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Learning and motivational effects of digital game-based learning (DGBL) for manufacturing education –The Life Cycle Assessment (LCA) game

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ABSTRACT

Despite its potential, empirical evidence of the educational effectiveness of Digital Game-based Learning (DGBL) for manufacturing education is still limited. To this respect, the Life Cycle Assessment (LCA) Game was developed in order to explain in an interactive way to university students life cycle assessment, a tool which is becoming increasingly important for sustainable manufacturing. The study was based on a two-group pretest-posttest quasi-experimental design involving 62 participants and was aiming at understanding the impact of LCA Game on both learning and motivation of university students. The results show that students using LCA Game performed significantly better on procedural knowledge while students involved in the non-gamified activity performed significantly better on factual knowledge. In addition, while higher levels of usability and enjoyment were associated to the LCA Game group, no particular differences were found on the other motivational dimensions. Thus, this study provides important insights about the specific educational benefits that can be obtained through DGBL in manufacturing education.

1. Introduction

1.1. The manufacturing skills gap

Manufacturing is one of the pillars of European economy. In the last years, despite the global crisis affecting the sector, several advancements in both technologies and processes are fostering its progress, leading to the so-called “Fourth Industrial Revolution”. Nevertheless, despite these widespread changes, manufacturing is increasingly suffering a lack of skilled human resources able to support them [1]. In particular, high skills are those most requested but at the same time most difficult to find and develop [2]. The causes of the skill shortage have already been identified and discussed in literature. The most important can be resumed in an aging workforce, an outdated workforce planning, the limited education efficiency, the changing nature of work and a poor image of manufacturing among youngsters [3].

Despite the presence of the abovementioned issues, the exploration of the possible solutions to the skill gap problem is still in its nascent phase. To date, some important initiatives have been developed and important institutions in the sector have provided their guidelines to face it [4]. From the educational side, in the last years new teaching approaches have been developed in order to update and improve the competences of young generations and to prepare them to the new challenges of the industrial world [5]. These methodological efforts have been also supported by the development of interactive learning environments able to virtually represent to students manufacturing concepts (e.g. servitization, sustainability) otherwise hardly communicable by means of traditional teaching approaches [6]. Moreover, the use of these technologies has allowed the design of more complex learning experiences that can involve the user in a more sophisticated educational route [7]. The potential of these technologies for the manufacturing sector is therefore extremely high, since through their use the new advanced competencies requested by the industrial world could be trained in advance, forming a young workforce already ready to support innovation in the companies. In order to make concrete this manufacturing skills revolution, considerable efforts in the development and validation of the most suitable educational technologies should be done.

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1.2. DGBL for manufacturing education

The use of interactive learning environments drew its concepts on *cognitive constructivism*, where the user is considered as actively developing his/her own knowledge according to his/her experiences [8]. On the basis of cognitive constructivism, *experiential learning theory* has been developed, considering as fundamental the role of the user and his/her interaction with the teaching activity [9]. Different types of interactive learning environments have been used in the last years in order to support the development of advanced manufacturing skills and hence allow students to explore in advance the challenges of modern industrial world. Indeed interactive learning environments enable the representation of concepts (e.g. servitization, sustainability) otherwise hardly communicable by means of traditional teaching methods. For instance, simulations [10], on-line distance learning [11], virtual factory teaching systems [12] and mobile technologies [13] can be mentioned.

When digital interaction meets game-based learning then Digital Game-based Learning (DGBL) arises. The main advantage of DGBL is represented by the association of the active involvement of the learner with the fun element, that is not used anymore for mere entertainment but to support the engagement of the student [14].

As a consequence, DGBL enables specific conditions that have been identified as extremely relevant for the success of manufacturing education. In particular, it allows the sequencing of task and activities, reducing the typical complexity of many manufacturing concepts and providing a structured learning path to be followed [15]. It continuously provides real-time feedbacks for self-assessment, making learners understand where they should improve [16]. It allows reflective practice, clarifying the objectives and expected outcomes of the learning activity [17]. It stimulates creativity and problem solving ability, representing an ideal environment to continuously explore, develop and test new ideas [18]. It lets the learners play with different roles, facing different situations and therefore understanding the implications of the different activities [19]. It facilitates the multidisciplinarity of the learning activity, in order to allow proper connections among the different disciplines of manufacturing [20].

For example, Coller and Shernoff [21] discuss the use of a serious game (*NIU-Torcs*) to support a numerical methods course for undergraduate mechanical engineering students. The authors developed an application where the user has to write a C++ program in order to give a car driving commands in a real-time race in a 3D environment. With the aim of optimizing the route of the car, the students have to explore on their own concepts such as numerical root finding, curve fitting and optimization, and apply them in the coding of the race. The results show a higher motivation of students if compared to traditional teaching activities. Gomes et al. [22] present the *5S Game* aiming at explaining main concepts of lean manufacturing to mechanical engineering MSc students. The user faces four different scenarios where the 5S concept should be applied, choosing each time the proper actions according to the principles of the methodology. The motivation of the participants and the usability of the game were in general encouraging. Li et al. [23] introduced *GamiCAD*, an interactive tutorial system for AutoCAD able to provide a gamified real-time feedback on the tasks performed by the learner. Results in terms of engagement of the learner and tasks' completion ratio were higher than the non-gamified version. Hauge and Riedel [5] presented *COSIGA*, a multi-player simulation-based game about concurrent engineering (CE) approach for new product development. The different players take a realistic role and mutually interact to develop a type of truck. Evaluation of the game showed the cognitive change of participants according to the nature of the different roles interpreted.

1.3. Learning and Motivational aspects of DGBL for manufacturing ***education***

It is evident that the two main objectives of DGBL are the learning and motivational ones, even though there is still in general a lack of empirical evidence supporting these hypotheses [24–26]. For motivational aspects, few interesting results have already been made available [25,27,28] that highlight the positive impact of DGBL on students' motivation towards learning. For manufacturing education, despite the benefits identified and the different applications developed, the issue becomes even more relevant, since rarely the results of the DGBL educational interventions are collected and follow a common approach. However, as already highlighted also for manufacturing education the few results available are mainly for the motivational aspects, with scant or no evidence for the learning ones [5,21–23]. Further knowledge about DGBL effectiveness could lead to its systematic use in manufacturing curricula, identifying the concepts for which is most suitable and the requirements that are needed for its scalability.

In order to structure an analysis of DGBL effectiveness, a first distinction should be done between *assessment* and *evaluation. Assessment* is about the measurement of the achievements of persons (i.e. the users interacting with the DG), while *evaluation* is about the measurement of objects (i.e. the DG itself) [29]. In DGs specifically designed for learning objectives, the final evaluation of their effectiveness can be reasonably translated in the assessment of the learning outcomes of the users playing with it [29]. As identified by the EQF [30], those learning outcomes can be identified in terms of *knowledge* (i.e. the information re-elaborated in a structured way while learning), *skill* (i.e. the use of knowledge to do activities) and *competence* (i.e. the use of knowledge, skill and other abilities in real situations). On the other hand, according to Anderson [31], knowledge can be classified in *factual* (i.e. the knowledge of terms and details), *conceptual* (i.e. the knowledge of the theories and models that link elements), *procedural* (i.e. the knowledge on how to do something) and *metacognitive* (i.e. knowledge of one's own cognition). While knowledge as meant by EQF can be associated to Anderson's factual and conceptual knowledge, skill as meant by EQF can be associated to Anderson's procedural knowledge. From DG perspective, all the learning outcomes identified can be considered as relevant, even though their achievement becomes more difficult as far as you pass on one hand from EQF's knowledge to competence [29], and on the other hand from Anderson's factual to metacognitive knowledge.

As already pointed out, the proofs of DGs learning effectiveness are in general pretty scant so far, also because of the intrinsic difficulty to capture and formalize the changes in user's learning. For this reason, some authors proposed to focus on the measurement of transfer and application, even though this way the assessment will be extended in time and several external variables could influence the results [32]. On the other hand, it should also be considered that learning by playing needs some time in order to be effectively elaborated by the user. As a consequence, it becomes extremely critical the proper time sequencing of the assessment measures. Finally, the definition of objectives and robust assessment methods should be addressed, trying to avoid as much as possible the use of self-reported answers to measure learning outcomes [32].

In DGs for manufacturing education, the user assessment as a measure of the overall educational effectiveness should be closely related to the objectives of the specific educational intervention. In particular, the general learning objectives of the educational intervention should be expressed in terms of one (or more) of the learning outcomes represented in Table 1, and then decomposed in the specific learning objectives of the DG to be implemented. On the base of the learning outcome(s) and of the specific learning