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A GAMIFICATION APPROACH APPLICATION TO FACILITATE LEAN MANUFACTURING KNOWLEDGE ACQUISITION

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Abstract
Current fast development requires continuous improvement of employees' skills and knowledge. Therefore, companies are looking for the best way for improving the employees' qualifications and understanding of new concepts and tools which have to be implemented in manufacturing areas. One method employs gamification for this purpose. The aim of this paper is to present how gamification can increase the acquisition of knowledge concerning lean manufacturing concept implementation. Gamification is an active learning approach for people who will understand the subject easier by 'feeling' and 'touching' personally the analysed problems. The research utilized a questionnaire which assessed the game participants' engagement level. The assessment focused specifically on the participants' motivation, cognitive processing and social aspects. The participants were also examined before and after the game in order to assess the increase of their understanding of different lean manufacturing topics and tools. Five different games with different groups of participants were played. The results confirmed the hypothesis that gamification has a positive impact on the knowledge acquisition as well as on motivation, cognitive processing and social aspects. Finally, various insights on how to better design, conduct and utilize gamification in the similar technical context are presented.

Keywords
Gamification; knowledge acquisition; lean concept; cognitive processing; motivation; competences.

Introduction

Companies struggle with the problem of improving and updating employees' knowledge due to the changes continuously implemented, especially in the manufacturing areas of companies. Among such knowledge requirement there is a well-known concept of lean manufacturing which is recognized as an increasing transformation trend in industry [1], that supports companies' development and has a positive effect on their performance [2]. By implementing different tools and methods, companies try to increase their leanness and speed their lean transformation in order to reach higher levels [3]. With the implementation of new manufacturing technologies, new organizational methods and new manufacturing tools, the challenge concerning employees' involvement and their preparation for this new environment in terms of both knowledge and attitude appears. Employees have to be able to undertake new tasks as well as they should be motivated and feel that they can overcome problems that arise in the novelty implementation. Different factors influence the success of lean manufacturing projects. These include: organizational culture, human factors and internal environment as just examples [4]. Therefore, in any training process, it is important not only to achieve knowledge but also to increase motivation, social skills and understanding of industrial problems. This paper investigates gamification as an influential approach which can be used to teach/train about complex manufacturing problems. Gamification has already a proven record in different educational contexts for many years. Many examples of lean education that uses a gamification approach in order to increase a company leanness are presented in the literature [5–8]. This paper focuses more on how to assess the success of using games in a lean manufacturing learning process when applied to both, employees and students (as companies future employees). Furthermore, the study discusses the idea of what companies should pay special attention to when designing games for their own training needs. Eventually, the analysis offers a set of recommendations to the lean manufacturing games development that will ensure attention, relevance, confidence, satisfaction and knowledge acquisition.

First, the paper discusses gamification and its place in the learning process. Then, games designing problems are deliberated. Next, the games assessment framework is discussed. After that, an experimental setup of five selected games is presented. It is followed by the results from the games participants and the games impact. Finally, observations and practical recommendations for the lean games design and training are presented.

Gamification

Gamification is the use of game design elements and game mechanics in non-game contexts. In an effort to define what a game is, Salen, K. and Zimmerman [9] compared 8 academic definitions, and proposed that a game is "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome". Kim [10] defined a game as: "a structured experience with rules and goals that's fun". Generally, one can claim that gamification is attributed to using the game approach to engage a group of people in a designed activity within a specific context. That context can be for example marketing, manufacturing or education. Educational gamification proposes the use of game-like rule systems, player experiences and cultural roles to shape learners' behaviour. Gaasland [11] reported on the wide application of gamification to both industrial and educational fields. The work [12] presents how different learning styles, defined by Felder-Silverman [13], can be incorporated in games.

In the literature, gamification belongs to a wider field of studying simulation in learning. Research work have identified three categories of simulation-based learning: role play, gaming and computer simulation [14, 15]. These categories are different in their design, objective and scope of application. In a role playing exercise, participants demonstrate the role of a specific job or worker in a particular situation following a set of rules and interacting with other role players. As for gaming (or gamification as referred to in the rest of this article as), the key elements entail interaction within a predetermined context, often involving forms of competition, cooperation, conflict or collusion. These interactions are constrained by a set of rules and procedures. Finally, computer simulations aim to replicate system characteristics using mathematics or simple object representations [14]. Ellington [16] differentiates between game-based simulations depending on their format. Specifically, his differentiation depends on the distinction made between manual exercises and electronic exercises. The examples of manual exercises identified by Ellington [16] include card, board and field games. Lean et al. [17] summarise this classification in Fig. 1.

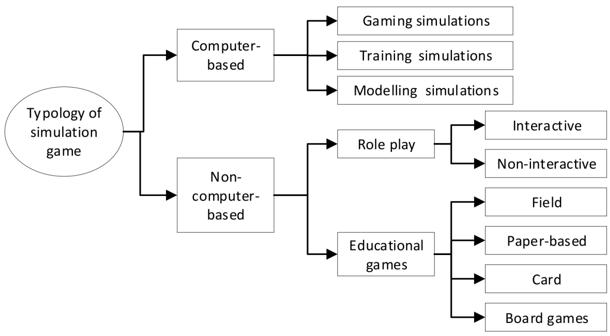

Fig. 1. Typology of simulation (adopted from Lean et al. 2006).

Other recommendations

The questionnaire was developed taking into account important aspects that had arisen from the literature review. The authors identified the three following design dimensions that need to be considered when gamification is applied as a tool to transfer knowledge efficiently.

• Cognitive dimension: Games provide complex systems of rules for learners to explore through active experimentation and discovery. They engage learners through a mastery process and the pre-designed difficult tasks [18]. One critical game design technique is to deliver concrete challenges that are tailored to each learner's skill level, increasing the difficulty as the player's skills expand. Specific, moderately difficult, immediate goals are motivating for learners [19], and they are precisely the sort that games provide [20]. Games also provide multiple routes to success, allowing players to choose their own sub-goals within the a larger task. This supports motivation and engagement as well [21].

• Emotional dimension: Games invoke a range of powerful emotions, from curiosity to frustration or joy [22]. Furthermore, they help learners overcome negative emotional experiences and sometimes to transform them into positive ones. A clear example of such transformation in a game is demonstrated in the concept of failure. Since games involve repeated experimentation, they also involve repeated failures. 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 [20]. Games maintain this positive relationship with failure by making feedback cycles rapid and keeping the stakes low. The former means that players can keep trying until they succeed; the latter means they risk very little by doing so.

• Social dimension: Games permit learners to experience different roles, asking them to make in-game decisions from their new vantage points [23]. Learners can also discover new sides of themselves in the safe space of play. Gamification can provide social credibility and recognition for various learning achievements, which, otherwise, might remain invisible or even be denigrated by other learners. Recognition can be provided by a teacher but gamification can also allow learners to reward each other [24]. Finally, games enhance various teamwork ethics among learners whether in their teams or across different teams. This is achieved through promoting positive cooperative and competitive social spirits.

Gamification assessment methodology

The impact of gamification on the engagement and learning performance of game participants in this research is captured through the motivational, cognitive and social processing. Different groups of participants were considered for the assessment during their engagement with various games in their Lean principles training provided by two different universities.

The motivation processing is measured using the attention, relevance, confidence, and satisfaction (ARCS) model of motivational design [25, 26]. This model is widely applied in instructional design processes and connects learning motivation with performance [19, 27–29]. The model suggests that learning motivation is dependent on four perceptual components: attention, relevance, confidence and satisfaction [29]. Attention refers to the learner's response to the 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 of a 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 programmes. Its main thesis is rooted in the expectancy-value theory that views human behaviours as evaluative outcomes among expectations (beliefs), perceived probability for success (expectancy), and perceived impact of success (value) [30].

Cognitive processing was assessed through requesting the game participants to self-report their mental effort investment level and the difficulty level associated with the learning task on a 9-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 as well as the germane cognitive load via rating the difficulty the participants encountered through the game.

Social processing was captured with a set of questions that integrated both cooperative as well as competitive interactions. Cooperation will create many important group dynamics that relate to multiple aspects of lean systems. On the other hand, competitive interaction will increase students' engagement enhancing the overall learning experience.

Lean games characteristics

In order to identify the impact of gamification on the learning performance through motivational, cognitive and social processing, five games were chosen to be played by different groups of people. For each game, a learning goal, intended learning outcomes and a game scenario were established. Each game is characterized by a subject of the game, its duration, a number of rounds, a number of people playing the game and a number of quality and/or lean tools that were incorporated in the game as shown in Tables 1 and 2. In Table 2, an additional game complexity criterion was presented. It was based on multiplying the duration by the number of rounds and tools incorporated. This parameter will support a comparative analysis that highlights the impact of game designing on learning and motivation. When selecting the games, the following criteria were taken into consideration:

- all games should concern the same concept: lean manufacturing,

- all games should have incorporated lean tools,
- all games should require team work,
- the games should have different complexity,
- the games should require the similar number of participants,
- the games with different duration and different number of rounds should be found.

All games required from the participants some lean knowledge in order to solve different manufacturing problems.

Table 1
Games goals and scenarios.

Name of the game and subject	Goal of the game	Scenario
Assembly game (AG) – Ball-pens	Understanding the flow and possibilities of increasing efficiency with the use of lean tools	1st Round – Performing an assembly process to identify and understand existing problems 2nd Round – Analysing, with the use of the chosen by participants quality tools, in order to identify sources of problems and to propose solutions and improvements implementation 3rd Round – Performing an assembly process under new conditions 4th Round – Assessment of achievements
Manufacturing game (MG) – Christmas tree decoration	Acquiring skills concerning manufacturing line balancing	1st Round – Performing a manufacturing process and collecting real data 2nd Round – Performing adequate analyses with the use of chosen lean tools to balance the manufacturing line 3rd Round – Performing a manufacturing process under new conditions 4th Round – Assessment of achievements
Push/Pull Game – Automotive assembly	Understanding and practicing the difference between push and pull production control in an automotive assembly line	1st Round: Control production using push scheduling and monitor cost, WIP and lead time. 2nd Round: Control production using pull approach and re-design the layout to facilitate pull flow. The same metrics are monitored as in round 1.
Value Stream Mapping Game – Automotive assembly	Apply value stream mapping skills to capture the production performance and to be able to improve it using lean tools	1st Round: Capture the current state value added activities and non-value added activities of an automotive line suffering from high level of variability and inefficiencies. In addition, they draw the current VSM. 2nd Round: Develop a future state for the same line through applying different lean tools within a limited budget. Drawing the future VSM and comparing value added and non-value added times.
Torch Factory Game – Torch assembly	Improve an assembly line of a torch factory suffering from productivity and quality issues	1st Round: Capture the current performance level of the line and analyse quality and productivity problems. 2nd round: Improve productivity through line balancing and Kanban system 3rd Round: Improve quality through root cause analysis, quality at the source and Andon.

Table 2
Game goals and scenarios.

Game	Duration of the game [hours]	Number of rounds	Number of incorporated quality and/or lean tools	Game complexity	Number of students playing the game
Assembly game (AG)	6	4	11	264	12–18
Manufacturing game (MG)	4	4	21	336	14–18
Push/Pull game	3	2	4	24	18
VSM game	4	2	5	40	17
Torch Factory game	3	3	9	81	15

Lean gamification approach and setup

As mentioned, this research had two goals. The first was to study the impact of gamification on three aspects of participants' engagement that were discussed in section three, namely: 'Motivational processing' (using the Attention, Relevance, Confidence, and Satisfaction model), 'Cognitive processing' and 'Social processing'. The second goal was to examine to what extent (if to any) the games can improve the participants' knowledge acquisition about the specific lean subject by playing a related game. The structured methodology of the carried study is outlined in Fig. 2.

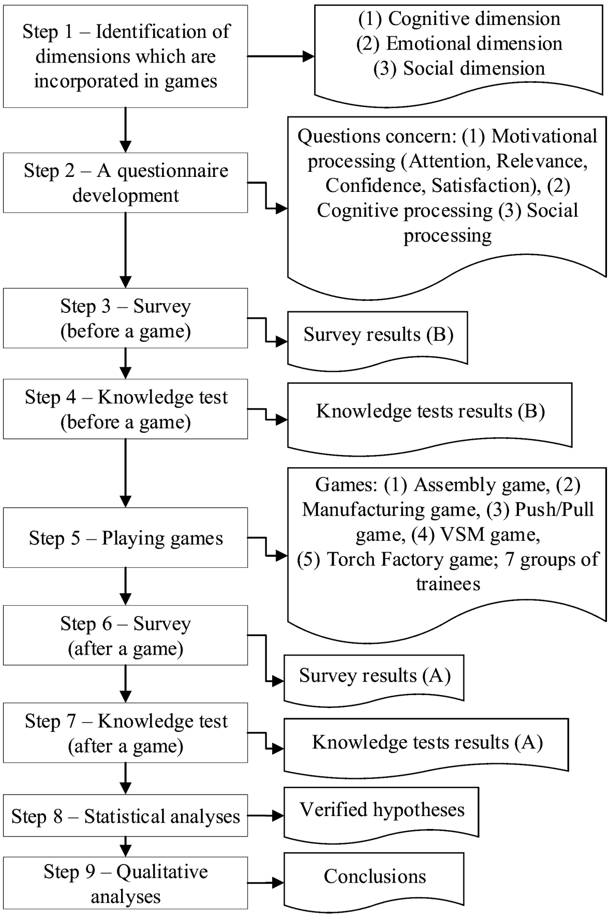

Fig. 2. Lean gamification research plan.

This paper discusses how gamification incorporated in learning process can increase acquisition of knowledge by games participants. The research was conducted among the chosen groups of American and Polish students and company employees. The students study on different levels of education (undergraduate and master). This way, it was possible to see if there is a significant difference between game participants engagement depending on the group to which they belong and their previous experience. The difference between students and employees is that the employees already work in companies and have different views on the analysed problems.

The research utilized a questionnaire which assessed different groups engagement levels before and after a game. The assessment focused on game participants' motivation, cognitive processing and social aspects. The authors assumed that participating in games can change the participants' attitude and can influence motivation, cognitive processing and social aspects. The participants were examined before and after the game to assess their increase of understanding the information, which had been presented to them in the form of lectures before the game and during the game.

The games were played in Poland with master students and employees, and in the USA with undergraduate students. The total number of the questionnaires obtained from game participants was 114. The percentage of the questionnaires collected in Poland was 55% and 45% the in USA. The percentage of questionnaires received from the undergraduate students was the largest, and totalled 45%, followed by the employees with 31% and then master students with 24%. Figure 3 outlines the distribution of participants among the considered games.

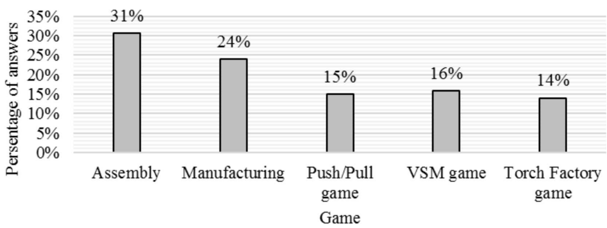

Fig. 3. Percentage of questionnaires from different game participants.

The developed questionnaire serving the first objective consisted of 25 questions (see Appendix) developed for all fields: 11 for MA, 3 for MR, 5 for MC, 1 for MS, 2 for CO and 3 for SO. For each question, the participants gave a value on a Likert scale from 1 to 9, where (1) means 'Absolutely disagree' and (9) means 'Absolutely agree'.

The prepared questionnaires were distributed among all game participants before the game and after the game.

The questions were coded with the use of letters and numbers, what was already mentioned. The first two letters refer to a processing type (MA – Motivational processing: Attention, MR – Motivational processing: Relevance, MC – Motivational processing: Confidence, MS – Motivational processing: Satisfaction, CO – Cognitive processing, SO – Social processing). A number refers to a question number in a group, the last letter refers to the time when a survey was conducted (B – before a game, A – after a game).

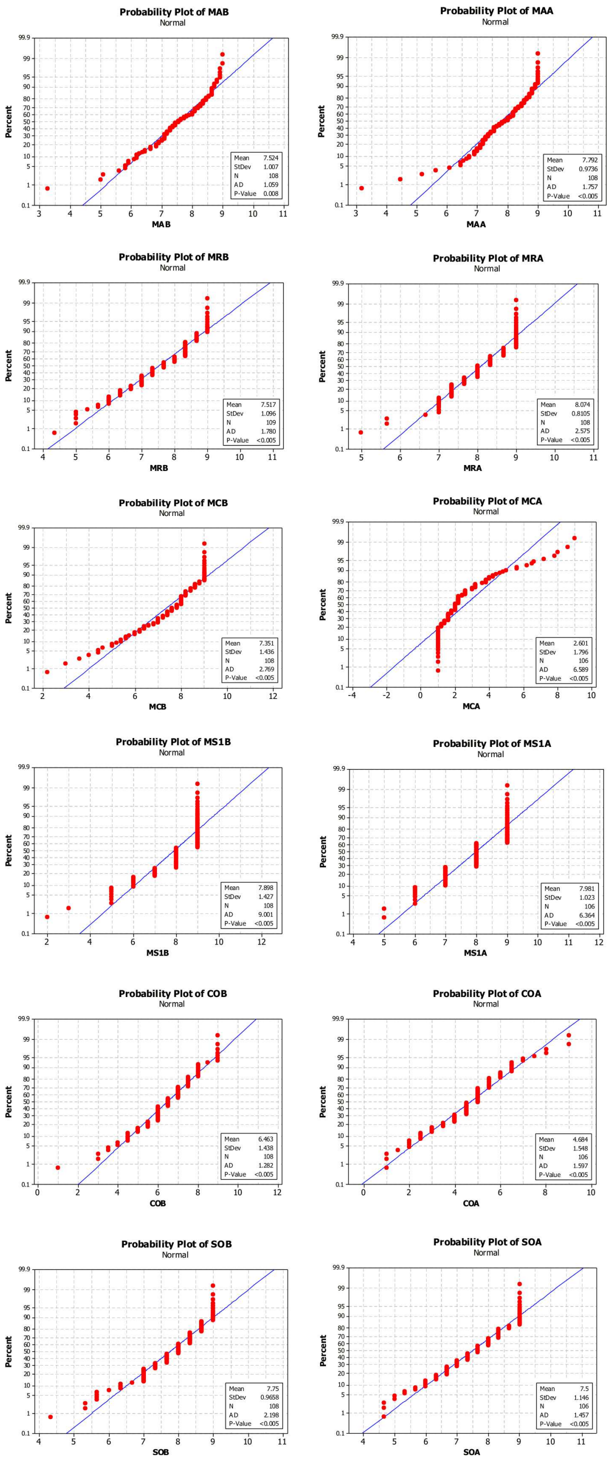

Fig. 4. Results of Anderson-Darling's normality test.

It is necessary to emphasise that some questions (MC1A, MC2A, MC3A, MC4A, MC5A, CO1A, CO2A) in the questionnaire used after the game were constructed that the lower score was the evidence of better results. The survey results were subjected to a statistical analysis.

First, Anderson-Darling's normality test was performed for the results obtained in the mentioned fields for the data obtained before and after the games in order to choose statistical tests for further analyses. Since the data are characterized by non-normal distribution (Fig. 4) in further analyses, the nonparametric methods such as Kruskal-Wallis test, Mann-Whitney test and Spearman Correlation were applied.

In a deeper analysis such factors as a country and group type (undergraduate students – US, master students – MS, employees – EM), game duration, a number of rounds and a number of tools incorporated in the game were analysed.

Finally, a discussion of the obtained results was conducted to derive recommendations for the game development and conclusions.

In order to evaluate the participants' knowledge acquisition (second objective), tests assessing the understanding of the lean topics and tools incorporated in the games were developed. The tests were prepared for the master students and employees to evaluate their knowledge before and after the games. Before the games, participants attended a training (lecture) session in which the specific lean subjects were explained. Thus, they could answer the test before the game based on how much they gained from these lectures.

For the reason that in the research the knowledge of the game participants was assessed before the game and after the game, it was possible to discover whether the participants' knowledge increased after the games. In the research a total of 114 game participants was involved: 35 company employees, 28 master students and 51 undergraduate students.

Lean gamification impact analysis

Gamification assessment with considered criteria

Basic descriptive statistical analyses were done for the data collected before and after the games. The maximum and minimum number of scores, the median, the standard deviation, Q1 and Q3, the range and the mode for each question and, then, for each analysed field were calculated. The mean values for each question were also calculated and they are further explained in the discussion section. However, an interesting initial observation from the results was that some questions had the possible maximum range (8) indicating that some answers were 'absolutely disagree' while others were 'absolutely agree'.

The descriptive statistics concerning the analysed factors, namely motivational processing: attention (MAB, MAA), relevance (MRB, MRA), confidence (MCB, MCA), satisfaction (MS1B, MS1A) as well as cognitive processing (COB, COA) and social processing (SOB, SOA), are presented in Table 3.

Analysing the first area of investigation in the 'Motivational processing' which is 'Attention' (MAB, MAA), the high scores of the questions before and after the games point to how just being engaged in a game setup can directly capture the attention of participants. The people expected that the game elements as well as obtaining role playing tasks will keep their attention. It reflects one important aspect of the positive impact that gamification has on the learning process over a traditional lecturing approach. The wide range of answers was due to only one person. According to this participant's opinion the game didn't keep his attention. Most participants had high attention towards the games and the results showed that they reported a higher attention level after the game.

Another area of 'Motivational processing' was 'Relevance' (MRB, MRA), which was analysed in 3 questions. The high constant scores of these questions before and after the games can be attributed to how most of the participants tried to link the game components (tools) with the things of their interest or which they had experienced before. The relevance of the studied components plays an important role in the participants' engagement and retention of knowledge. It adds another positive impact of gamification in the learning process. After the game, the relevance was even better.

Confidence was the next area in 'Motivational processing' (MCA, MCA), and the scores show that a few people did not feel confident playing some games. These results suggest that the participants' expectation of success in these games was not always high or uniform. Confidence, as discussed earlier, is highly related to the perception of success. Therefore, additional mechanisms that check if all participants understood the topic and the problems well should be incorporated in some games.

Most participants expected that the game will not contain too much information. Thus, those games with too much information or difficult to understand or a bit abstract had relatively lower confidence scores even after the game completion.

The last area of 'Motivational processing' was 'Satisfaction' (MS1B, MS1A) with only one question used for the assessment. The high scores for the before and, even higher after the questions, reflect how games satisfy and cater for the participants' interests in general. This is another important indication of a positive gamification impact on the learning process, at least in this technical context of lean learning.

The next area of assessment was 'Cognitive processing' (COB, COA) with two questions. The scores show that a little more than a half of participants expected that they would not have to put too much mental effort to learn the content from the game. After the game more people assessed that they did not put too much effort to learn the content from the game. Furthermore, most participants expected that they would be able to learn the content from the game without difficulties, and the after game scores confirm such expectations. Although cognitive load is always the most challenging aspect for person's learning, the gamification approach shows through these scores that such a challenge can be better ma-

Table 3
Descriptive statistics.

Variable	N	Mean	St.Deviation	Minimum	Q1	Median	Q3	Max	Range	Mode
MAB	108	7.52	1.01	3.27	7.00	7.55	8.36	9.00	5.73	8.64
MAA	108	7.79	0.97	3.18	7.27	7.91	8.55	9.00	5.81	9.00
MRB	109	7.52	1.10	4.33	7.00	7.67	8.33	9.00	4.67	8.33
MRA	108	8.07	0.81	5.00	7.42	8.00	8.67	9.00	4.00	9.00
MCB	108	7.35	1.44	2.20	6.60	7.70	8.40	9.00	6.80	9.00
MCA	106	2.60	1.80	1.00	1.40	2.00	3.20	9.00	8.00	1.00
MS1B	108	7.90	1.43	2.00	7.00	8.00	9.00	9.00	7.00	9.00
MS1A	106	7.98	1.02	5.00	7.00	8.00	9.00	9.00	4.00	9.00
COB	108	6.46	1.44	1.00	6.00	6.50	7.50	9.00	8.00	6.00
COA	106	4.68	1.55	1.00	4.00	5.00	5.50	9.00	8.00	5.00
SOB	108	7.75	0.97	4.33	7.00	8.00	8.33	9.00	4.67	8.00
SOA	106	7.50	1.15	4.67	6.67	7.67	8.33	9.00	4.33	9.00

naged through it. Nevertheless, some participants reported that it was more difficult than they had expected.

The last area of the assessment was 'Social processing' (SOB, SOA) with three questions. Most participants expected a high spirit of teamwork and cooperation in their team. However, the answers after the game showed that this spirit was less than what it had been expected. Although this is a counter intuitive to the expected impact of gamification on the social processing, a justification for that would be the level of excitement that games generate among the participants before being engaged in the games. The complexity and dynamics of games interaction can decrease such excitement suggesting the importance of setting expectations among participants when leading them through gamification.

Gamification assessment with considered criteria

The next analysis explored whether the country, type of participant, game duration, number of rounds or number of tools incorporated in the games have an influence on the research results.

Different hypotheses were put and then tested with the use of Kruskal-Wallis test, and Mann-Whitney test in Minitab 16 as well as Spearman Correlation in Statistica 12. The key parameter, taken into account in statistical tests for assessing the reliability of estimation, is the sample size. In the literature, the suggestion can be found that in order to obtain reliable results, it is advisable to analyse a relatively large number of data pairs (more than 30) [31]. However, in the work [32] the authors state that in most cases 10 bootstrap draws is enough to establish basic behaviours. In the performed statistical tests the minimal number of data pairs was 16.

In this paper different hypotheses were explored. The results of the performed tests are presented in Tables 4–6.

Table 4
Results of statistical analyses: Kruskal-Wallis and Mann-Whitney tests; P-value; TP – type of participants.

Variable	Country	TP	Variable	Country	TP
MAB	**0.023**	**0.001**	MS1B	0.684	**0.009**
MAA	0.762	0.502	MS1A	0.964	0.215
MRB	0.462	**0.003**	COB	0.447	0.191
MRA	0.199	0.060	COA	0.783	0.215
MCB	0.294	0.252	SOB	0.281	0.116
MCA	0.165	0.376	SOA	**0.005**	**0.015**

The proposed hypotheses are presented and analysed as follows:

Hypothesis A0: There is no difference between the results obtained from Polish and American game participants in the area of social processing.

Hypothesis A1: The results obtained from Polish and American game participants differ significantly in the area of social processing.

Hypothesis B0: The competition existing in the games enhanced the engagement of participants from different types of participants equally.

Hypothesis B1: The competition existing in the games enhanced the engagement of participants from different types of participants differently.

Because P-value equals 0.005 ($P\text{-value} < 0.05$), Hypothesis A0 is rejected in favor of Hypothesis A1.

Table 5
Results of statistical analyses: Spearman correlation; R Spearman value; GD – game duration, NR – number of rounds, NT – number of tools.

	GD	NR	NT	MAB	MAA	MRB	MRA	MCB
GD	1	**0.690**	**0.512**	–0.084	–0.152	**–0.328**	**–0.233**	–0.076
NR	**0.690**	1	**0.919**	0.111	–0.115	–0.115	**–0.225**	0.044
NT	**0.512**	**0.919**	1	**0.199**	–0.069	–0.015	–0.139	0.065
MAB	–0.084	0.111	**0.199**	1	**0.419**	**0.619**	**0.461**	**0.367**
MAA	–0.152	–0.115	–0.069	**0.419**	1	**0.412**	**0.594**	**0.231**
MRB	**–0.328**	–0.115	–0.015	**0.619**	**0.412**	1	**0.363**	**0.492**
MRA	**–0.233**	**–0.225**	–0.139	**0.461**	**0.594**	**0.363**	1	**0.190**
MCB	–0.076	0.044	0.065	**0.367**	**0.231**	**0.492**	**0.190**	1
MCA	0.137	–0.028	–0.002	–0.093	–0.006	–0.184	–0.097	–0.169
MS1B	**–0.248**	–0.070	0.049	**0.336**	**0.314**	**0.469**	**0.190**	**0.392**
MS1A	–0.124	–0.079	–0.006	**0.348**	**0.539**	**0.260**	**0.471**	0.145
COB	–0.098	0.006	0.108	**0.370**	0.127	**0.397**	0.180	**0.465**
COA	–0.050	0.084	0.177	0.008	**0.224**	–0.007	–0.035	0.046
SOB	–0.207	–0.130	0.009	**0.521**	**0.384**	**0.393**	**0.285**	**0.303**
SOA	–0.141	–0.123	–0.047	0.186	**0.358**	0.041	0.150	0.068

Table 6
Results of statistical analyses: Spearman correlation; R Spearman value.

	MCA	MS1B	MS1A	COB	COA	SOB	SOA
Game duration	0.137	**−0.248**	−0.124	−0.098	−0.050	−0.207	−0.141
No of rounds	−0.028	−0.070	−0.079	0.006	0.084	−0.130	−0.123
No of tools	−0.002	0.049	−0.006	0.108	0.177	0.009	−0.047
MAB	−0.093	**0.336**	**0.348**	**0.370**	0.008	**0.521**	0.186
MAA	−0.006	**0.314**	**0.539**	0.127	**0.224**	**0.384**	**0.358**
MRB	−0.184	**0.469**	**0.260**	0.397	−0.007	**0.393**	0.041
MRA	−0.097	**0.190**	**0.471**	0.180	−0.035	**0.285**	0.150
MCB	−0.169	**0.392**	0.145	**0.465**	0.046	**0.303**	0.068
MCA	1	−0.065	−0.033	−0.065	**0.463**	−0.168	0.107
MS1B	−0.065	1	**0.240**	**0.245**	0.094	**0.336**	0.057
MS1A	−0.033	**0.240**	1	0.026	0.214	0.107	**0.309**
COB	−0.065	**0.245**	0.026	1	−0.121	**0.480**	0.062
COA	**0.463**	0.094	0.213	−0.122	1	0.023	0.154
SOB	−0.168	**0.336**	0.107	**0.480**	0.023	1	**0.309**
SOA	0.106	0.057	**0.309**	0.062	0.154	**0.309**	1

This means that the country where the games were played in this specific experiment might have an influence on social processing.

Because P-value equals 0.001 (P-value < 0.05), Hypothesis B0 is rejected in favor of Hypothesis B1 which means that the type of participants might have an influence on the participants' engagement.

In further analyses it was discovered that the difference comes from the questions: 'I expect that the competition can only enhance my engagement in the game' (SO2B) and 'The competition enhanced my engagement in the game' (SO2A) (Fig. 5). After the games, the engagement in the game decreased in some cases. Therefore, it is interesting to consider why this happened. Thus, it will be discussed later in this work.

Table 4 shows that the type of participants has also a significant influence on social processing. The details concerning particular questions are presented in Fig. 6. Figure 6 presents that mostly the employees' engagement enhancement by competition was lower after the game. Possible reasons will be discussed later in this work. Furthermore, although a game duration has no significant influence on general social processing, Fig. 7 suggests that when a game duration is 6 hours, the engagement enhanced by competition is much lower.

However, the engagement decreased when a game duration was 4 hours. Therefore, it can be suggested that the game duration should be 3 hours in order to keep the participants engaged. Additionally, in deeper analyses, it was discovered that the lower employees' engagement enhancement by competition occurred in longer-lasting games.

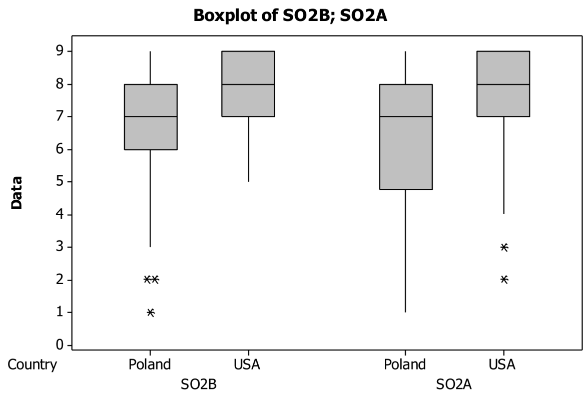

Fig. 5. Boxplot of the results obtained for the questions 'I expect that the competition can only enhance my engagement in the game' (SO2B) and 'The competition enhanced my engagement in the game' (SO2A) in the countries.

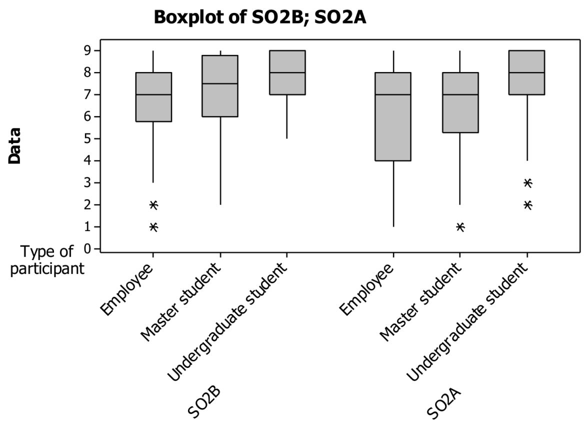

Fig. 6. Boxplot of the results obtained for the questions 'I expect that the competition can only enhance my engagement in the game' (SO2B), 'The competition enhanced my engagement in the game' (SO2A), for different types of participants.

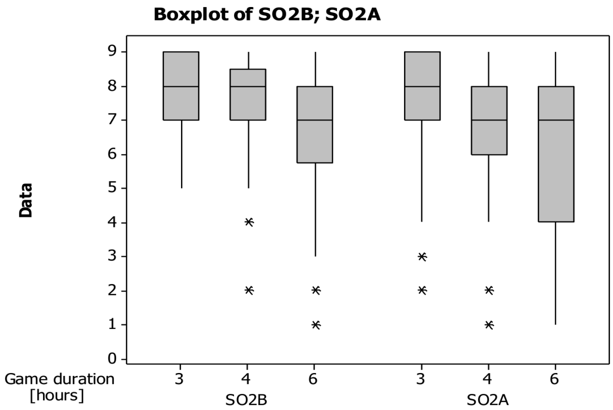

Fig. 7. Boxplot of the results obtained for the questions 'I expect that the competition can only enhance my engagement in the game' (SO2B) and 'The competition enhanced my engagement in the game' (SO2A) for different duration of games.

Moreover, it was noticed, that relevance scores were better when the number of rounds was 2 and the game duration was 3 or 4 hours (Fig. 8).

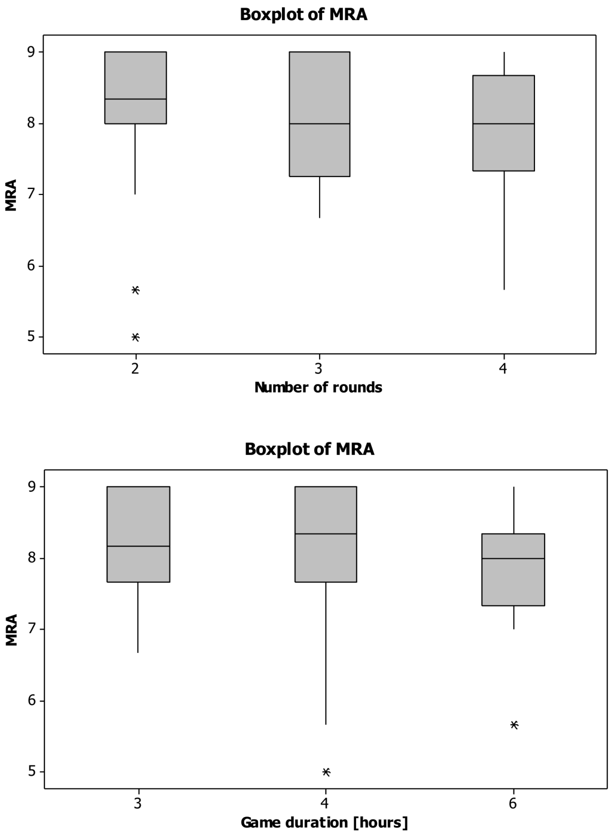

Fig. 8. Boxplots of the relevance for a different number of rounds and different duration of games.

The impact of game complexity on competition was investigated and tested with the following hypothesis: Hypothesis C0: The competition existing in the games enhanced the engagement of the participants playing game with different complexity equally.

Hypothesis C1: The competition existing in the games enhanced the engagement of the participants playing game with different complexity differently.

Because P-value equals 0.01 (P-value < 0.05), Hypothesis C0 is rejected in favor of Hypothesis C1 which means that the game complexity might have an influence on the participants' engagement. The results in Fig. 9 show that the engagement of people was the highest when they played a game characterised by a complexity index around 81, suggesting a balance between over simplified games and highly complex games to be the best target for the improved engagement.

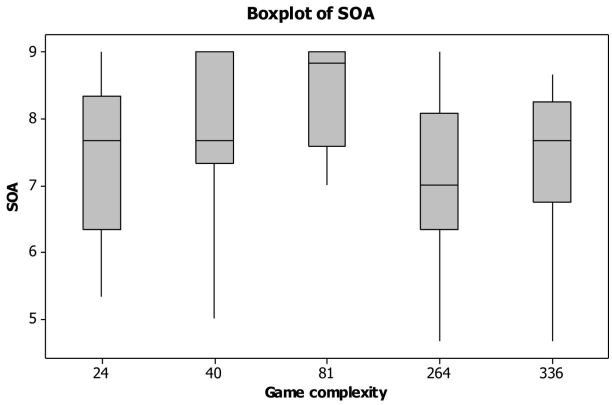

Fig. 9. Boxplot of the results obtained for the question 'The competition enhanced my engagement in the game' for games complexity.

For example, game duration between 3 to 4 hours played in 2 or 3 rounds that has from 5 to 9 incorporated tools can match this criteria.

Generally, these results point to the importance of game design when it comes to engaging participants by means of gamification.

Knowledge acquisition improvement test

Finally, the analysis of the participants' knowledge improvement was assessed on the basis of the performed knowledge tests. Two tests were carried out by two different groups of participants (the master students and employees). The first test was taken after a lecture explaining the lean concept before the game. The second test was taken after the game highlighting the same lean concept. Normality distribution tests for the knowledge assessment results were performed. It was revealed that the distribution is normal for master students as well as for employees, before and after the games (Fig. 10). Descriptive statistics for the scores received before and after the

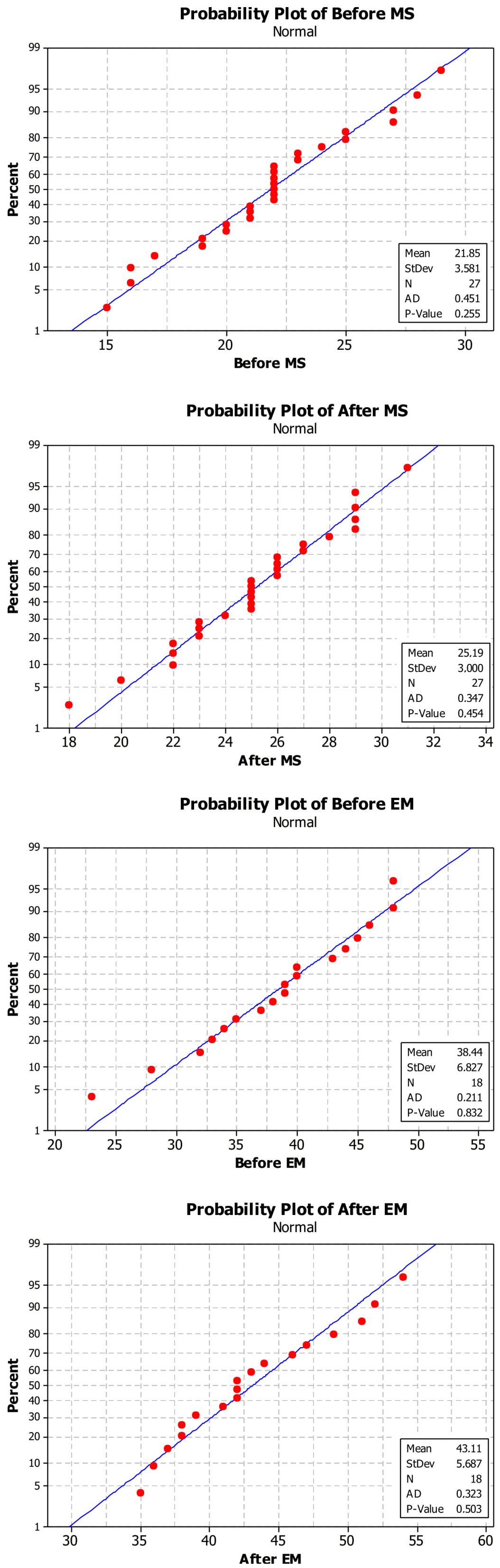

Fig. 10. Results of Anderson-Darling's normality test for the results of a knowledge test; MS – master students, EM – employees.

games by master students and employees are presented in Table 7, while descriptive statistics for the knowledge improvement (KI) are presented in Table 8. Figure 11 presents an interval plot of the scores received from a knowledge test before and after the games of master students and employees.

Table 7
Descriptive Statistics for scores; St. Dev. – Standard Deviation; Me – median, V – variable, B – before, A – after.

V	N	Mean	St. Dev.	Min	Q1	Me	Q3	Max
B-MS	27	21.9	3.6	15	20.0	22	24.0	29
A-MS	27	25.2	3.0	18	23.0	25	27.0	31
B-EM	18	38.4	6.8	23	33.8	39	44.3	48
A-EM	18	43.1	5.7	35	38.0	42	47.5	54

Table 8
Descriptive Statistics for knowledge improvement (KI); V – variable, F – factor.

F	N	Mean	St. Dev.	Min	Q1	Me	Q3	Max
EM	18	4.67	3.43	-1	1.75	5	6	12
MS	27	3.33	2.60	-1	1.00	3	5	9

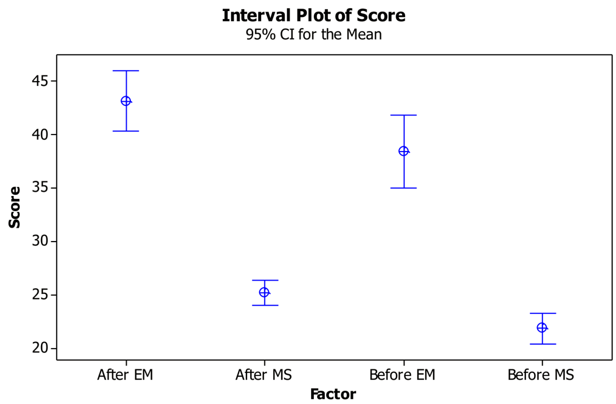

Fig. 11. Interval plot of scores received from test before and after a game; MS – master students, EM - employees.

Based on the previous data, the following hypotheses were tested in order to explore the relation between the knowledge acquisition and type of participants:

Hypothesis D0: There is no difference between the knowledge acquisition by master students (MS) and employees (EM).

Hypothesis D1: There is a difference between the knowledge acquisition by master students (MS) and employees (EM).

The results present that there is no statistically justified difference between knowledge acquisition by master student and employees, since P-value equals 0.171.

On the basis of the performed analyses, it can be concluded that average improvement of the participants' knowledge acquisition in case of master students was 17%, and it was 14% for employees. Max knowledge improvement was 56% for a master student and 52% for an employee.

It can also be noted that in almost all cases the tests results after the games were better than before the games. Therefore, the positive impact of gamification on learning and retention of knowledge is highlighted.

By playing the game the participants were able to understand the problems better because they were learning by doing [33, 34].

Recommendations for games development for lean education and training

This research analysed different aspects connected to games development and utilization. Taking into account that there is a necessity for games development for the companies' specified needs, it is important to present clear guidelines which can help companies to develop their own games (or modify existing ones) in order to reflect the specific problems and environment of companies. This way, the employees will learn not only how new tools or concepts work but also why it is important to implement them in a company environment.

Based on these research results, first of all, it can be concluded that games increase the participants' knowledge significantly. Therefore, games are recommended as good tools to train company employees.

Furthermore, the following set of recommendations is suggested to allow for an effective design of games in order to ensure attention, relevance, confidence, satisfaction and knowledge acquisition:

- A game should not be too complex to ensure cognitive processing because the game participants might lose their understanding of the situation in the game:
  - (a) The recommended game duration should be from 3 to 4 hours.
  - (b) The game should have from 2 to 3 rounds.
  - (c) The game should incorporate from 5 to 9 tools that the game participants will learn about in the game.
- When introducing the game, attention, relevance and confidence can be enhanced by:
  - (a) Presenting in a clear way a game goal which seems to be very difficult or impossible to achieve, what ensures the attention of participants.
  - (b) Motivating employees to look for connections between the game elements and their own work environment. Therefore, the relevance can be noticed by participants.
  - (c) Presenting a set of tools which are incorporated in the game, hence a participant confidence can be ensured.
- At the end of the game, a satisfaction rate can increase by summarizing the obtained results and comparing them to the goal.
- By incorporating the elements of competition in the game, the need of collaboration and communication, as well as social processing can be increased.

Conclusions

This research aimed at assessing the impact of gamification on the lean manufacturing knowledge acquisition and learning process. The assessment was based on exploring motivational, cognitive and social processing associated with gamification as well as pre and post gamification exams. The attention, relevance, confidence and satisfaction (ARCS) model was used to capture motivation processing of the learners. Data was gathered from the students and employees in the US and Poland. The game participants learned different lean manufacturing principles and tools using physical games that mimic real manufacturing and service environment. In general, the reported results showed that gamification seems to enhance participants' motivation, cognitive and social processing as well as the knowledge acquisition, leading to an improved learning process. The paper presented recommendations to design effective games.

Some further observations and recommendations are mentioned as follows:

The participants were motivated by the engagement of the gamification process as the games managed to catch their attention, enabled them to relate many of theoretical concepts to the real life and, to an acceptable extent, made them confident that they would success in their tasks. These factors led to a high score of satisfaction reported by the participants and confirming that gamification enhances motivational processing during the learning process.

The gamification approach in this study demonstrated an ability to manage the cognitive processing challenge typically faced in a similar technical learning setup. The participants reported that the played games did not require high cognitive load or effort. This could mean that the required mental processing to understand and apply the considered lean manufacturing tools was achieved with a higher success level than the a typical lecturing approach that tries to achieve the same goal.

The social processing assessment of gamification was positive as expected in such participants' context. However, the study encountered an interesting observation regarding how the excitement and social interaction expectation among participants can be affected by the difficulty of and effort put in the games. It was one way to explain the slight drop in the scores of the social processing questions before and after the game.

Although gamification had a clear positive impact on the learning process as stated above, the results of a further analysis showed that the extent of such impact is also influenced by the participants' learning setup, experience and the game's design. Undergraduate students with more hands-on education were more engaged in the games than master students with a less exposure to this type of a learning process. Moreover, games designed with an average challenging level and with ability to have significant success results tend to be more engaging to game participants. These results should highlight the important aspects to be considered by trainers when endorsing a similar gamification approach.

Gamification also showed, through the pre and post games tests, that in addition to engaging game participants, it improves knowledge acquisition and retention as well.

It is important to note that the results of this study are bounded by the chosen games which were played only in two countries with the people studying on different study levels and employees. Moreover, because small samples were used, the results of statistical analyses might not be valid for the entire population. Therefore, in future research, the survey can be performed among more groups of students involved in playing the games. Nevertheless, much of the general findings can be extended and applied in the context of gamification application in technical trainings.

The limitation of this work is related to the fact that all analysed games concerned the lean concept implementation in manufacturing and assembly processes in order to identify and eliminate waste, improve a material flow and solve quality issues to facilitate production planning and control. Therefore, the presented research results might not be valid in other contexts. In the future work, it is planned to conduct similar analyses for other games used in a different learning context related to the problems such as a product and process design. Additionally, the future research would include exploring the interaction between different learning components, and extending the analysis to include the impact of more social aspects to make the game participants even more open for collaborative work.

Appendix

Questions used in surveys: before (B) and after (A) a game

Motivational processing: Attention

MA1B: A possibility of topic presentation by attending the game seems to me as an interesting idea
MA1A: There was something interesting at the beginning of the game that got my attention
MA2B: The game should be eye-catching
MA2A: The design of the game is eye-catching
MA3B: Playing the game will help me to hold my attention better then attending the lectures
MA3A: The quality of the game kit helped to hold my attention
MA4B: Playing the game might awaken my curiosity about this topic
MA4A: I enjoyed the game so much that I would like to know more about this topic
MA5B: In the game I should obtain tasks to do to keep my attention
MA5A: The way the tasks were arranged in the game helped keep my attention
MA6B: The game should contain things which will stimulate my curiosity
MA6A: The game has things that stimulated my curiosity
MA7B: It is important to me to really enjoy learning with the game
MA7A: I really enjoyed learning with the game
MA8B: After the game I expect feedback or comments concerning my tasks realization, which will help me to feel awarded for my effort
MA8A: The wording of feedback or comments after the exercises helped me feel rewarded for my effort
MA9B: I expect the variety of reading passages, exercises, illustrations, etc., which will help me to keep my attention on the game
MA9A: The variety of reading passages, exercises, illustrations, etc., helped keep my attention on the game
MA10B: The content of the game should be related to things I have seen, done or thought about in my own life
MA10A: I could relate the content of the game to things I have seen, done or thought about in my own life

MA11B: I expect that it will be a pleasure to work on the game
MA11A: It was a pleasure to work on such a well-designed game

Motivational processing: Relevance
MR1B: It should be clear to me how the content of the game is related to things I already know
MR1A: It is clear to me how the content of the game is related to things I already know
MR2B: I think that the game can be important for me and help me to understand game topic
MR2A: There were examples that showed me how the game could be important to some people in the learning setting
MR3B: In the content of the game I should find something what is interesting to me
MR3A: The content of the game is relevant to my interests

Motivational processing: Confidence
MC1B: I expect that the game will not be difficult to understand
MC1A: The game was more difficult to understand than I would like for it to be
MC2B: I expect that the game will not contain too much information that will be too hard to pick out and remember the important points
MC2A: The game had so much information that it was hard to pick out and remember the important points
MC3B: I expect that the game will not be too abstract that it would be too hard to keep my attention on it
MC3A: The game is so abstract that it was hard to keep my attention on it
MC4B: I expect that the exercises in the game will be not too difficult
MC4A: The exercises in the game were too difficult
MC5B: I expect that I will be able to understand quite a bit of the material in the game
MC5A: I could not really understand quite a bit of the material in the game

Motivational processing: Satisfaction
MS1B: I expect that the game will be successfully completed
MS1A: It felt good to successfully complete the game

Cognitive processing
CO1B: I expect that I will not have to put too much mental effort to learn the content from the game
CO1A: How much mental effort did you invest to learn the content from the game?
CO2B: I expect that I will be able to learn the content from the game without difficulties
CO2A: How difficult was it for you to learn the content from the game?

Social processing
SO1B: I expect a spirit of teamwork and cooperation in my team
SO1A: A spirit of teamwork and cooperation exists in my team
SO2B: I expect that the competition can only enhance my engagement in the game
SO2A: The competition enhanced my engagement in the game
SO3B: I think that my team will be able to communicate effectively with other teams
SO3A: My team communicates effectively with other team

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