Insights on lean gamification for higher education

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Abstract

Purpose – There is no argument that using games (gamification) is an efficient way of learning in higher education. The questions, though, are which gamification approach is most suitable at that level and how to assess its suitability? This paper aims to attempt to partially answer these two questions, in the context of lean thinking education.

Design/methodology/approach – The paper offers an assessment criteria to investigate the impact of lean gamification based on the evaluation of motivational, cognitive and social processing during games. In addition, a study is conducted among selected games using these assessment criteria. The study included statistical as well as comparative analysis. The study was based on a sample of undergraduate students learning various lean thinking concepts through physical games over the course of six months.

Findings – Results showed different interaction levels between the three evaluation criteria depending on the type and design of the lean game. The reported scores and analysis drew various lessons on how to use gamification in the context of lean teaching, outlined some best practices in lean games design and suggested recommendations in mapping lean games from industrial domain to higher education domain.

Research limitations/implications – The scope of this research was bounded by the sample size of students as well as the selected nine lean thinking games. Larger pool of students as well as other lean thinking games can offer further insights and confirm the outlined ones.

Practical implications – The presented work will help lean thinking educators in higher education to better understand the student dynamics associated with engaging them in this type pf pedagogical approach. It will help guiding lean thinking games' designer on how to better cater for this segment of lean thinking learners. Finally, it will aid in promoting lean gamification as an effective learning tool.

Social implications – The social impact is achieved through enhancing lean thinking education to a wide number of students. This will positively impact the society through the application of the effective lean tools at different stages, levels and places in these students' life experiences.

Originality/value – This study offers one of the very few applications in gamification assessment in the context of lean thinking. Furthermore, it integrates the social processing criterion for the first time with the classical two other criteria (motivation and cognitive) used in games education assessment. Finally, it offers new insights for lean thinking game designers for higher education learners.

Keywords Assessment, Gamification, Lean thinking education

Paper type Research paper

1. Introduction

Experiential learning approaches (including gamification) can be dated back to the late 1960s. These approaches are supposed to address many of the limitations of more traditional teaching specifically cognitive and effective learning issues while facilitating interactivity, collaboration, peer learning and active learning. Learning occurs naturally while playing games, and as stated by Gee (2007, p. 3), "you cannot play a game if you cannot learn it". Although fun and entertainment are generally what first attract students to games, the engaging learning experience of game playing is contributed to the effective principles or approaches embedded in the game designs, to facilitate positive learning outcomes (Becker 2007; Gee 2007). It is thus reasonable to claim that the desire to create fun games seems to correlate well with the desire to create good learning experiences. As Deterding *et al.* (2011) further stress it: Fun is learning under optimal conditions.

Gamification as an educational and commercial approach is experiencing a rising trend in all aspects. For example, estimates from 2013 showed that at least 44 per cent of the 1.6 billion internet users play online games on a regular basis (Wiklund and Wakerius, 2016). Furthermore, by 2017, the gamification industry is expected to grow to 82 billion USD (Seiffert and Nothhaft, 2014).

Gamification in lean thinking learning context aims to imitate an overall system (manufacturing, service, supply chain [...] etc.), subsystems or process using collaborative and/or competitive games. Lean games are designed to represent or predict aspects of the behavior of the problem or issue (waste, inefficiency, variation [...] etc.) being studied through the different game components and mechanics. Lean games can allow experiments to be conducted within a fictitious situation to show and teach students the real behaviors and outcomes of possible condition at different systems setups before and after implementing various lean tools and principles. These system setups can include production, service, government, health and supply chain environments at different degrees of details and complexity.

Lean gamification has been well established in the industry by trainers and consultants for teaching lean thinking. However, and given that its usage is now growing within higher education, the suitability of these games requires further investigation. This is mainly due to the difference in both the environment as well as the practical background.

This research is concerned with assessing the impact of a subset of lean games in higher education using the motivation, cognitive and social processing evaluation of a group undergraduate students. In addition, various insights about the selected subset of games and their suitability for lean thinking teaching is solicited based on a comparative analysis using the aforementioned assessment criteria. Furthermore, the relations and interaction between the three processing aspects of the assessment criteria are explored to gain better understanding of lean thinking gamification. The gained insights and revealed findings will hopefully contribute to successful lean gamification in the education field. Such contribution is well needed, especially as research has shown that 80 per cent of all gamification initiatives will fail (Gartner, 2012).

The scope of the study covers the non-computer-based type of games. The general assessment approach is based on actual, direct evidence of learning or objective evidence as referred to in the literature (Anderson and Lawton, 2009). The specific assessment tool used is based on the attention, relevance, confidence and satisfaction (ARCS) survey model to measure motivational processing. As for the cognitive and social processing, both were measured using designed questioners focusing on the mental effort investment level and the difficulty level associated with the learning task as well as some of the social interaction aspects during the learning games.

2. Literature review

A good review on game-based learning in science education can be found in Li and Tsai (2013). Some of the work in this field focused on the scientific concept of gamification, its knowledge (e.g. facts, ideas, models, relationships) and the targeted science domain (e.g. physics, chemistry, biology, earth science). Examples of this work include Barab *et al.* (2007), Gåsland (2011), Antin (2009) and Hsu *et al.* (2011).

Other works focused on the use of games and simulation in academic learning and a detailed literature review about this use can be found in Burgess (1991), Wolfe (1993), Faria (1987, 1998, Faria and Wellington (2004). In addition, Moizer *et al.* (2009) discussed the barriers of adopting gaming in higher education and further Mozier and Lean (2010) analyzed such adoption using a quantitative system dynamics model.

A group of other research focused on the different implementation aspects and how gamification can be used to learn or perform the scientific methods including observing, explaining, predicting, investigating, interpreting and concluding as in Spires *et al.* (2011) and Squire and Jan (2007). To learn how to solve problems or to perform the cognitive process of problem solving (e.g. understanding, characterizing, representing, solving, reflecting, communicating and reasoning) using games was also the focus of some work like Moreno and Mayer (2000) and Nilsson and Jakobsson (2011).

Research that explored the role of gamification in student engagement and their involvement in learning including cognitive, affective and behavioral engagement include the work of Lim *et al.* (2006) and Spires *et al.* (2011). Some of that research investigated gamification's affective side of science learning such as attitude, motivation and interest like the work of Ting (2010) and Li (2010). The social or contextual aspects of science learning was emphasized in related research as in Khalili *et al.* (2011) and Squire and Klopfer (2007).

The previous review shows that the literature body has a good emphasis on different gamification aspects in education. However, other than the work of Candido *et al.* (2007) at MIT, who explored how lean education can be enhanced using active learning and gamification, there is not enough research dedicated to assess application of gamification in lean education for undergraduate students, as well as its impact on their learning performance. This paper attempts to fill part of this gap in the literature body.

3. Assessment methodology and study setup

As mentioned earlier, the learning performance is captured through the motivation, cognitive and social processing of students during their engagement with various games in their learning about lean thinking principles and tools.

The motivation processing is measured using the ARCS model of motivational design (Keller, 1987a, 1987b). This model is widely applied in instructional design processes that connects learning motivation with performance (Ames, 1992; Anderman and Maehr, 1994; Bandura, 1997; Keller, 2008). The model suggests that learning motivation is dependent of four perceptual components: attention, relevance, confidence and satisfaction (Keller, 2008). Attention refers to the learner's response to perceived instructional stimuli provided by the instruction. Relevance helps learners associate their prior learning experience with the given instruction. Confidence stresses the importance of building learners' positive expectation towards their performance on the learning task. Satisfaction comes near the end of the learning process, when learners are allowed to practice newly acquired knowledge or skills. ARCS model focuses on the interactions between learners and the instructional programs. Its main thesis is rooted in the expectancy-value theory that views human behaviors as evaluative outcomes among expectations (beliefs), perceived probability for success (expectancy) and perceived impact of the success (value) (Palmgreen, 1984).

The cognitive processing is assessed through requesting the students to self-report the mental effort investment level and the difficulty level associated with the learning task on a nine-point symmetrical Likert scale. The reason for selecting these two cognitive processing dimensions is to try to capture intrinsic cognitive load via the mental effort experienced and also the germane cognitive load via rating the difficulty the students encountered through the game (Huang, 2011).

The social processing is captured through a group of questions that integrated both cooperative as well as competitive interactions. Cooperation will create different important group dynamics that relate to multiple aspects of lean systems. On the other hand, competitive interaction will increase students' engagement, enhancing the overall educational experience.

The research setup in this study involved a total of 60 students across two classes, where every student was asked to fill a designed questionnaire that captures the three discussed assessments processing after each game. The students were engaged in nine different games over the duration of their lean thinking course for six months. The course curriculum was redesigned to include games that demonstrated different lean principles and tools in a competitive way among students' teams. The selected games included physical sets of systems that mimic production lines and service environments. Students used these sets to compete using predefined performance metrics (like cost, quality and time) to see which team will implement the best lean tool (like pull system, line balancing or value stream mapping) to improve performance.

Table I lists the selected games, the lean principles they cater for and categorizes them into easy, moderate and difficult games. The categorization is based on duration, quantitative analysis involved and required tasks for each game. The reason for selecting this categorization criteria is that these three aspects are typically related to games complexity assessment as described in Bergeron, (2006). Games are categorized with a

		Classification criteria			
Game name	Lean principles	Tasks required	Quantitative analysis	Duration	Category
Mouse trap	PDCA/Kaizen cycle	Improve process through multiple cycles (Medium)	Low	Medium	Moderate
Push and pull	Pull systems using Kanban	Demonstrate push and pull policies to control material and production (Advanced)	Medium	Long	Difficult
Value stream mapping (VSM)	Value stream mapping	Draw current VSM, analyze it and develop future VSM (Advanced)	High	Long	Difficult
Visual management	Standardization	Compare process with and without standards (Simple)	Low	Short	Easy
Line balancing	Line balancing	Capture takt time and balance the line (Advanced)	High	Long	Difficult
5S	Workplace organization	Improving assembly using 5S method (Simple)	Low	Short	Easy
Beer game	Variation management	Analyze impact of variation in supply chain (Medium)	Medium	Long	Moderate
Torch factory	Quality at the source	Improve quality of the system and product (Medium)	Medium	Long	Moderate
Catapult	Process control	Control process through $Y=F(x)$ (Advanced)	High	Medium	Difficult

Table I.
Selected lean games description and classification

fuzzy-like approach in which the ones with long duration, higher level of analysis and advanced tasks are categorized as difficult, while those with short duration, low analysis requirement and simple tasks are categorized as easy. The spectrum in between these two ends will depend on the combination of the criteria scores that each game will possess across the three aspects.

4. Overall results

Table II lists the summary of the average scores for all reported survey questions by the students.

Before looking into the different insights revealed by the reported data, analysis of variance was conducted. The main objective of the analysis was to ensure that student's bias

Items for motivation	Reported level
Attention Absolutely disagree (1) ~ Absolutely agree (9)	
There was something interesting at the beginning of the game that attracted my attention	7.39
The design of the game is eye-catching	7.39
The quality of the game kit helped hold my attention	7.23
I enjoyed the game so much that I would like to know more about this topic	7.13
The way the tasks were arranged in the game helped keep my attention	7.35
The game has things that stimulated my curiosity	7.35
I really enjoyed learning with the game	7.46
The feedback or comments after the exercises helped me feel rewarded for my effort	7.42
The variety of exercises, illustrations, etc. helped retain my attention on the game	6.82
I could relate the content of the game to things I have seen, done or thought about in my own life	7.55
It was a pleasure to work on such a well-designed game	7.17
Relevance	
It is clear to me how the content of the game is related to things I already know	7.93
There were examples that showed me how the game could be important to some people in the learning setting	7.88
The content of the game is relevant to my interests	7.68
Confidence	
The game was more difficult to understand than I would like for it to be	2.97
The game had so much information that it was hard to pick out and remember the important points	2.76
The game is so abstract that it was hard to keep my attention on it	2.4
The exercises in the game were too difficult	2.26
I could not really understand quite a bit of the material in the game	2.25
Satisfaction	
It felt good to successfully complete the game	7.48
Items for cognitive processing Very low mental effort (1) ~ Very high mental effort (9)	
How much mental effort did you invest to learn the content from the game?	5.45
How difficult was it for you to learn the content from the game?	3.87
Items for social processing Absolutely disagree (1) ~ Absolutely agree (9)	
A spirit of teamwork and cooperation existed in my team	7.8
The competition enhanced my engagement in the game	7.45
My team communicated effectively with other teams	7.41

Table II. Reported average scores for learning performance questionnaire as a parameter was masked and that the different assessment scores reported were varying mainly due to the different games setups. Summary of the ANOVA results is shown in the Appendix 1, and the calculated p - values indicate that students' biases had no effect on the reported survey values of the different assessment aspects.

Figure 1 summarizes the overall scores for each of the motivational criteria parameters [Figure 1(a)] and the three assessment components selected in this study [Figure 1(b)]. Figure 1(a) shows that the relevance scale has the highest mean of 7.8, while the confidence scale has the lowest mean at 2.53. Satisfaction and attention scales were close at 7.48 and 7.3 respectively. The reported scores generally suggest a good motivational performance since all ARCS components scored around the top third of the used one-nine Likert scale, except for the confidence component. This finding suggests that gamification positively impacts students' motive to engage in the learning process and aligns with similar results like those found in Huang (2011).

The higher relevance score is attributed from one aspect to how games were relevant to students in terms of their goal orientation to learn about how lean principles and tools improve systems and thus their motive to play the games matched their expectations. However, and as shown later, this component will suffer with some games that rely on expected industrial experience of the learners. In addition, the high score of attention performance was achieved through perceptual arousal, inquiry arousal and variability of games layouts that the students experienced. Attention and relevance lead to a high satisfaction score since satisfaction is related to both factors as will be explained in the comparative games analysis. The low confidence score is mainly due to lack of clarity in the learning requirements of some games and also to the perceived low success opportunities of other games. These low scores will be more manifested with games analysis and will lead to some design guidelines for lean games in higher education.

Figure 1(b) captures the overall averages of the three learning assessment criteria; motivational processing, cognitive processing and social processing. Social processing had the highest score among the three highlighting the importance of the social interaction in the gamification learning approach. The internal dynamics among the team as well as the competitive spirit between teams contributed to the positive learning experience of students.

The cognitive processing scored the lowest as students reported above average in their mental effort investment to learn the content game while they reported below average in the difficulty to learn the game content. The cognitive challenge in gamification learning is very important. Researchers argue that cognitive load can demotivate learners (Sweller *et al.*, 1999). In the conducted study, the general above-average performance of the cognitive

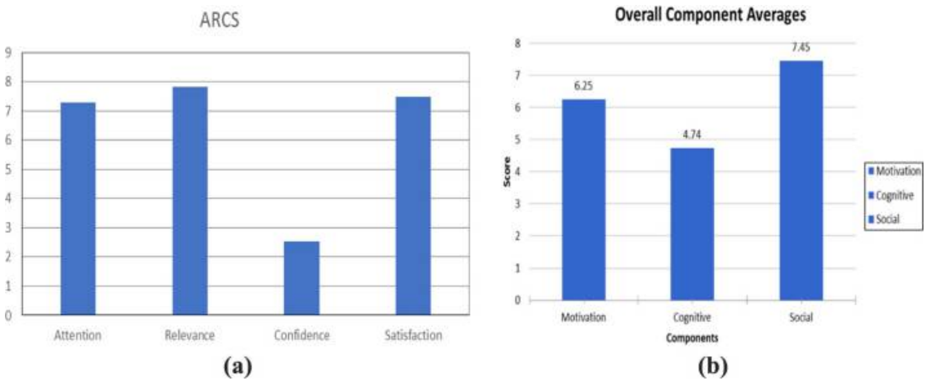

Figure 1.
(a) Scores for each of the motivational criteria parameters; (b) scores for the three assessment components selected in this study

processing can be attributed to the lecturing components that usually preceded each game and thus relating the game content to that principle or tool was easier for the student.

The three assessments processed constitute the requirements for a typical learning cycle; however, their different scores reflect how learners would interact differently with each of them. In a higher education setup, usually student experience more positive encounter with social processing followed by motivation processing and least with the cognitive processing as illustrated by the reported results.

5. Lean gamification insights using comparative analysis

In this section, we focus more on the insights revealed to us from comparing the performance of the selected lean thinking games using the different assessment criteria. Statistical analysis was first conducted to identify if there were significant differences between the games at the different assessment criteria. Tukey method, with 90 per cent confidence, was used for this purpose, and Table III lists the summary of games with significant differences (see Appendix 2 for detailed results). It is important to note here that the list presented in Table III does not mean that other non-listed games in any of the assessment criteria are not significantly different; however, the available data only enabled us to be confident to report these listed games. Further data gathering can reveal more analysis to what will be discussed here.

Looking into the results in Table III reveals some interesting observations. The game Line Balancing was significantly different than half of the other played games in the attention criteria. This difference can't be attributed to the difficulty or ease of these games (as other different games like Value Stream Mapping (VSM) are also difficult) but to the design of the game. The game is dedicated to teach students how to balance the different line stations at a cycle time close to the takt time. This task required multiple time measurements, system analysis and redesigning many of the work content of the line's stations. These tasks required an attention level much different than the other compared games which either had simpler tasks (Mouse Trap and Visual Management) or more difficult tasks (like Push/Pull and VSM) but in both students were well guided on how to perform them in a systematic way

Games with significant differences (in ARCS)	Assessment criteria
Mouse trap and line balancing	Attention
Visual management and line balancing	Attention
Push/pull and line balancing	Attention
VSM and line balancing	Attention
Push/pull and beer game	Relevance
Beer game and push/pull	Confidence
Beer game and mouse trap	Confidence
Beer game and visual management	Confidence
VSM and push/pull	Confidence
VSM and mouse trap	Confidence
VSM and visual management	Confidence
Mouse trap and visual management	Satisfaction
Mouse trap and torch factory	Satisfaction
Games with significant differences (in M/C/S)	Assessment criteria
VSM and push/pull	Cognitive
VSM and visual management	Cognitive
VSM and beer game	Social

Table III. Summary of games with significant differences within the considered assessment (better instruction). Furthermore, Line Balancing was the only paper-based game which was not as attractive in its physical appearance as other games that had kits mimicking real systems. It can be assumed that the attention of the students in lean games is positively related to the design of the game's both tasks and layout.

The Push/Pull game was significantly different than the Beer Game in the relevance criteria. This difference can be associated with the practical background of the students. The Push/Pull game introduces the students to a very new lean concept of production being controlled using Kanban cards and pull systems. On the other side, the Beer Game manifests to students the impact of time delays and lack of communication on the performance of supply chains and both concepts relate to many of the students experiences. This highlights the importance of considering the students' practical background in the performance expectation.

In the confidence criteria, VSM and Beer Games were both significantly different than Push/Pull, Mouse Trap and Visual Management games. A clear distinction between the first two games and the other three ones is the scope of these games and accordingly the success opportunities associated with them. VSM and Beer Games are geared toward a system wide perspective and looking from a more comprehensive scope (full manufacturing line for the VSM and full supply chain for the Beer Game). On the other hand, the other three games are geared towards a specific problem (or waste) that needs to be tackled (production control in the Push/Pull, PDCA cycle in Mouse Trap and developing standards in Visual Management game). The success opportunity (and thus the positive expectation of the student) with tasks related to system wide improvement is relatively lower than that for a specific task dedicated for a component in the system. This suggests that students are more confident and better understand games that are less abstract or general and more specific and focused on limited tasks. Such confidence cannot be attributed to the difficulty of the games in our case, as the previous mentioned games all vary in their degree of difficulty, but to the positive expectation of the students.

Mouse Trap was very satisfactory game to students due to its simplicity and ease in teaching the continuous improvement (PDCA) cycle using a childhood-related game. This maintained a sense of equal opportunity to win for all students competing. In addition, the ability to complete the tasks easily and multiple times maintained an intrinsic reinforcement feeling among students. In comparison to Visual Management and Torch Factory, games where students did not achieve the maximum expected performance (best SOP design or total elimination of defects) led to a reduced feeling of satisfaction. It is clear that equity, successful fulfillment and relating to previous experience contribute to the satisfaction of students during game-based learning process.

When considering other assessment criteria in addition to the motivational processing specific components, VSM stands out as more significantly different than Push/Pull and Visual Management games in the cognitive processing and the Beer Game in the social processing. The amount of information required to be gathered and processed in the VSM game with its system wide scope required higher cognitive load than the other two compared games. This load made the mental capacity of students on higher demand during the VSM game explaining its cognitive processing difference. In the social processing, significance difference between the VSM and Beer Games can be attributed to the design of each game. Beer Game demonstrated how each component (echelon) of the supply chain can be working as in isolated island leading to bad performance and waste generation. Such isolation negatively impacts the social interaction within students' teams. VSM on the other hand required an intense team work in gathering data, discussing improvement options and sharing tasks. The level of teamwork is clearly an important parameter in improving social processing during lean learning process among students.

Figure 2 offers another dimension of comparative evaluation for the selected games by showing the individual scores of each game across the ARCS components of the motivational processing criteria. Some insights gained from this comparative dimension include noticing that Mouse Trap scored the highest in satisfaction component while Line Balancing scored the lowest. One way to understand that is to consider the other three components scores (ARC) in comparison to the satisfaction score (S). The satisfaction component, based on the theory of motivation, volition and performance (Keller, 2008), becomes the result of the outcome processing at the end of the motivational learning cycle. This means that if the input to that learning cycle in terms of attention, relevance and confidence was positive to students, the output in terms of satisfaction will also be positive. Mouse Trap has collectively the highest scores in the (ARC), while Line Balancing had the lowest score in these components explaining the satisfaction level difference between these two games.

Other insights include acknowledging that the Torch Factory game scored the highest in the attention component. Small (2000) indicates that attention in gamification is related to perceptual arousal, inquiry arousal and variability. The Torch factory was the first game in the lean course to introduce students to different quality concepts after series of games focusing on productivity leading to increasing both perceptual and inquires arousal levels of students. In addition, the game had various quality problems built in both the system and some of the components exposing the student to wide scope of problems variability and thus increasing their attention level. Attention can be stimulated with a good design of the games instruction, scope and timing.

It is also worth noting that all games had very close scores in the relevance component. This observation is important in the context of this study, as it focuses on students with very minimal practical experience. As stated before, relevance in general helps learners associate their prior learning experience with the games, and it enables learners to understand the applicability of learned knowledge or skills in their future tasks. The lean games were designed and dedicated to industry people and exporting these games to the higher

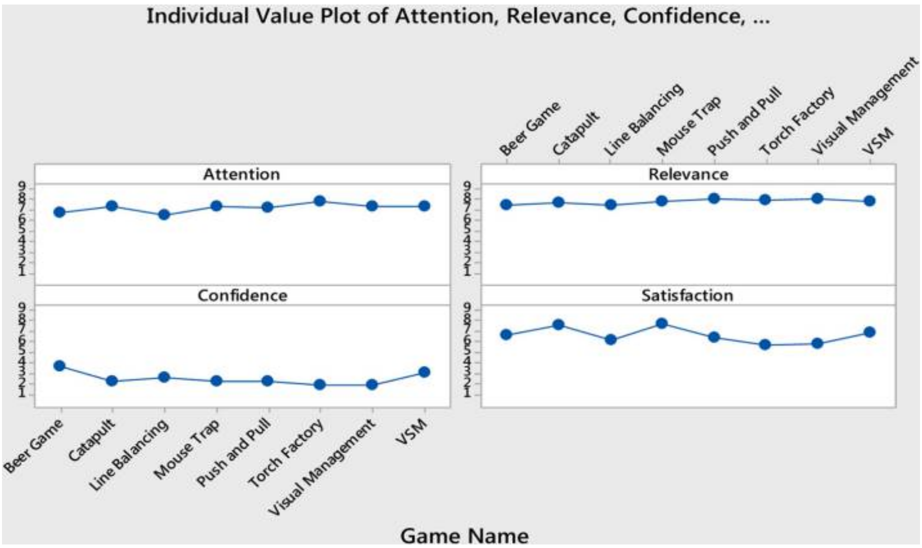

Figure 2.
ARCS scores of the selected lean games

education domain will face a clear challenge in these criteria. The higher education students will not be able to clearly differentiate among different games which ones are more applicable to their undecided yet career path as well as relating them to previous industrial experience.

Figure 3 extends the comparative evaluation between the games to all three considered processing criteria. In the cognitive processing criteria [Figure 3(b)], the Catapult game scores were significantly higher than all other games. The Catapult game introduced the students to using various statistical process control concepts to eliminate wastes and variability. These concepts required some statistical analysis depth raising the cognitive load required by this game as well as the difficulty level to learn the game. This high cognitive score is also supported with the low confidence score (2nd lowest among the games) emphasizing the difficulty students encountered to master the game. This observation is important given the educational setup of the experiment in terms of required explanation and supporting effort by teachers leading similar games in teaching lean thinking. On the other end of the spectrum, and, as expected, Mouse Trap scored significantly lower on the cognitive metric due to the previously discussed simplicity and relevance to all students. Finally, and within the adopted definition of games' complexity, it is worth mentioning that games' with easy category scored higher than others with moderate category in these cognitive processing criteria. This highlight that cognitive load is not only related to the complexity of the game but also to how students perceive that complexity and be able to deal with it.

In the social processing criteria [Figure 3(c)], it is clear that all games scored relatively high with minimal variation. This brings attention to the importance of considering the

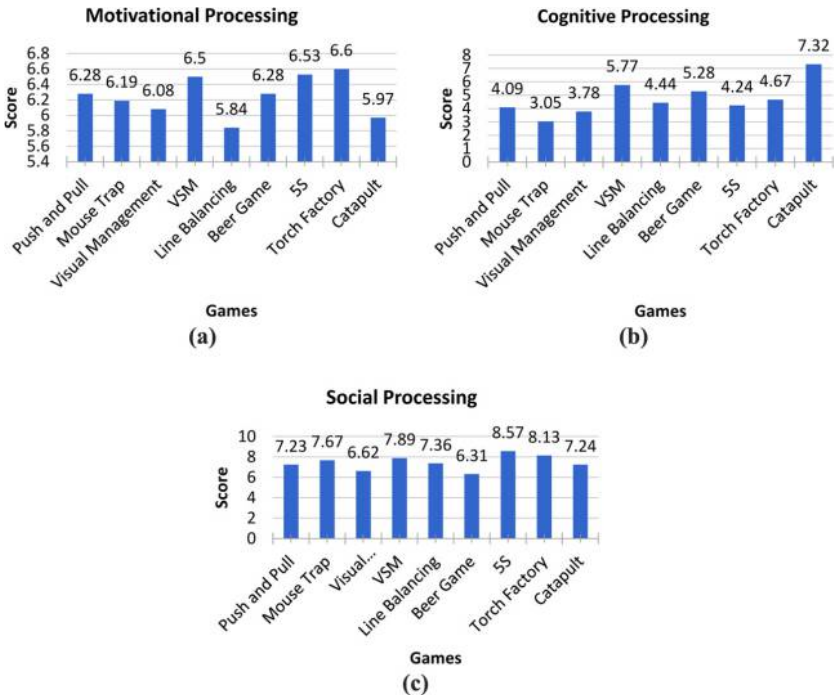

Figure 3.
(a) Motivational, (b) cognitive, (c) social and (c) processing scores of the lean games

social component in game-based learning as an integral element of its success. This element improves students' engagement and align with the various educational theories promoting cooperation/competitive to enhance students' learning. At the comparative level, 5S game scored the highest. The game had a stressful beginning, where it asked teams to compete in assembling parts in a clearly unorganized environment. This led to developing a high level of both cooperation and competitiveness to figure out the best organization of the workplace in a timely manner to win. On the other side, the relatively lowest scoring games were Beer Game and the Visual Management Game. The former is based on demonstrating the negative impact of system disconnectivity and the latter was mainly an individual game with limited social activity. The teams' interaction in both games was minimal leading to low social processing scores. In addition, games that allowed students to play different worker roles in a factory scored higher than others with limited role playing (Torch Factory vs Catapult for example). This is an important consideration in designing effective lean games for undergraduate education.

In the motivational processing criteria [Figure 3(a)], Torch Factory scored the highest among other games as well as VSM (very close scores). In addition to the earlier analysis of the different motivational processing elements (ARCS), these scores can also be related to success and failure. These games enabled students to succeed in achieving the game goal after multiple attempts (Torch Factory) or experimentation (VSM). Motivation is highly related to failure, and because games involve repeated experimentation, they also involve repeated failure. In fact, for many games, the only way to learn how to play the game is to fail at it repeatedly, learning something each time (Gee, 2008). Games need to help players persist through negative emotional experiences and even transform them into positive ones.

The previous analysis supports the argument about the existence of a relationship and interactions between the three considered evaluation processing criteria. For example, it was demonstrated that cognitive capacity can demotivate students while social interaction does the opposite. Previous research work suggested the existence of a statistical correlations between motivational and cognitive processing (Sweller *et al.*, 1999; Huang, 2011). The data gathered in this conducted experiment do not have enough evidence to statistically confirm such correlation when the three processing are considered simultaneously as shown in the values of Pearson correlation and p-value parameters in Table IV. However, Figure 4 depicts some aspects of the interaction between all three processing together for the selected lean games. The main observation is that as much as a general relationship can be understood between each two of the three evaluation criteria, there is no clear relationship (linear or nonlinear) between all three evaluation criteria together. On the statistical side, this may be better solved by increasing the sample size of the data. However, it also points to the complexity of studying the impact of all three processing criteria simultaneously on lean gamification. Previous works investigated motivational and cognitive interaction, but this work is one of the few attempts to add the social processing as part of the evaluation analysis concurrently. An opportunity for further research exists in this direction.

Table IV. Correlation between motivational processing, cognitive processing, social processing

Assessment component	Motivational processing Pearson correlation	Motivational processing p-value	Cognitive processing Pearson correlation	Cognitive processing p-value
Cognitive processing	0.610	0.146		
Social processing	0.622	0.136	−0.22	0.636

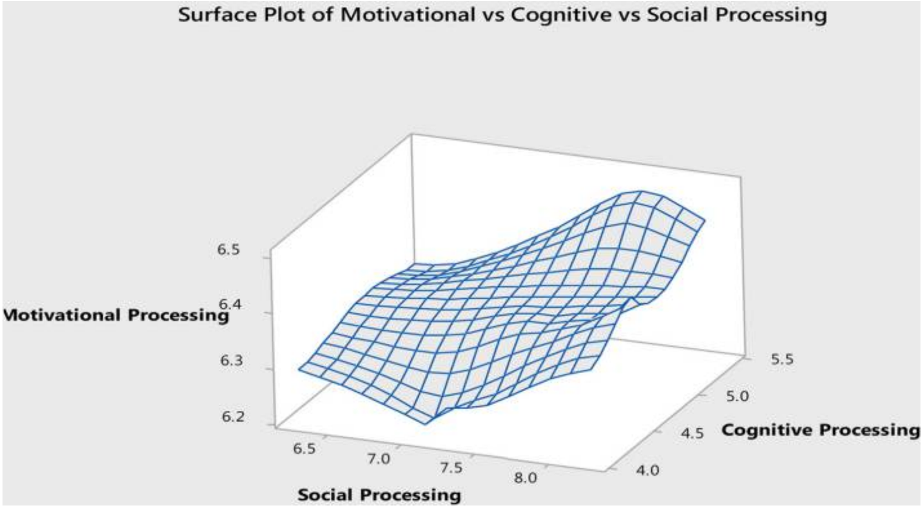

Figure 4.
Surface plot for the motivational, cognitive and social processing interaction for the considered lean games

6. Summary and recommendations

The impact of lean gamification and its role in teaching lean thinking in higher education was a main objective of this study. The study attempted to understand under what circumstances different game elements can drive lean thinking learning behavior among students. Furthermore, this study offered a diagnostic evaluation of selected lean physical games using motivation, cognitive and social processing assessment criteria. Various insights were revealed during the analysis of the reported data as well as investigating the interaction between surveyed students and the selected games along the three evaluation criteria. The recommendations gathered from the conducted analysis are related to both; lean gamification as a pedagogical approach for lean thinking in higher education and lean games design for this specific segment of learners. The recommendations can be summarized as follows:

- The lean thinking gamification process should align with the learning cycle that usually starts with motivation and then cognitive exercise within a social setup. Such alignment qualifies the gamification approach to be one of the efficient mechanisms for teaching lean thinking at higher education.
- Motivating students to engage in lean thinking education through games is highly related to the interaction level between games' components (design, layout, materials and tasks) and these students. This was well demonstrated when investigating reasons for high attention level scored by some games as well as lower confidence and cognitive processing scores of other games. Lean game designers for higher education need to avoid abstract and complex task and focus on concrete achievable tasks to motivate students and raise their satisfaction during the learning process.
- There is a clear challenge in the direct import of the currently used lean games from industry to higher education when it comes to relevance. Results showed that although the selected games varied in their degree of difficulty, ability to motivate students and cognitive load; however, they all shared relatively low relevance scores. This can be attributed to some reliance that these games have on practical experience to understand some system's performance challenges. Such experience is lacking to some

extent at that educational level. Educators need to account for that through the academic content (like case studies and lectures) as well as redesign efforts to have games tailored to students' experience level.

- The reported results in general pointed to the effectiveness of non-computer based games as they appeal more to students. This can be attributed to the level of personal interaction (as reflected in the social processing scores) as well as the realistic sense that such game topology offers to students.
- The cognitive processing component in the gamification learning approach was shown to be critical as it could impact learners' perceived satisfaction levels. Learners with a high level of intention to pursue the performance goal of the game could be either encouraged or frustrated at the end of the game due to the experienced high cognitive load. This is translated to another important recommendation to lean game designers for students to balance and critically assess the required mental effort as well as the impact of the games' components on that effort. Results showed that games' complexity is not necessary the main reason for high cognitive load, but how students' perceive that load and deal with it.
- A well-designed lean game should encourage players take on meaningful roles that are fruitful for learning as well as create a positive cooperative and competitive environments. The social processing assessment demonstrated the previous recommendations through its reported scores. The social processing scores were the highest both at each game level as well as among the other two processing level. In students' learning environment, social components of the game are very critical to their success.
- Success and failure in the lean gamification context requires attention to how to balance between satisfaction achieved through easy success (as shown in this study) and learning achieved through failure attempts. Games has the potential to maintain a positive relationship with failure by making feedback cycles rapid (players can keep trying until they succeed) and at low risk. Such potential is essential in lean thinking as continuous improvement culture is based on non-stop trials of success and failure sometimes.
- From a sustainability standpoint, the above average scores for all considered assessment criteria suggests that students will most likely engage in more games as they perceived gamification to be motivational and satisfactory.
- Further work is required to capture and model the correlation and interaction between the motivational, cognitive and social processing in lean thinking learning using gamification. The data in the conducted study failed to offer a statistically backed correlation among these three assessment criteria opening the door to future work in this direction.

In summary, in teaching lean thinking, gamification has the potential to motivate students to engage in the classroom, gives teachers better tools to bring a practical and applied sense to students and gets students to bring their full selves to the pursuit of learning. For this to happen with complete success, lean games need to be well chosen and adapted to align with the higher education pedagogical dynamics as well as with the limited industrial experience of students.

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Appendix 1

Source	DF	Adj SS	Adj MS	F-value	p-value
Analysis of variance for attention					
Game name	7	17.21	2.4589	2.59	0.014
Name	55	234.05	4.2554	4.48	0.000
Error	222	210.93	0.9501		
Total	284	477.14			
Analysis of variance for relevance					
Game name	7	10.57	1.5101	2.33	0.026
Name	55	118.23	2.1496	3.32	0.000
Error	222	143.65	0.6471		
Total	284	276.50			
Analysis of variance for confidence					
Game name	7	83.04	11.863	6.28	0.000
Name	55	227.73	4.140	2.19	0.000
Error	222	419.61	1.890		
Total	284	741.02			
Analysis of variance for satisfaction					
Game name	7	140.3	20.040	3.00	0.005
Name	55	894.9	16.271	2.44	0.000
Error	267	1784.1	6.682		
Total	329	2826.0			
Analysis of variance for cognitive					
Game name	7	67.34	9.620	4.87	0.000
Name	55	400.67	7.285	3.69	0.000
Error	223	440.50	1.975		
Total	285	910.42			
Analysis of variance for social					
Game name	7	43.34	6.192	5.45	0.000
Name	55	355.24	6.459	5.69	0.000
Error	223	253.23	1.136		
Total	285	681.45			

Table AI.
ANOVA results between games and students

Appendix 2

Game name	N	Mean	Grouping	
Attention				
Catapult	13	7.43235	A	B
Mouse trap	54	7.41215	A	
Torch factory	13	7.38169	A	B
Visual management	42	7.30780	A	
Push and pull	49	7.27414	A	
VSM	49	7.26392	A	
Beer game	32	6.87100	A	B
Line balancing	33	6.57995		B
Relevance				
Push and pull	49	8.05490	A	
Visual management	42	7.90525	A	B
Mouse trap	54	7.88456	A	B
Catapult	13	7.73894	A	B
Torch factory	13	7.71857	A	B
VSM	49	7.71095	A	B
Line balancing	33	7.56537	A	B
Beer game	32	7.40902		B
Confidence				
Beer game	32	3.52253	A	
VSM	49	3.15680	A	
Line balancing	33	2.60861	A	B
Catapult	13	2.20344	A	B
Push and pull	49	2.20053		B
Mouse trap	54	2.16348	B	
Torch factory	13	2.12239	A	B
Visual management	42	1.78777	B	
Confidence				
Beer game	32	3.52253	A	
VSM	49	3.15680	A	
Line balancing	33	2.60861	A	B
Catapult	13	2.20344	A	B
Push and pull	49	2.20053		B
Mouse trap	54	2.16348	B	
Torch factory	13	2.12239	A	B
Visual management	42	1.78777	B	
Satisfaction				
Mouse trap	56	7.73214	A	
Catapult	14	7.17268	A	B
VSM	56	6.83929	A	B
Beer game	36	6.68899	A	B
Push and pull	56	6.42857	A	B
Line balancing	36	6.21677	A	B
Visual Management	56	5.83929	B	
Torch factory	20	5.55982		B

(*continued*)

Table AII. Grouping Information Using the Tukey Method and 90% confidence (Means that do not share a letter are significantly different)

Game name	*N*	Mean	Grouping		
Cognitive					
VSM	49	5.31077	A		
Beer game	32	5.28455	A	B	
Mouse trap	54	4.49812		B	C
Line balancing	33	4.49390	A	B	C
Torch factory	14	4.36571	A	B	C
Catapult	13	4.16567	A	B	C
Push and pull	49	4.11580			C
Visual management	42	3.97233			C
Social processing					
VSM	49	7.82104	A		
Torch factory	14	7.70346	A	B	
Mouse trap	54	7.64282	A	B	
Line balancing	33	7.59310	A	B	
Catapult	13	7.57441	A	B	
Push and pull	49	7.18708		B	
Visual management	42	7.16256		B	C
Beer game	32	6.46118			C

Table AII.

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