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Serious Games in Manufacturing Education: Evaluation of Learners' Engagement

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Abstract

Presently industries need new generation of knowledge workers who are adept with the dynamics of manufacturing systems. Consequently, application of serious games as a promising learning method has emerged in manufacturing education. Serious game is aimed at learning rather than pure entertainment. Thus, evaluating the effectiveness of a serious game in improving the learning outcome is a paramount issue. In this paper, after reviewing efforts which have been made in serious games' evaluation, the level of learners' engagement that played the Set Based Concurrent Engineering (SBCE) game is examined. The game is designed at Politecnico di Milano, Italy to bring a hand-on experience on lean product development for practitioners and academia. The study is based on one company case in Italy. The results show that a high level of engagement among learners is exhibited based on the evaluation framework adopted.

Keyword: Manufacturing education; Serious game evaluation; Engagement

1. Introduction

Nowadays, increasing the intensive competition between manufacturing companies compels them to reorganize their human resources seriously by recruiting multi skilled engineers and technicians who have enough knowledge and expertise. Several efforts have been made to design new learning methods in order to train novice engineers about the production concepts in diverse manufacturing areas as well as teaching engineering students in novel ways to transfer real world applications to educational class.

Today, serious games are known as a new and promising instructional method in different areas, and recently they have also appeared in manufacturing and engineering education. In particular, serious games

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provide opportunities for learners by putting them in a specific learning environment where players can assume different roles in a manufacturing firm. In this case, the entertainment characteristics and educational contents are seamlessly integrated. Serious gaming as similar as other well-known learning methods needs to be established on prominent learning theories in order to improve the learning outcome. The application of serious game in manufacturing education is still at infant stage and only few studies have focused on measuring the effectiveness of serious games on cognitive and affective learning outcomes in manufacturing area. Most of grounded and application theories in learning have highlighted the importance of applying learning methods in which learners are engaged in the learning process where they are encouraged to be involved actively to improve specific learning outcomes[3], [7] and [26]. In this paper, the level of engagement among players who have played SBCE game is the main focus of the study. This game is designed to enhance the knowledge of "Lean Thinking" in "New Product Development Process" both in engineering schools and industrial centers. "Challenge", "Control", "Immersion", "Interest" and "Purpose" are considered as factors that drive engagement and motivation based on the previous studies, particularly efforts made by Malone and Leaper (1987) and Csikszentmihalyi (1990).

2. What is a Serious Game?

"Game" can cover variety of activities and its definition strongly depends on the authors' perspective of the game. There are various characteristics of a game which are identified in the literature. Serious game is still not a well-defined term and there are some related and similar terms in the literature such as "Simulation game", "Game Based Learning", "Educational game" and "Edutainment". In general, the application of games which are aimed at education and learning can be defined as "Serious Games" [32]. It is defined by some researchers as an activity whose main purpose is learning serious context through playing [5], [11] and [36]. Learning and education via games are the main objectives rather than pure entertainment in serious games [10]. Yusoff considers three different perspectives for design a serious game: "Educational" perspective, where the grounded and application theories of learning are considered; "Psychology" perspective, which represents factors that make a serious game motivational and engaging, "Computer science" perspective, that specified by using tools and technologies for enhancing the learning effectiveness [35].

3. Current Challenge for Learning in Manufacturing Education

Noticeable changes are happening in technological and economical aspects in the new century, all parts of society have to face both threats and opportunities. These challenges are strongly affecting manufacturing systems where context and content of engineering practices need to be harmonized by technological evolutions. Reforming the engineering education, both in engineering schools and industries, is an interest among all stakeholders, though the efforts yet made have not be able to make significant improvements so far [8]. In manufacturing systems, employees in different positions and lines, in particular managers and engineers, need to take regularly both simple and critical decisions such as: how to communicate with other people, how to design a production system, how to deal with environmental issues, how to operate a sophisticated machine and so on. On the other side, traditional education systems in business and engineering schools are noticeably converting to the modern systems where students' participation and satisfaction are contemplating towards enhancing the learning outcomes. These bring the roles of engineers and managers to "knowledge workers" in industrial systems and force them to quickly adapt the economical, technological and social changes. In this context, companies are also looking for dexterous employees who can build persuasive added-value in unstable situations [29]. In this case, new approaches have been emerged. For example, "Teaching factory" is aimed to make integration between industry and academia in order to define common projects, so that new knowledge is created and skills are improved. Teaching factory patterns itself from medical schools where learners are

trained in a hospital [6]. Similarly, "Serious Game" in last decade has been distributed considerably in many education programs in several domains, and recently engineering and manufacturing domains also have been influenced significantly. Serious games provide virtual environments where learners can assume different roles in a manufacturing system, and interact with other roles in sophisticated virtual environments. Serious games also enable players to make complicated decisions without interfering the real practices. Thus, avoid irreparable damages if it would have been done otherwise. Therefore, serious game is an outstanding mechanism to offer educational training in more engaging and saver manner both in academia and industries.

4. Application of Serious Game in Manufacturing Education

Previous studies have indicated that the traditional learning methods based on "reading", "listening" and "observing" are ineffective, and around 10% to 30% of contents might be recalled by students [29]. Applying advanced learning technologies in order to train high knowledge and multi-skills employees increase the effectiveness of the educational values of the game.

In recent years, applying serious games is getting popular because of expanding the evidences of their benefits in various areas such as health care, soft skills and military. The concept is also developing in manufacturing and engineering domains by focusing on multiple issues such as: supply chain management, new product development, logistic, maintenance, lean production, sustainable production, capacity planning, etc. Furthermore, serious games are applied in order to teach a number of complicated courses in electrical, mechanical, industrial and aerospace engineering. It increases students learning productivity on courses which most students have avoided to take them even as elective.

5. Effectiveness of Serious Game

Searching in literature determines a number of frameworks for evaluating the effectiveness of serious games. Bloom presented a prominent taxonomy in learning domains where three types of learning outcomes are identified [3]. Cognitive type describes acquired knowledge in different level. This is classified in a hierarchy that begins with recalling information and data in the lowest level to the highest one where learners will be able to evaluate information and make judgment. Psychomotor is the second type that focuses on improving skills including physical movement, coordination, etc. Finally, affective learning type identifies the role of emotional attributes in order to reinforce learners feeling so that they are engaged in the learning process [3]. Certainly, serious game as a learning methodology in manufacturing domain is not an exception. Manufacturing domain encompasses complicated scenarios in terms of involvement, complicated decision making, and collaborative environment. Serious games have to be designed and presented in engaging manner to give motivational inertia for players in this domain. Therefore, effectiveness of serious games need to be well investigated from the design phase of a game.

In literature, there are some frameworks designed to evaluate the effectiveness of serious games as listed in Table 1. Explanations are provided below addressing those which focuses on motivation and engagement.

Garris, Ahlers and Driskel (2002) develop a model to show how a game supports learning outcomes (Figure 1). Blurring the educational contents and game characteristics is highlighted in this model [27]. A game needs to be designed so that players are stimulated to repeat the game process, and during this iteration cycle players are engaged in the game to acquire the target knowledge and skills. This framework emphasize on three main phases. First, instructional attributes and game characteristics are incorporated as inputs to the learning model. Second, the input features should able to make a reaction in players such as engagement or fun, also changing learners' behaviors such as concentration in given task. In this phase learners receive immediate feedback based on their performances, and finally in the last phase the learning outcome happens [12].

Table 1. Existing frameworks for serious game evaluation

Study	Framework
de Frietas and Oliver (2006)	Four Dimensional Framework
Amory (2006)	Game Object Model version 2
Kiili (2005)	Experiential Gaming Model
Egenfeldt – Nielsen, Simon (2003)	Learning environment, personal learning factor, learning outcome
Garris et al., (2002)	Game Based Learning model
Hu (2008)	Adventure Game Framework
Wouters et al., (2008)	Learning outcomes taxonomy
Karoulis and Demetriadis (2005)	Motivational matrix
Malone and Lepper (1987)	Design Heuristic for Motivating Instructional Environment
Hainey (2010)	Game Based Learning

de Freitas and Oliver (2006) present a framework for evaluation the effectiveness of serious games with focusing on tutors' interest. They explain that a few efforts have been done to assist teachers in order to assess the learning impact of the simulation and serious games [8]. At present, when teachers are considering in employing a game for a specific learning purpose some questions arise. Which games they need to choose to support a particular learning context? Or, what is the effectiveness of selected games?

They develop the Four Dimensional Framework (FDF) model taking pedagogy approach. "Context" represents where the learning and game happens, the structure of its application and how it is supported by technical tools. These factors support learners to overcome different challenges during the game. "Learners" is the second one that describes factors related to learners that can impact on learning effectiveness such as learners' preferences, level, age and background. As the third attributes, "Mode of representation" represents interactivity, the level of immersion and the level of fidelity considered in the game or simulation. Specifically, the role of briefing and debriefing in order to boost the learning outcomes that happens before and after an educational game is considered in this part. Finally, "Pedagogy" is designed to stimulate the participants about the method, model and theories applied to enhance learning outcomes. E-Contents, advances software and e-Assessment are some examples in this final aspect.

These four dimensions have not to be considered separately in order to measure the effectiveness of a serious game or simulation in a learning process [8].

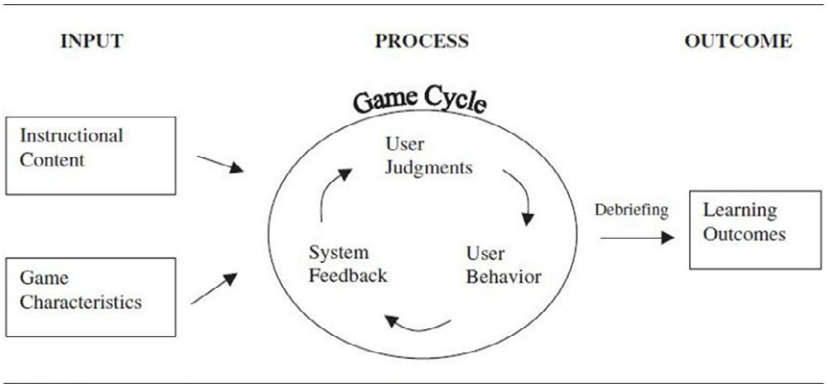

Fig. 1 Game-Based Learning model [12]

Hainey (2010) develops an assessment model for Game Based Learning based on literature and surveys. The framework includes six categories, "Learners' performance" is the first aspect and it focuses on measuring the improvements in the performance of the learners because of playing a game. For example, enhancement in the different levels of knowledge acquired based on Bloom taxonomy [3]. "Learners and instructors' motivation" represents the level of interest and motivation of learners in the game. He emphasizes that players need to be engaged in the learning process and also identifying factors that impact on teachers' motivation to use serious games into their curricula. "Learners and instructors' perception" deal with the perception of time within a game or simulation, the level of reality perceived and the perception of complexity. "Learners and instructors' attitude" can be identified as Players' attitudes towards the teaching context and game, teachers' attitude about fitting the game into the specific curricula and their attitudes toward game characteristics. The next one, "Learners and instructors' preferences" explains players' preferences about application of educational games. Learners desire to achieve knowledge or skills in different ways and might use different styles [24]. These can be investigated by asking questions like, do they prefer learning or teaching by using serious games rather than conventional approaches. On the other hand, "GBL environment" includes all of the factors in the game environment which can affect a game's effectiveness. Finally, "Collaboration" is considered as an optional aspect when the game is played in cooperation and competitive group level.

In this paper, we focus on the level of motivation and engagement of adult learners in playing SBCE game designed to improve the knowledge of people about "Lean Thinking" and "New Product Development Process" [22]. The applied framework in this study is based on two prominent studies have been done by Malone and Leaper (1987) and Csikszentmihalyi (1990) described in the methodology section. An interesting and unique character of this framework is that it is primarily developed to provide motivating learning environment. After applying it successfully in various learning environment, it was especially customized for designing serious games [26]. Malone and Leaper define two kinds of motivation: Individual motivation and Interpersonal motivation. Challenge, Curiosity, Control and Fantasy are presented as attributes which affect motivation in any learning situation. They are explicated such that designers will be able to allocate each of them in the game scenario. For example, it is clarified that how well different kind of feedback need to be presented in the game [26].

Considering that there are few existing studies in measuring the level of motivation in manufacturing serious games, implementing this framework in this study seems to be a good selection. Thus, designers of serious games will be able to understand and perceive the results easily and consider to improve features of a game.

6. SBCE Game

The game is designed to bring a hand-on experience to practitioners. It was designed also to narrow the existing gap in understanding the concept of Set-Based Concurrent Engineering process, which has not been well practiced in industries [28]. The game principally follows a simplified version of a Toyota approach to design a simplified Airplane [21]. The airplane has four sub-systems to be designed (body, wing, cockpit and tail). Thus, each team should be composed of four players in the game. The game is developed both in a computer based platform and a role game (Lego based game). This study is based on the Lego game since the case company (CAREL industry, www.carel.com) needed a simple and physical game. CAREL is an Italian company which designs innovative humidification and control systems in the HVAC/R market.

The game is divided into two stages: first stage, where players design an airplane for a given list of customer requirements without following a SBCE process; second stage, where players are provided with the necessary instruments to execute SBCE process. The instruments will help players to explore alternative design concepts, communicate about alternative solutions within a team, and converge into an optimal one.

Once players complete a prototype design in the first stage, they should submit it to "testing department" to check for stability, flying conditions and dimensional configurations. If it fails, the prototype should be

redesigned and players will penalized with additional time and cost. If the prototype passes the testing constraints, players will be given the breakdown of their performances in terms of quality, time and cost. Before starting the second stage, a facilitator will introduce payers with the concept of SBCE. In the second stage, players do the same as in the first stage; however, this time players will follow a structured SBCE process with its associated instruments to support player. Finally, a comparison of performances will be presented to players to compare the two stages in terms of total development cost, time and quality (quality is defined as the capability of players to design as close as what a customer wants). A total "Lean Score" will differentiate teams involved in a game play, which is obtained by aggregating the performances of a team, [21].

7. Methodology

Motivation is considered as one of the main features in affective learning outcomes in Bloom taxonomy [3]. Keller states that even the most appropriate designed game will not be successful if the learners are not motivated to learn [20]. Therefore, for answering the research question of this study (i.e. "Does SBCE game improve the learning outcome of players?"), the level of engagement and motivation are taken as factors instead of evaluating the direct learning outcomes.

Malone and Leaper present a framework based on several studies for designing motivating educational games. The four main attributes of this framework are "challenge", "curiosity", "control" and "fantasy" [26]. Killi also highlights the concept of "flow" stating that 'games are useful and engaging when they can consider the flow experience [23]. Flow is defined as an ideal experience when a person acquires a high level of concentration and enjoyment [7]. The framework for evaluating the engagement in this study is shown in Figure 2.

Players are challenged in the game process when they face with situation neither easy nor difficult and estimate the amount of probability in achieving the goals [31]. Moreover, the objectives of the game and the challenges involved in the game need to be specified obviously for the players [12]. The ability of players to take decisions and choose various options during a game play is defined as the "level of control" [26]. The degree in which players are engaged in a game represents the "level of immersion" [16]. Jannet and others state that both subjective (through questionnaires) and objective (task completion time, eye movement) measures can be applied to determine the level of immersion [17]. The level of emotion that makes positive reactions in players' behaviors is defined as interest [13]. The value perceived by players in providing different kind of feedback and debriefing process is considered as "purpose" [25].

A structured questionnaire has been prepared to validate the model and answer to the research question. The questionnaire contains 21 questions based on Likert five-point scale and categorized according to the above five classifications to measure the level of engagement. Eight questions for "challenge", five questions for "immersion", three questions for "interest", three questions for "purpose" and two questions for "control" The survey was distributed to 36 engineers and project managers who are working in the Carel Company in Italy and played the game. They were asked to answer and give it back immediately. The game session was scheduled in a workshop that held in the Carel company and it took around four hours, a screenshot of the game session is shown in Figure 3. The data collected from the survey was analyzed by both descriptive and inferential statistics. The result of this analysis is explained in details in the next section.

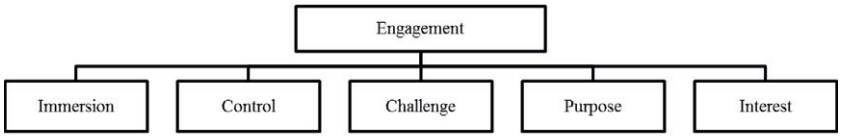

Fig. 2 Framework for evaluating the level of engagement [7, 26]

Fig. 3 A screenshot of SBCE game session

The data collected from the survey was analyzed by both descriptive and inferential statistics. The results of this analysis are explained in detail in the next section.

8. Results

Since the study is carried out in an industrial centre, one of the general questions is particularly designed to ask the "experience years" of the players in their field. The players' demographic distribution is shown in Table 3. As it is shown, 88% of learners have more than 10 years of experience in manufacturing domain (Designers and Managers). Moreover, the game play included both young and matured industrialist from both genders.

Table 2. Engagement scores: minimum, maximum, mean, median and variance

Min	Max	Mean	Median	Variance
65	104	86.5	86	86.2

The result of Skewness/Kurtosis test shows that the level of significant "P-value" for most of the questions is more than "0.05". It means that the distribution of data is not normal and one of the non-parametric tests has to be used for analyzing data [38]. Therefore, the "Wilcoxon signed-rank test" is applied to signify the effectiveness of "challenges", "control", "immersion", "interest" and "purpose" on learners' engagement.

Table 3. Percentage distribution of players' demography

Years of experience		Gender		Age	
1 to 4	6%	Male	88%	25-29	6%
5 to 9	6%	Female	12%	30-34	6%
10 to 14	53%			35-39	47%
More than 15	35%			40-44	12%
				45-49	29%

In this test, the values of each question is compared by median value. As shown in Table 5, the "positive", "negative", and "zero" values indicate if it is greater than, less than and equal to the median value respectively. In this study the five points Likert scale is employed, thus the value of median is equal to "3". For example, 192 positive value out of 288 for "challenge" determines that the given score is higher than the median, either

"4" or "5". In contrast, 28 negative value for "challenge" determines that the given score is less than the median. Therefore, most of the players had a strong feeling of challenge during the game which can stimulate learners to engage in the game and therefore learning outcome will increase. Since the level of significant value (prob>|z|) is less than "0.01" for all the variables, it can be concluded that the SBCE game with 99% probability makes sense for "challenge", "control", "immersion", "interest" and "purpose" among players, and these attributes are considered in designing the game.

Table 4. The Mean score of "challenge", "control", "immersion" ,"interest" and "purpose"

	Mean	Std. Err.	95% Conf. Interval	
Challenge	3.528	0.130	3.270	3.787
Control	3.806	0.088	3.631	3.980
Immersion	4.472	0.077	4.320	4.625
Interest	4.611	0.064	4.483	4.740
Purpose	4.278	0.095	4.088	4.468

Table 5. The result of Wilcoxon signed-rank test

		Challenge	Control	Immersion	Interest	Purpose
Observation	Positive	192	44	158	102	92
	Negative	28	0	0	2	2
	Zero	68	28	22	4	14
	All	288	72	180	108	108
	H0	3	3	3	3	3
	Z	11.192	6.501	11.714	8.923	8.816
	Prob> |Z|	0.001	0.001	0.001	0.001	0.001

Moreover, examining the reliability of the questionnaires by the "Cronbach's α" test indicates the high reliability coefficient among questions (α=0.89). One of the main challenges in designing a questionnaire is the degree of correlation between each pairs of questions which measure a common variable. The low level correlation means the method of gathering data is not reliable and consequently the result of the study will not reliable too. In this study, the correlations between each pairs of questions for each variable are calculated by "Kendal rank correlation coefficient" method [38]. For example, Table 6 shows the degree of correlation between questions designed to measure the level of "immersion". In that case, the highest correlation is "0.7869" for Q9 and Q15 and the lowest one is "0.3278" for Q9 and Q20. These results indicate an acceptable reliability of the questions to evaluate the level of engagement among SBCE players.

Table 6. The result of Kendal rank correlation coefficient test for immersion. Where: Q9 (I felt absorbed in the activity), Q11 (I felt excited during the activity), Q15 (The feedback I was given was useful), Q17 (The goal of the activity was clear), Q20 (I did enjoy the activity)

	Q9	Q11	Q15	Q17	Q20
Q9	1.0000				
Q11	0.6749	1.0000			
Q15	0.7869	0.4709	1.0000		
Q17	0.7826	0.6272	0.6216	1.0000	
Q20	0.3278	0.4804	0.4201	0.4352	1.0000

9. Conclusion

The ability of serious games to motivate learners and increase their engagement is highlighted in most of learning theories. The effectiveness of SBCE game is evaluated in this study, and the result shows a higher level of engagement among players. It also demonstrates that the components of motivation introduced in serious game evaluation taxonomies [7, 26] are considered in designing the SBCE game. This study was carried out in an Italian company that produces humidification and control system in the HVAC/R market and the results cannot represent the effectiveness of serious games in various domain of engineering education. Therefore, further studies can evaluate the game in engineering school. Further, other well-known frameworks can be used to evaluate the game in order to compare the results. Finally, the game can be run and assessed in other companies to investigate the usefulness of the game in different industrial contexts.

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