alternative about advanced production systems and industrial challenges. The simulations are becoming more accurate, detailed, and holistic, often integrating more mature concepts and robust models (Holweg and Bicheno 2002; Van der Zee et al. 2012).

Since the mid to late 2000s, an exponential growth of games and business simulations was also observed. For instance, the ‘CityCar’ simulation has been used to teach new product development to engineering and management students as well as for professional training (Cousens et al. 2009; Baxter et al. 2011). Participants compete against each other in teams of 5 to 7 to develop a fully functional self-parking car using Lego Mindstorm. The participants experience the challenges involved in managing cross-functional teams to carry out a series of activities: research the market, define a manufacturing strategy, design the product offering, implement the specified features and capabilities in a prototype product, present the prototype with a sales pitch, compete to win sales at a fictional motor show, and generate profits. Importantly, the teams conduct a post-simulation review to reflect, consolidate and share their learning (Baxter et al. 2011). This business simulation provides a complete learning experience by bringing together the technical and commercial aspects of a new product development project.

Going back to digital games, Perini et al. (2017) present the results of using the LCA Game developed since 2013. This computer-based simulation adopts a first-person perspective and takes place in factory making coffee machines. The player is a newly-hired sustainability manager who must perform an environmental impact analysis of the coffee machine produced by the company. To do so, the player needs to complete four tasks matching the four phases of a Life Cycle Assessment (LCA) as defined by ISO14044: goal and scope definition, inventory analysis (including data collection), impact assessment, and interpretation. The endgame goal is to identify improvements over the whole life cycle of the coffee machine and report these opportunities to the company CEO (Perini et al. 2017). The first-person perspective adopted in the LCA Game provides an immersive personal experience for the learner. New development in Virtual Reality (VR) have opened a whole new arena for training and education using virtual environments such as virtual learning factories (Weidig et al. 2014; Gong et al. 2017; Thiede et al. 2017). While VR equipment is still expensive, it is less so than physical learning factories.

On the opposite end of the digital spectrum, exponential growth in tabletop games for engineering education is also observed. Games focusing on global issues are becoming pervasive as gamification lends itself very well to such topics. An increasing number of tabletop games were developed to teach sustainability in production engineering. For instance, Despeisse and Lunt (2017) presented a competitive card game One thousand kWh in which players score points equal to the energy savings in fictional manufacturing sites. The game has simple mechanics largely luck-based with each card representing important aspects for operational efficiency: good manufacturing practices, barriers to improvement, remedies to these barriers, and systematic processes based on Lean thinking. Another tabletop game called In the Loop was developed by Whalen to teach about material criticality and circular economy (Whalen et al. 2017). Its game mechanics capture various drivers and consequences of changes, from political context, environmental concerns and ethics, to supply shortages, high market demand and price volatility. Finally, Despeisse (2018) developed the collaborative board game Factory Heroes focusing on four dimensions of sustainable manufacturing, namely, information, people, resources and technology. It aims to convey the delicate balance between dealing with immediate problems (short-term survival) and progressing towards strategic goals (long-term survival) in a manufacturing company (Despeisse 2018).

2.2 Some Common Game Aspects

Although it is may not be possible to generalize how games and simulations should be developed—as evidenced by the broad range of topics, teaching media and methods used in the examples reviewed—it is possible to identify some design patterns which meet specific learning objectives. This subsection discusses the benefits and drawbacks of the most common aspects of educational games.

The most common game dynamic used in production simulation and games is systems thinking: small deviations or seemingly unimportant decisions taken in a specific part of the game model will have a bigger impact elsewhere, e.g. supply-demand dynamics or life cycle assessment. Trial-and-error game mechanics in quantitative models and experiments (e.g. sensitivity analysis) can be used to learn about the impact of different parameters, conditions, actions or decisions. This represents a clear advantage for most digital games as they have high replayability (instant game setup) and repeatability (deterministic simulation model). In contrast, board games and business simulations usually require long preparation ahead of the game session and time-consuming procedures before and after each game, thus limiting or preventing game mechanics such as trial-and-error and optimization. Repeatability along with workload reduction for facilitator has been a major drivers for fully or partially digitizing tabletop games and business simulations, e.g. the Beer Game and Fishbanks.

The two most common game mechanics both in tabletop and simulation games are collaboration and competition. Many games combines these two game mechanics by allowing players to team up (collaboration) in order to achieve a better performance than the other teams (competition). While it is tempting to consider the learning benefits of competition and collaboration as comparable, they actually act on different levels. Competition has a strong motivational effect on most players as they want to win, thus resulting in higher cognitive learning outcomes. However, competitive behavior sometimes inhibits situational interest as the focus is on comparing one's performance to another player or team. Thus, collaborative mechanics better address affective learning outcomes and abstract concepts. The next subsection goes into more details on cognitive learning outcomes and affective learning process of games.

The most common game element is quantitative scoring. It is used to show performance and progress made in the game. The scoring systems can be directly linked to typical production Key Performance Indicators (aka KPIs), such as productivity, efficiency, time, product quality and profit. Digital scores in computer-based games are easier to keep track of, and sometimes automatically calculated and updated. On the one hand, digital games enable more complex, multi-dimensional scoring systems than scores which must be mentally or manually updated, e.g. counting points at the end of each round or tracking score with pen and paper. On the other hand, some game aspects are more difficult to capture in a digital format, such as information completeness and fulfilling winning conditions. Digital scoring systems are generally employed in games where visibility and responsive feedback are important to drive performance, e.g. closing the gap with target or the leading team. In collaborative games, the interaction between players is more important. Therefore, cooperation and teamwork game dynamics tend to be a stronger feature in tabletop games and business simulations than in digital games.

3 COGNITIVE AND AFFECTIVE LEARNING IN GAMES

The games reviewed in this paper aim to enhance the students' learning experience (affective level) and equip them with a more practical understanding of industry needs and challenges (cognitive level). This section describes various games aspects aligning with the cognitive and affective domains of learning.

3.1 Learning Outcomes in the Cognitive Domain

From a cognitive perspective, games and simulations challenge the learner's mental models and build new ones (Anderson et al. 2001). Therefore it is critical to consider how games enable the cognitive processing of information to generate learning outcomes. In other words, the game objectives should align with intended learning outcomes, and the game aspects (elements, mechanics and dynamics) should represent information sufficiently realistically to be meaningful and relevant to meet a given learning objective.

Games and simulations cannot be fully realistic as some simplifications are required to create usable game elements, articulate game mechanics (relationship between game elements) and promote the desired game dynamics (game environment and player's behavior). Thus, balancing the real-world complexity and the necessary simplicity of games and simulations requires careful judgement (and artistry) from the game designer. Game aspects reviewed in this paper are highly specific and do not transfer easily to other topics and contexts. While it is difficult to generalize how games should be developed, the revised Bloom's taxonomy can be used to guide game design by selecting game aspects in line with different levels of learning outcomes. Some of the examples reviewed in this paper attempted to capture complex societal and industrial challenges using simplified game aspects aligning with specific learning levels in the cognitive domain as shown in Table 1.

Table 1: Games in the cognitive learning domain.

Cognitive learning	Example of game elements, mechanics or dynamics
Remembering	CityCar: reading role sheets One thousand kWh: reading cards, repetition
Understanding	CityCar: role allocation, role-playing Factory Heroes: storytelling, role-playing, give examples LCA Game: narrative, role-playing, goal and scope definition
Applying	Beer game: forecasting, planning, trial-and-error CityCar: discussion, planning Factory Heroes: cooperation, prediction, planning Fishbanks: forecasting LCA Game: data collection, inventory analysis
Analyzing	CityCar: selection, prioritization Fishbanks: debate, prioritization LCA Game: impact assessment
Evaluating	CityCar: scenario planning, decision making Fishbanks: decision making LCA Game: interpretation of results
Creating	CityCar: building prototype according to specs, synthesis, presentation LCA Game: summary, report

3.2 Learning Outcomes in the Affective Domain

At an affective level, games and simulations challenge the learner's attitudes, values and beliefs (Krathwohl et al. 1964). Careful considerations for the affective learning domain is required when designing and implementing games as they engage the learner's feelings and emotions, more so than with traditional teaching methods such as lecturing.

The first level of learning in the affective domain is *receiving*: it corresponds to the learner's ability and willingness to receive information. For instance, accepting to engage with the game activity and understanding the rules of the game. In most simulations and games, this is done before the activity begins. But new rules can also be introduced later during the game, such as in CityCar and Factory Heroes where new information and events alter the state of the game. The second level is *responding* where the learner becomes active and is able to respond and act as expected. For instance, conforming with the newly learnt rules while playing the game. Obviously, this step is necessary in all games as the students are expected to comply with the rules; cheating usually hinders the learning process as the learners does not go through the intended thought process. The third level is *valuing* and affects the learner's beliefs and attitudes. For instance, making sense of these rules in a real-world context, thereby making the game mechanics and dynamics more intuitive to follow. For games played in iterative rounds, such as the Beer game and Factory Heroes, this is manifested by the students being able to play faster in later rounds as they have internalized the rules and gave them meaning in a real-world context. At the fourth level, *organization* refers to the ability to organize, prioritize and synthesize information. For instance, combining information to create new ideas or planning a course of actions to achieve a specific objective. The players (or teams) able to do so usually achieve better in-game performance. If the game is well-designed, this should translate into students' learning performance. However, winning (or losing or any other game outcomes) does not necessarily mean the players understood the point of the game. Therefore, post-game reflection is critical to achieve intended learning outcomes. Reflection is essential to enable the fifth and last level of affective learning: *characterization*. The learner reaching this highest level of internalization should be able to judge and act according to the acquired values in a generalized manner. This entails a change in belief and behavior to internalize the learning experience from the game and apply the newly learnt principles in the real-world.

The examples reviewed in this paper follow this internalization process (Table 2) whereby the learner's affect moves from general awareness to new beliefs and behaviors. This process—from receiving to responding and valuing, all the way to organization and characterization—adopts a developmental approach (Piaget 1972) as the learner must complete each level sequentially in order to move on to the next level. Therefore it is critical to consider the requirements of each individual level based on the learner's prior knowledge and abilities. For instance, if the rules of the game are too complicated or numerous, then the learner has difficulties in following the rules and thereby generating learning outcomes, i.e. the learner is stuck at this level (receiving). The need for simplicity in game aspects means that the game cannot fully capture the real world realistically and (over)simplification is required to take the learner through the initial steps. A solution proposed is to start with basic rules (e.g. beginner level with limited game elements and mechanics in play), and to introduce new game aspects incrementally as the learner gains proficiency with the rules. Tutorials in computer-based simulations are often used to guide the learning process through the first two levels. Similar systems need be developed to support non-digital games, but these are still largely under-developed. This challenge highlights the importance of facilitation in delivering an affective learning process from the first to fourth level (receiving, responding, valuing and organization). This however is not specific to games and simulations, as the same challenge applies for other teaching methods, e.g. lecturing, lab-work and supervision.

For the last level of the affective learning domain (characterization), post-game review and reflection have been repeatedly highlighted as critical in the literature. The review process is often conducted via group discussions whereby students share their experience and learn from each other. This discussion-based review has limitations since the quality of the learning is highly dependent on the discussion itself and does not necessarily meet the original intended learning outcomes. Therefore guiding questions and "cheat sheets" can be used to guide the learner through the desired learning process. Another method to achieve characterization is individual reflection via written assignments such as reflective essays and mindmaps. Kolb's experiential learning cycle (Kolb 1984) and Gibbs' reflective cycle (Gibbs 1988) can be used for this exercise. Ultimately, the learner should be able to generalize and adapt the learning outcomes to new contexts and situations arising.

Table 2: Games in the affective learning domain.

Affective learning	Game activity and internalization process
Receiving	Passively listening to receive information and willing to engage in the game
Responding	Conforming with rules and using information provided during the game
Valuing	Giving meaning to the rules so they become more intuitive and easier to follow
Organization	Combining information and taking action accordingly towards game objectives
Characterization	Adapting belief and behavior to apply game learning outcomes in the real-world

4 DISCUSSION AND CONCLUSION

The current and future generations of engineers require a broader knowledge base and wider skill sets encompassing new disciplines beyond traditional topics, while at the same time deepen their expert knowledge on specialized topics—also known as the T-shaped engineer (Kordova and Frank 2014). Gamification (as defined in this paper, see section 1.2) in engineering education encompasses tools and methods in the digital and physical realm, aiming at developing skills and knowledge. It is clear that gamification is a powerful (yet largely misunderstood and under-exploited) tool to foster the development of both technical and professional skills in industrial engineering education. Used alongside traditional lectures, games allow students to apply theories learnt and reflect on the impact of their decisions.

Whether an educational method can be considered as game-based learning or gamified is still subjective. For instance, learning factories and discrete-event simulations in manufacturing are rarely called games, but they include many game aspects. Recognizing that it is difficult to distinguish between game and non-game environments, the author has adopted a definition as broad as possible while still remaining relevant for educational purpose in order to review a wide range of game elements, mechanics and dynamics. The examples reviewed in this paper show that digital content and competitive games are well-adapted to develop technical skills and generate cognitive learning outcomes. In contrast, non-digital methods and collaborative game mechanics (mostly in tabletop games and business simulations) tend to focus on social and professional skills at an affective level, also known as soft skills. The dichotomy between digital and non-digital is not binary: other games and simulations are using mixed media, with most of the game activities taking place in the physical worlds and information flows and scoring systems managed in a digital format. It is important to note that all the games included in this paper reported positive results, and thus it is likely that this review benefits from a strong publication bias (i.e. studies with negative outcomes are less likely to be published). Sadly, this is a common phenomenon affecting all scientific disciplines and a clear limitation in this study.

More rigorous and systematic design methods for gamification are required to ensure its pedagogical effectiveness (Lewis and Maylor 2007; Dichev and Dicheva 2017). Most of the publications reviewed in this paper focused on reporting game use and results, but did not systematically include a detailed account of how the games were developed. While some authors provide details on their empirical approach to game design, they also call for guidance and methodologies in future educational game development (e.g. Van der Zee and Slomp 2009; Despeisse 2018). To support further development in this direction, this paper presented some notable examples of games and simulations used in industrial engineering education. Various game aspects were reviewed and aligned with different levels of learning. While the author focused on the cognitive and affective learning, it is important to note that other learning domains could be added in further research to include behavioral/psychomotor (e.g. VR for operator training) and social/cultural dimensions (e.g. multi-cultural and multi-lingual settings). With the current trends in digitalization and internationalization both in industry and academia, these domains are increasingly relevant. Finally, the real benefits of gamification on long-term knowledge retention still need to be validated; most notably the effect of students' emotional engagement on their learning performance still needs to be demonstrated.

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