A new approach to Gamification in engineering education: the Learner-Designer Approach to Serious Games

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ABSTRACT
Gamification is usually defined as the use of game structure components in circumstances that are not commonly associated with games. In engineering studies, Gamification and its sub-concept of Serious Games are rather widespread pedagogical models. Just like in other application scopes, the approach to their utilisation or analysis is always concerned with the players, their psychological experience and the relevance of their learning outcomes. The aim of this work is to illustrate the results of a different approach, the 'Learner-Designer Approach to Serious Games' (LDASG). The study was carried out through a single group variation on the two-group posttest-only randomised experiment and performed on 79 second year undergraduate students of an Industrial Plant Design course within a Management Engineering programme. Quantitative data on the students' learning performance and learning experience were collected through a test and a questionnaire, respectively. The test results were analyzed by means of the Paired Samples Test and effect sizes were calculated. As to the questionnaire, a descriptive analysis was employed. The outcomes obtained show how LDASG can successfully compete with other active learning methodologies.

1. Introduction

A broadly accepted definition of Gamification describes it as an action of strategic and methodological type that inserts game elements in real contexts that are not strictly related to or have nothing to do with games (Deterding et al. 2011). Originated within commercial contexts, Gamification has extended to the education sector as well as to other fields where continuous effort is required to develop skills or new knowledge, such as enterprise resource planning, intra-organizational communication and activity, government services and public engagement, crowdsourcing, commerce, exercise, health, environmental behaviour, marketing, to mention a few (Koivisto and Hamari 2019). Gamification is claimed to integrate many of the elements that are considered effective in the learning process. Moreover, it gives an answer to some major issues every teacher or instructor faces (motivation, participation, voluntary commitment and practice). Hence, it has rapidly expanded to a wide range of disciplines and contents. Along with Science, Technology, and Mathematics, Engineering education is among the educational areas where it has been more exploited (Alanne 2016; Koivisto and Hamari 2019). The increasing interest in Gamification has led to a shift from practice-based to science-based reflections (Hamari, Koivisto, and Sarsa 2014).

The focus of this study is on Serious Games, which are 'a specific sub-set of the meta-concept of Gamification' (Kapp 2012). Among the many pros in terms of learning experience and performance, the main downsides of Serious Games are related to the high level of difficulty in creating flawless and effective games. 'Unless it has already been created by a third party, it would be seen as difficult for a teacher to create a sophisticated environment of learning as seen in majority of serious games' (Sanmugam 2014). The core goal of this study is to turn these cons into educational advantages. The focus of research on Gamification and Serious Games is almost always on the players, since they are regarded as 'the real performers' (Robson et al. 2015). However, players are the recipients of a complex and articulated gamified project they are not in control of. Players, in fact, depend on the quality of the gamified experience. Therefore, this study shifted attention towards designers, rather than players. 'Designers are the decision makers … who develop and design, as well as often manage and maintain, the gamified experience' (Robson et al. 2015). Individually, or often in teams, they transfer behaviours or information to a non-expert counterpart (Hays 2005).

Through an empirical study, this article wants to analyse whether the role of designers could be taken over by engineering undergraduates. The aim is to investigate the possible advantages deriving from it in terms of learning achievement and learning experience. To this end, a comparison was carried out between the Learner-Designer Approach to Serious Games (LDASG) and the Frontal Lesson teaching mode (FL). FL is also known as 'recitation method', traditional lecturing, conven-tional-direct-recitation method or initiation-response-evaluation cycle (Hattie and Yates 2013). Its most recognisable features can be found in the role of the teacher who is in charge both of the choice of the contents and the pace of the lesson. On their part, students usually listen, take notes and rarely get involved in answering questions. LDASG, instead, represents a new educational path towards an original methodologythat merges and takes advantage ofGamification and active learning features. Students become designers or, in more traditional educational terms, instructors. But who are they really teaching? Even if the goal of their design is to transfer information to future players, in the design phase they are actually unwittingly teaching themselves too. This is a new perspective within Gamification implementation which has been very little investigated in literature. In this approach, students are pushed towards an activity which is characterised by metacognition along with the motivating drive of a gameful context. The design of a gamified instructional activity compels them to organise the inner structural hierarchy and correlation of the contents (Burke 2014; Kapp 2012). Moreover, LDASG is not just a simulation, but it is real and for real recipients, that is, their own peers (the players) and teachers. Hence, it is socially motivating. From now on, the authors will refer to this new role taken up by the students as to that of the 'learners-designers'. In fact, the two roles of the learner and the designer overlap and are simultaneously exploited.

The specific segment this article is focused on is the first part of the design process, the one that comes before the implementation of a serious game. The consequent phase of restructuring the design according to the feedback received by the players and their learning performance has not been considered for now. However, it would represent the unavoidable path for future research. This choice was dictated by the need not to overload the non-expert designer with too much com-plexity (Sweller, Ayres, and Kalyuga 2011) and to limit the number of variables in the field of study.

Hence, this article intends to investigate and give an answer to the following research questions:

- What is the effect size of LDASG in terms of student achievement and how effective is this approach in comparison with FL and other methodologies?
- How do students perceive this approach and its consequent learning experience?

These questions are at the heart of the study presented. A positive outcome would imply the possibility of employing a new methodological tool which is capable of motivating students and enhancing their performance while avoiding the typical pitfalls that Gamification users very often experience (Burke 2014; Kapp 2012).

1. 1. Literature review

In the early stages, knowledge about Gamification was characterised by a pragmatic approach. Its description and definition were given either by those who strongly promoted it or those who criti-cised it. Hence, reasoning and reflections could not be valued as objective. Best practices were derived empirically (Koivisto and Hamari 2019), and the actual experiences on the field were the basis discussion about Gamification stemmed from. Reference to scientific data was still far to come and not supported by sufficient research. Then, when research increased, the studies were numerous but dispersed, providing a limited quantity of information for each single subject. Never-theless, they made it possible to recognize the trademark and transversal features of the model (Koi-visto and Hamari 2019).

As an unavoidable methodological premise to scientific inquiry, the research tried to circumscribe and specify the meaning of Gamification (Deterding et al. 2011; Huotari and Hamari 2012) and then rapidly occupied this field of investigation (Hamari, Koivisto, and Sarsa 2014). The most popular definition describes it as 'the use of game design elements in non-game contexts' (Deterding et al. 2011). Given its characteristic of being broad and flexible, this definition includes many subsets of meaning and implementations. In fact, just like a set of building blocks, the presence of some elements belonging to the Gamification constellation (Rodrigues, Oliveira, and Rodrigues 2019) has in itself the necessary conditions and ability to have a project or process labelled as 'gamified' (Deterding et al. 2011). Hence, Gamification refers to various models comprising different mechanics and engagement strategies that go from intrinsic motivation to transactional dynamics (Burke 2014). But, whatever the model or the strategy, Gamification is regarded as a driver to motivate, engage and enhance the user experience (Zainuddin et al. 2020). In literature, the concept of Gamification refers both to entertaining and serious purposes or a mix of the two (Gerow et al. 2013). In fact, some implementations are openly playful and mostly based on amusement, whereas in others, the goal is not playful (Berta et al. 2015), and there is no conscious perception of being in a game.

Serious Games, which are the subject of this study, stem from Gamification. Born at the beginning of this century (Djaouti et al. 2011), they are often referred to as an experience connected to game mechanisms and game thinking that are not strictly correlated to purposes such as fun, entertainment or enjoyment. As intended in this work, Serious Games can be defined by rephrasing Deterding's definition of Gamification as the use of games in non-gaming circumstances (Abt 1987; Sanmugam 2014). Hence, though sharing many features and goals with Gamification, Serious Games are not just the implementation of some elements within an already existing real scenario. A Serious Game is the design of a whole brand new setting with its own specific rules and goals developed to transfer content and/or skills to learners (Kapp 2012; Sanmugam 2014). Compared with Gamification, Serious Games turn to be a more reliable tool to enhance learning performance, even if the two overlap in terms of fostering collaboration, engagement and motivation (Sanmugam 2014).

Academic investigations about Gamification and Serious Games have been carried out in numer-ous fields, but education appears to be among the most analysed and significant ones (Koivisto and Hamari 2019). In fact, many studies gathered in meta-examinations explored the viability of Gamifi-cation in the field of education (Hays 2005; Ke 2009; Randel et al. 1992; Sitzmann 2011; Vogel et al. 2006). They generally show enhanced learning experience and learning achievement. However, the results obtained tend to be very dependent on the context and the quality of implementation. Hence, a definite assessment of Gamification features is not always possible (Burke 2014; Hays 2005; Kapp 2012).

As to the fields of implementation, Engineering education is among the areas where gamified designs are mostly employed (Alanne 2016; Berta et al. 2015; Chachanidze et al. 2019; Koivisto and Hamari 2019). The goal is to increase aspects that are valued as fundamental for engineering students, such as motivation, engagement, learning in context, deliberate practice (Alanne 2016; Darling et al. 2008; Mayer, Warmelink, and Bekebrede 2013), soft skills, competent inventive and creative critical thinking capabilities and mentality (Bodnar et al. 2016).

In the time interval of around two decades, review studies show an increasing interest in Engineering education (Bodnar et al. 2016). From the rise of PCs and web-advanced innovations to game-based teaching/learning activities (Bodnar et al. 2016) up to the present day, research has been characterised by some major patterns. As to this paper, the attention was captured by a specific pattern: focus on the players. In fact, the literature on Gamification shows that, whatever the variants employed and regardless of the subject tackled, the only recipients of the whole training/instruc-tional activity have always been the players. Research itself has only been interested in computing or determining the levels of performance or satisfaction of the players. To the authors' knowledge, the only exceptions to this rule are the studies by Sillaots (Sillaots 2015; Sillaots and Maadvere 2013), where the core of the articles is a shift of focus from the players to the designers. Therefore, the focus on the designers represents a new approach which is, however, characterised by a still limited level of knowledge and in depth-analysis in literature, and this is what has inspired this article, whose aim is to explore the effectiveness of this approach as well as students' perceptions.

2. LDASG framework

LDASG is a new approach that has been developed to gain advantages from Serious Games by assuming the designers' perspective. This way, it is possible to bypass the common pitfalls (e.g. poor design, low quality of the games or badly managed implementations) students might come across as serious game users. Designers are students themselves who are asked to develop a learning game to transfer specific course contents to their fellow students. The core idea is to involve students in a process that will bring them to learn the allotted contents in turn. It represents a harmonisation of Gamification with active learning and social constructivist methodologies such as Project-based learning, Self-regulated learning, Reciprocal Teaching, Cooperative learning and a transversal meta-cognitive element. The metacognitive elements involved in LDASG are to be found in the active self-regulated and decisional process students undertake. Designers are forced to understand, organise and reason on the learning material that needs to be transferred to the players (i.e. their fellow stu-dents). Design and Gamification play the major role in this instructional process. The first fosters an analysis and active manipulation of the contents. The latter, thanks to its ludic components, boosts motivation (Hartmann and Gommer 2019) and a pleasurable learning experience.

The LDASG framework could ideally be divided into five linear and consequential phases (Figure 1).

2.1. Introduction of Gamification to students

According to The Cognitive Load Theory (Sweller, Ayres, and Kalyuga 2011) and the Meaningful Learning Theory (Ausubel, Novak, and Hanesian 1978), the first phase is dedicated to the presentation of Gamification to students. A general framework consisting of conceptual and structural principles (fields of application, dynamics, features, flexibility, implementations) is provided. This is necessary to allow students to make sense of the activity they will be involved in. Moreover, it represents a useful set of references in the following design phases too. Particular effort is dedicated to creating a bridge between didactic activity and reality. In fact, the meaningfulness of learning in a lifelong perspective has been proved to be a valuable incentive to motivate students' engagement (Ausubel 2000). Not to overload students with new information, more specific operational support

indications like prompts and self-assessment questionnaires are handed out. Specific guidelines are employed too. They are meant to get the students acquainted with the structural elements and their implementation or efficacy in specific contexts or phases of the design. The serious game design process is indicated in terms of linear subsequent steps. The features are shown as possibilities rather than constrictions. The learner-designer will make the final decision about what to utilise or not. In the event of an impasse due to the many features of Gamification, students can refer to this support material. Indeed, when it comes to novices, a restricted area of choices can help avoid a cognitive overload (i.e. no learning) (Kirschner, Sweller, and Clark 2006; Sweller, Ayres, and Kalyuga 2011). Moreover, this readily available support material makes it clear to the students what a successful result should look like and develops worthwhile skills such as self-evaluation and problem-solving attitude. These skills both represent efficient instruments to enhance the stu-dents' learning experience and favour more efficient studying (Hattie 2009).

2.2. Group formation

The choice behind the employment of the group work modality is related to the social constructivist theory. By fostering internal discussion and tutoring, group work makes it possible to exploit the peer-to-peer relationship as a lever for deep learning and soft skills acquisition (Vygotsky 1986). A considerable amount of information is shared and lightened (Sweller, Ayres, and Kalyuga 2011). This modality provides opportunities for giving and receiving feedback while letting the students own the learning process and become learning resources for each other (Black and Wiliam 2009). In the initial phase, general instructions are given on how to manage group work (i.e. division of tasks, sharing modes of producing and selecting ideas, role divisions, decision-making processes).

The size of the group cannot be given in a rigid form. It depends very much on the contexts in which the group operates. On the contrary, with regards to students' levels, it is possible to rely on specific evidence in the literature. In fact, no significant difference in performance between hom-ogenous and heterogeneous groups has been shown (Bowers, Pharmer, and Salas 2000). The type and difficulty of the task used in the investigation have appeared to be more determining than the group formation criterion (Bowers, Pharmer, and Salas 2000). In social learning and motivational terms, it has also been proved that grouping by levels is counterproductive (Chiu, Chow, and Joh 2017); hence, a mixed ability group formation is recommended.

It is during this phase that each group is randomly assigned a set of contents that are part of the syllabus of the course. The homogeneity of tasks is the real shared principle within the groups. Stu-dents are all committed to one common task, and this favours a better learning experience (Seltzer and Kilmann 1977).

2.3. Development of the 'learning game'

The third phase is the operative one. Initially, the students start to become familiar with the concepts of the course syllabus previously assigned. Material on the subject is made available by the teacher. This way, with the inclusion of guidance, the pure constructivist approach is partly diluted (Keller and Sherman 1974)(Adams and Engelmann 1996). Being the students non-experts, some teaching strat-egies have been valued as necessary, such as moving from general to details, from pre-knowledge to new information (Kirschner, Sweller, and Clark 2006; Prince 2004), and clearly stating the level of performance expected. Finally, the students summarise the ideas developed and discussed within the group and begin to materialise their projects.

According to the Feedback theory (Gan and Hattie 2014; Hattie and Timperley 2007; Sadler 1989), groups are granted the opportunity to receive/give feedback from/to the teacher during the realis-ation of the 'learning game'. This occurs in the form of an on-time specific feedback with the main goal to preserve the instructional function of the projects and their gamified nature in an 'all winners' perspective. It is an inclusive vision of Gamification which is not characterised by selective competition (Johnson et al. 1981; Kapp 2012; Qin, Johnson, and Johnson 1995). During the design phase, the students are encouraged to browse the support material, to stick to the rules of group-working, and to double-check their own project through a checklist. This would allow a read-justment of the project according to the success criteria defined, if necessary. At this stage, no man-datory indication is given regarding the typology of the game nor the number of players. As a consequence, in the study here presented, a variety of serious games was created: online quizzes via different platforms (e.g. Instagram, Kahoot, Scratch, and original sites created by the students), board games, and card games to name a few (see online Appendix D).

2.4. Submission of the 'learning game'

Once the 'learning game' has been designed and double-checked by the learners-designers, it is sub-mitted to the fellow students belonging to the other groups. Depending on the nature of the pro-jects, the games could be played individually or in teams. Hence, each student is given the opportunity to look at Serious Games from two different complementary points of view: that of the designer and that of the player. The metacognitive strategy adopted in this phase is obvious: students observe strengths and weaknesses of the designs of their peers and at the same time reflect on their own work.

2.5. Peer-to-peer feedback

Receiving feedback on how to bridge the gap between students' current knowledge and their learn-ing objectives is a fundamental opportunity in any learning process (Hattie and Clarke 2018). This obviously applies also to the learners-designers wanting to fill the gap between their current project and a flawless serious game. In addition to learners-designers' self-assessment and scaffold-ing by the teacher, a peer-to-peer feedback is fostered too. Peer-to-peer feedback represents the largest part of the whole feedback detectable in a classroom, and it takes place in the private-social world of peer interactions (Hattie 2009). There is a caveat; however, peer-to-peer feedback is often incorrect (Nuthall 2005). So, how can one take advantage of it? To minimise risks, the authors referred to Gan's work and developed their own feedback prompt (Gan 2011). Following guiding questions, the players can give the learners-designers a more useful and correct feedback on specific aspects of the project. This way, the learners-designers are offered a chance to make adjustments and, therefore, to make the game more effective. Indeed, it is a specific and focused success criteria-oriented feedback (Hattie and Clarke 2018; Sadler 1989) that allows a review of the work and pinpoints what has to be done or better learnt.

3. Method

The phases of the research presented can be summarised as follows (Figure 2).

The research method used in this study represents a variation on the two-group posttest-only randomised experiment (Trochim and Donnelly 2001). In the latter, one randomised group (R) receives the treatment (X), while the other randomised group used for relative comparison does not, or receives a standard or typical one. In this specific design, only a posttest (O) is employed. In fact, a pretest is not necessary since it is possible to assume that experimental and comparison group are statistically equivalent, being both randomised (Trochim and Donnelly 2001).

R X O

R − O

When coming to this study, a variation was implemented. The two randomised groups were sub-

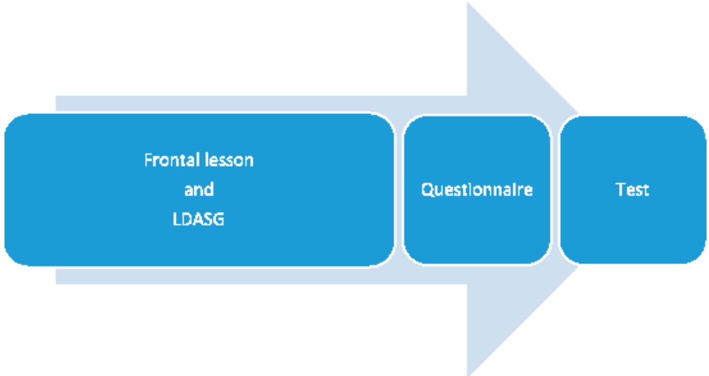


Figure 2. Research phases.

at the same time. Moreover, the treatment for the 'comparison group' was not absent but consisting of the typical treatment, i.e. FL methodology.

Single group X (LDASG)	O
Single group Typical treatment (FL)	O

The authors valued this variation as an improvement to the research, since the single group method makes it possible to avoid ethical issues connected with random assignments (Cohen, Manion, and Morrison 2017). Moreover, often conducted to evaluate the effectiveness of an edu-cational intervention, this method 'can be used with smaller sample sizes with little or no error variance concerning individual differences between conditions' (Edmonds and Kennedy 2016). As to its cons, they are represented by possible threats to internal validity and primarily maturation, history, and sequencing effects (i.e. order and carryover effects) (Edmonds and Kennedy 2016). To deal with them, 'it is recommended to randomize the order of the treatments (also known as counterbalancing) to control for sequencing effects' (Edmonds and Kennedy 2016). Given these considerations, FL and LDASG were implemented in parallel. While the FLs continued, one lesson per week was dedicated to LDASG. With the single group representing both the experimental and the control group, the study was also able to manage other typical internal validity threats related to this research method. In fact, the single group experience not just the same maturation and history, but also the same testing and instrumentation issues, as well as similar rates of attrition and regression to the mean (Flannelly, Flannelly, and Jankowski 2018).

A test and a questionnaire made it possible to collect quantitative data on the students' learning performance and perception of the learning experience. The study was conducted on 79 s year undergraduate students of an Industrial Plant Design course within the Management Engineering programme. This particular course was selected since it is characterised by the low interdependence of the modules and related contents. This allowed an easier formation of groups, choice of contents to be submitted, as well as a greater independence from students' specific pre-knowledge.

3.1. Frontal Lesson

Students were taught the following topics through the FL methodology: introduction to production facilities, service facilities, risk analysis, LCA – life cycle assessment. With FL, the teacher is in charge of both the transmission of information and the pace of the lesson. Questions from the teacher are rhetorical and students work, listen, and take notes individually (Hattie 2009).

3.2. Implementation of LDASG

. *The goal: development of a learning game* — Students were asked to develop a learning game to transfer specific syllabus topics to their fellow students, that is, siting of industrial plants, Hollier's method, balancing of production lines, optimal number of machines serviced by an operator/ robot, materials flow analysis.

. *Design support material* — The class was provided with general information about Gamification as well as operational indications. Design support material was made available for ready consultation. In particular, the designers were given a six-page booklet that aimed at facilitating their decision-making process (see online Appendix B) by giving them advice on the sequence of actions and the design possibilities within serious games. The booklet also offered the students tips to avoid typical pitfalls as well as guidance on how to conduct group work. It served as a guideline/safety net they could rely on in the wide freedom of action that was guaranteed and promoted.

. *Group formation* — The class was divided into 17 randomly formed groups composed of minimum 4 to maximum 6 participants each.

. *Analyzing the topic assigned in depth* — First, the students had to become familiar with the topic, referring to the material made available by the teacher: course slides, guidelines, and reference textbooks. They then shared, collected and summarised their ideas, and began to materialise their projects.

. *Designing the learning game and self-assessment document* — To clarify contents or readdress the design process, in-lesson feedback and scaffolding was provided by the teacher. Moreover, the 'design support material' was always made available. To self-assess their work, the learners-designers were given a first mid-term document (see online Appendix C) which consisted of a prompt, that is, a set of guiding questions they had to answer. This was an opportunity for the learners-designers to reflect, test and readjust the project with a metacognitive mindset.

. *Learning game submission and feedback from the players* — Once the 'learning games' had been com-
pleted and double-checked by the designers, they were submitted to their fellow students. To foster metacognition, the players were asked to answer questions and provide evaluations through a second 'feedback document' (see online Appendix C), which was strictly related to the one the designers had previously filled out. This relatedness was meant on purpose to consolidate and focus on specific serious games, thus avoiding too many different requests. Finally, a third 'feedback document' (see online Appendix C) was drawn up and submitted to the students, who had to answer an open question by indicating the Gamification features (Sillaots, Jesmin, and Rinde 2016) they had identified and the missing ones they would have implemented. The three mid-term feedback documents were not meant as sources of data but as practical formative assessment.

3.3. The questionnaire

A 9-item, 5-point Likert scale was submitted to the 79 students on the course and the answers (79 out of 79 anonymous responders) were graded accordingly to PANAS scale (Watson, Clark, and Telle-gen 1988) as follows: 1 (not at all); 2 (a little); 3 (moderately); 4 (quite a bit); 5 (extremely). The ques-tions focused on the learning experience and asked the students to provide an evaluation based on their perception (see Table 4). The theoretical grounding of the items lies in the concept of quality-teaching (both in general and in Higher Education) which was first elaborated (Ramsden and Martin 1996; Trigwell 2001; Trigwell, Prosser, and Waterhouse 1999) and later confirmed and specified (Bradley, Kirby, and Madriaga 2015; Hattie 2009; Hill, Lomas, and MacGregor 2003), as well as in the students' reliable capacity to assess it (Aleamoni 1999).

The analysis of the data was conducted by means of SPSS. Before its use, to ensure it could not be misinterpreted, the questionnaire was checked by two scholars with previous research experience with Likert questionnaires and a professional in statistical analysis. To validate the questionnaire, the responses were subjected to an exploratory factor analysis (Table 1). The KMO test (0.805) confirmed that the suitability of data for factor analysis was acceptable: good (Hair Jr 2006) or meritorious (Kaiser 1974). As to reliability, the Cronbach's alpha was computed (0.837). A descriptive analysis was conducted and median, skewness, and frequencies are reported in Table 4.

3.4. The test

A multiple-choice test was developed to assess the contents of the Industrial Plant Design course syllabus. All students answered three questions for each of the topics treated. Regarding LDASG, students answered only the questions concerning the subject matters dealt with in their own game. The test was submitted at the end of the two treatments, which were implemented in parallel (FL and LDASG). The questions on FL and LDASG were submitted simultaneously at the end of both treatments. The design of the test made it possible to link the names of the students to the answers that specifically referred to the topic they had been assigned for the realisation of their own learning game. Through SPSS, the Paired Samples Test was applied (significance <.05) to the results of the test. The Cohen's *d* effect size for within-subject (paired samples) results were calculated through G*Power and the formula

$$d = \frac{|m_1 - m_2|}{\sqrt{s_1^2 + s_2^2 - (2rs_1s_2)}}$$

(where s is the standard deviation, m the mean, and r the correlation). A further effect size was computed too,

$$d = \frac{m_{posttest} - m_{pretest}}{ms}$$

This formula was used by Hattie in his classification of influences on student achievement (Hattie 2012).

Through it, it is possible to compare LDASG with other methodologies within the specific field of education (Hattie 2018) and particularly with those strictly related to or part of the LDASG proposal (e.g. Problem-based learning, Meta-cognitive strategies, Feedback, Mastery Learning, Cooperative Learning, Reciprocal teaching).

4. Results and discussion

This section starts by referring to the first research question: what is the effect size of LDASG in terms of student achievement, and how effective is this approach in comparison with FL and other methodologies? The results obtained from the questions related to the contents used by the students in their design process (Tables 2 and 3) show higher performance and a significant statistical difference

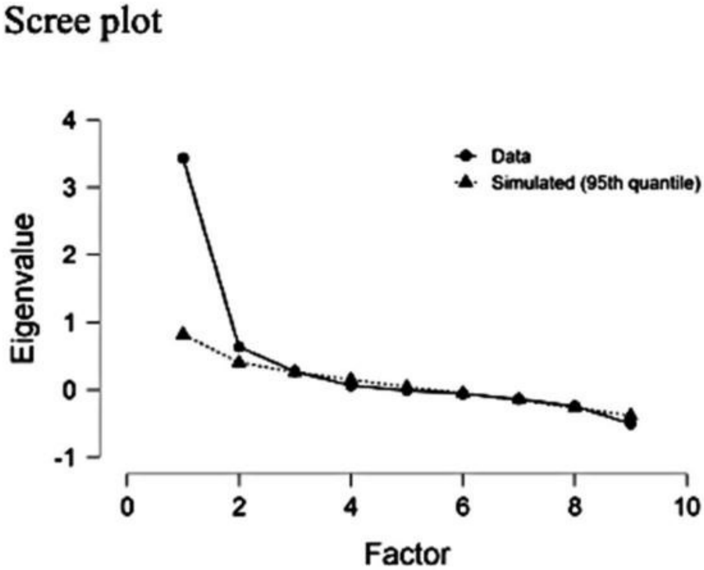
Table 4. Items of the questionnaire.

	Questions	Median	Valid	Skewness
1	How much did the request to work on the development of the learning game stimulate/ motivate you?	4.00	79	−0.235
2	How involved did you feel during the designing of the learning game (by commenting or developing ideas, contributing to the work, exchanging views …)?	4.00	79	−0.378
3	How interested have you become in Gamification?	4.00	79	−0.241
4	Did the implementation of a learning game increase your motivation to participate in the lessons?	4.00	79	−0.608
5	Did you think working in a team represented an added value for designing gamification?	4.00	79	−0.796

6	During the design of the learning game, did you have the opportunity to clarify any doubts or difficulties within the group or with the teacher?	4.00	79	−0.102
7	How clearly do you think the designing of a learning game has allowed you to understand the content assigned to your group?	3.00	78	−0.312
8	In view of the exam, was home study of the content assigned to your group facilitated by the design process experienced in the classroom?	3.00	79	−0.280
9	From a job perspective, how useful do you think it will be to have acquired the ability to develop a learning game?	3.00	79	0.060

Note: The scale grades are: 1 (not at all); 2 (a little); 3 (moderately); 4 (quite a bit); 5 (extremely).

Table 1. Exploratory factor analysis: KMO, factor loadings and scree plot.



(<.05) compared to FL contents. The Cohen's effect size is d = 0.58. By employing Hattie's choice of Cohen's d formula, d = 0.74 (Hattie 2012).

The significant statistical difference is already a valuable result in itself. In the wide dissemination of FL, LDASG represents a viable alternative. Moreover, the effect size index allows the authors to make the results more generalisable and, hence, to carry out comparisons with all the other methodologies and not just FL. Referring to Cohen's d scale, the means of the two conditions differ by 0.58 standard deviations. This value stands in the medium range (Cohen 1988). When adopting the Cohen's d formula used by Hattie, the two conditions differ by 0.74 standard deviations, which stands in the zone of the desired results. Through this formula, Hattie's study on meta-analyses has been able to list the most effective influences on achievement. As to d = 0.74 for LDASG, this value would rank LDASG among the most effective teaching/instructional strategies in the field of education (Hattie 2009, 2018). In fact, LDASG would outperform many active learning/teaching strat-egies that also contribute to its identity, for example, Problem-based learning, Meta-cognitive strat-egies, Feedback, Mastery Learning, Cooperative Learning. And it would be equivalent to Reciprocal teaching (Hattie 2009, 2018). Hence, it is possible tostate that LDASG actually represents a valuable method to enhance learning achievement. However, a learning process can be better exploited if students' subjective assessment displays important traits connected to the quality of the lesson such as motivation, engagement, sense of usefulness (Ausubel, Novak, and Hanesian 1978; Darling et al. 2008). With regards to the second research question, a Likert questionnaire helped investigate how the students perceived the LDASG approach and its consequent learning experi-ence. The following conclusions were derived from the descriptive analysis.

The discussion that follows will always referto Table 4 and the figures in online Appendix A. The results from question 1 show important outcomes in terms of perception of involvement (Table 4

Table 2. Test of the exam session – Learner-Designer Approach to Serious Games (LDASG) and frontal lesson (FL) – Mean and Standard Deviation.

		Mean	*N*	Std. deviation	Std. error mean
Pair 1	LDASG	6624	79	29,954	0.3370
	FL	4979	79	14,747	0.1659

Table 3. Test of the exam session – Learner-Designer Approach to Serious Games (LDASG) and frontal lesson (FL) – paired samples test.

		Paired differences					*t*	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	LDASG F L	16.456	28.661	0.3225	10.036	22.875	5103	78	0.00

and Figure 3 (online Appendix A)). More than 54% of the students evaluated the motivational strength of the proposal from 'quite a bit' to 'extremely'. About 89% of them are to be found in a satisfactory range with answers going from 'moderately' to 'extremely'. Literature has widely confirmed the motivational value of hands-on, project-based, active-learning, reciprocal teaching approaches (Hattie 2009). However, even if predictable, such a response could not be given entirely for granted. The uncertainty was mostly related to the novelty of the proposal (LDASG) inserted in a methodology (Serious Games) that in itself is not routine within engineering courses. FL as the proper example, idea and grammar of schooling is still persistent (Cuban 1984; Hattie and Clarke 2018). The answers to question 2 (Table 4 and Figure 4 (online Appendix A)) show that most of the students felt involved and perceived their proposals and opinions were listened to (0% 'not at all', 65.8% from 'quite a bit' to 'extremely' and as much as 89.9% from 'moderately' to 'extremely'). The authors believe these results are remarkable, especially when compared to the almost absolute passivity of FLs (Goodlad 1984) that, in Engineering Education, are traditionally given as almost the only form of teaching (Stains et al. 2018), or to the difficulty to involve a large number of students, even in more active forms of lecturing (Van Dijk and Jochems 2002). In pedagogy, the presence of open discussion, peer confrontation, active participation belongs social constructivism (Daniels 2001). Detractors of this approach identify the lack of guidance or inconclusive freedom as its limit-ations (Kirschner, Sweller, and Clark 2006; Mayer 2004; Sweller, Ayres, and Kalyuga 2011) since they could make it difficult to create coherent and structured learning. This is why scaffolding strategies, along with the linearity of the design process, have been implemented in LDASG. They exploit and canalise the autonomy granted in a profitable way. With regards to question 3, the results show a growth of interest in Gamification with percentages that are similar to those of the previous answers, although more centrally distributed (Table 4 and Figure 5 (online Appendix A)). The value of these data could be considered in the light of some procedural elements included in the first phase, that is, having introduced the students to the concept of Gamification and its structural elements, having clarified the goals and level of performance expected according to the Mastery Learning Theory (Keller and Sherman 1974) and Direct Instruction (Adams and Engelmann 1996), having exemplified the possible applications in real life and in the professional field. These elements probably conveyed meaningfulness to the work required (Ausubel 2000).

The ability of Gamification (Darling et al. 2008) and Serious Games (Hartmann and Gommer 2019) to increase motivation and engagement was confirmed by the answers to question 4 (Table 4 and Figure 6 (online Appendix A)). In fact, approximately 87% of the participants gave answers ranging from 'moderately' to 'extremely' and about 50% from 'quite a bit' to 'extremely'.

Along with feedback and scaffolding, group work is part of an environmental support that is strongly valued by engineering students and is predictive of their academic satisfaction (Lent et al. 2007). In fact, group work consists of specific dynamics of social interaction and mutual support, the possibility to create comparisons and the construction of articulated and deep under-standing (Vygotsky 1986). While the literature has shown that individual projects are less attractive and challenging (Lee, Huh, and Reigeluth 2015), group work is proved to enhance learning outcomes (Zhang et al. 2015) as well as meaningful learning (Miller 2017). The answers to question 5 confirm the value that students attribute to group work modality (Table 4 and Figure 7 (online Appendix A)).

In its formulation, question 6 could be summed up in one sentence: the possibility for students to receive feedback. The results are clear since no answers can be found in the 'not at all – little' range (Table 4 and Figure 8 (online Appendix A)). At all levels of education, feedback seems to be a rather rare element to trace (Hattie 2009), even if literature has largely demonstrated the effectiveness of this educational tool (Hattie and Timperley 2007). Despite the many caveats to the development of an effective feedback, offering students the possibility to adjust the course of their learning at different levels (Kluger and DeNisi 1996; Sadler 1989) represents an added value to the didactic pro-posal. LDASG fosters feedback through different means such as material distribution, checklists, mid-term documents, the availability of the teacher to clarify and accompany the phases of the design, and comparison with the peer. Prompts have been used to avoid the high percentage of wrong feedback that might be involved in peer-to-peer discussions (Hattie 2012).

With regards to question 7, the results continue to show a prevalence of positive judgements, with about 40% of the answers ranging from 'quite a bit' to 'extremely', and about 43% choosing 'moderately' (Table 4 and Figure 9 (online Appendix A)). Compared to the questions related to par-ticipation and motivation, a decrease in the level of satisfaction is shown. In this regard, the literature confirms that learning satisfaction is more related to underlying theories that translate back the game experience (Mayer 2004). However, the authors claim that other possible reasons to this outcome could be found in the following two aspects: the presence of constructivist features and a cultural component. With regard to the first aspect, in literature, constructivist strategies show a valuable psychological influence (motivation, self-regulation, etc.). However, the results are not always consistent or perceived as such when coming to possible better outcomes of learning performance (Adams and Engelmann 1996; Hattie 2009; Keller and Sherman 1974; Mayer 2004; Prince 2004; Prince and Felder 2006). As for the second aspect, it could be assumed that LDASG is an innovative proposal compared to an established educational context (Stains et al. 2018). This per-ception could thus determine lack of references and difficulty in identifying one's own learning land-marks, and at the same time highlight a certain grade of uncertainty or inability to assess one's own level of knowledge acquisition (Cuban 1982; Hattie 2009; Regmi 2012).

In the answers to question 8, it is possible to detect a positive influence of LDASG on the home study in preparation for the exam, since 41.8% of the students gave answers ranging from 'quite a bit' to 'extremely' and 39.2% answered 'moderately' (Table 4 and Figure 10 (online Appendix A)). From these data, a perception of clarity of understanding emerges.

Coming to the last item of the questionnaire, which helped answer the second research question, the perception of usefulness of what is to be studied and of a connection with one's own future was investigated. The answers to question 9 reveal that students do perceive such usefulness (Table 4 and Figure 11 (online Appendix A)). In fact, 45.5% of the answers given range from 'quite a bit' to 'extremely'. Only 15.2% of the students found LDASG 'little' useful, while none of them considered it useless.

An overall consideration of the data from the questionnaire leads to the following reflection. LDASG is perceived as motivating by most of the students. Active participation, responsibility, and its 'gameful' connotation might be some of the reasons behind these results. Students welcome LDASG positively, even if it breaks consolidated teaching/learning routines (van Dijk, van den Berg, and van Keulen 1999) with their already shared and reassuring mechanisms and functions, roles and demands (Hattie and Yates 2013). Qualifying elements appear to be the initial phase of presentation to students aiming at fostering meaningful learning, the provision of guidance capable of conveying even those phases characterised by a higher level of freedom towards profi-table pathways, the opportunities for discussion among peers and the relational aspects involved. With regard to feedback and autonomy, they represent complementary aspects. They offer a more comprehensive experience to the learner-designer. As such they were positively valued by the students. The psychological, social and learning features were appreciated too. Moreover, a large majority of the students assessed their own perception of learning within LDASG as improved. In literature, self-assessment shows a high level of concordance between the personal perception of the learning performance and the real one (Hattie 2009). Therefore, although they do not have an absolute value, these data appear encouraging. Finally, with regard to lifelong perspective, this concept is part of the 'meaningful learning' theory (Ausubel 2000; Bretz 2001). Having the students confirmed this approach as valuable, in this perspective LDASG seems to represent a further reason to justify its implementation.

5. Future developments

5.1. Generalizability

LDASG gave positive indications in terms of both learning achievement and perception of teaching quality. Nevertheless, it seems possible to hypothesise future developments or adjustments in those areas that emerged as weaker, that is, perception of knowledge acquisition and lifelong per-spective. Moreover, it would be advisable to develop studies capable of comparing the question-naire results with those related to other methodologies, which would make them more generalisable.

5.2. Feedback and testing the quality of the learners-designers' understanding

As to the formative-assessment (Hattie and Timperley 2007; Sadler 1989), it could be useful to test the quality of the learners-designers' understanding of the contents. In fact, in an early stage of the designing process, a double-check would allow the instructor and the learner-designer to get back onto the right path before progressing with the design phase.

5.3. Selecting and reducing Gamification features

The list of characteristic elements of Gamification is broad and articulated (Rodrigues, Oliveira, and Rodrigues 2019; Sillaots, Jesmin, and Rinde 2016). Students who have to manage these features in conjunction with all the possible problems connected with the design phase could find themselves feeling a sense of disorientation. In literature, this loss of engagement is defined as cognitive over-load (Sweller, Ayres, and Kalyuga 2011). This occurs especially when the students are non-expert lear-ners (Sweller, Ayres, and Kalyuga 2011; Van Gog et al. 2005). Hence, it would be desirable to limit the structural elements of Gamification both in quality and number.

5.4. Group formation

It would be advisable to have a more detailed distribution of roles and responsibilities. This would prevent students from not contributing to the design as well as avoid an unbalanced allocation of the workload. Finally, to enhance participation and engagement, more midterm assessments (both formative and summative) are recommended.

5.5. Test, feedback, and redesign

Having to avoid too many variables is the specific research reason that has led to disregard stu-dents' learning achievement when playing other groups' games. This self-imposed limit could and should be overcome through the actual implementation and test phase of the serious game itself. Analyzing the players' learning performance is certainly a desirable future develop-ment. Moreover, its testing and consequent redesign would refine the serious game as an instruc-tional tool.

5.6. Method and research questions

The current study is related to a small sample. Larger samples and a true experimental longitudinal design would represent desirable features for future research to derive more definitive conclusions. The appreciation of the teaching experience also by the teacher and the practical pros and cons of the methodology should be investigated, too.

6. Conclusions

In this study, a different use of Serious Games has been experimented. In fact, in engineering education, just like in other subjects, the approach to Gamification employment or analysis is always concerned with a specific role, that of the user. A different perspective to its implementation can rarely be found in literature. The aim of this work was to fill this gap by shifting the focus on the role of the designer and present a 'Learner-Designer Approach to Serious Games' (LDASG). In practical educational terms, this can offer the possibility of employing Serious Games avoiding the risks of poor designs or implementations for the users. Through this approach, it has also been possible to merge important features belonging to Gamification with those of other active/metacognitive approaches. As a result, a specific identity of LDASG has emerged, which distinguishes it from other active teaching approaches. With regards to the research questions:

- What is the effect size of LDASG in terms of student achievement and how effective is this approach in comparison with FL and other methodologies?
- How do students perceive this approach and its consequent learning experience?

this article shows that both learning outcomes and learning experience are enhanced. Computation of two effect sizes has made it possible to rank this methodology among the most influential teaching strategies in terms of student achievement.

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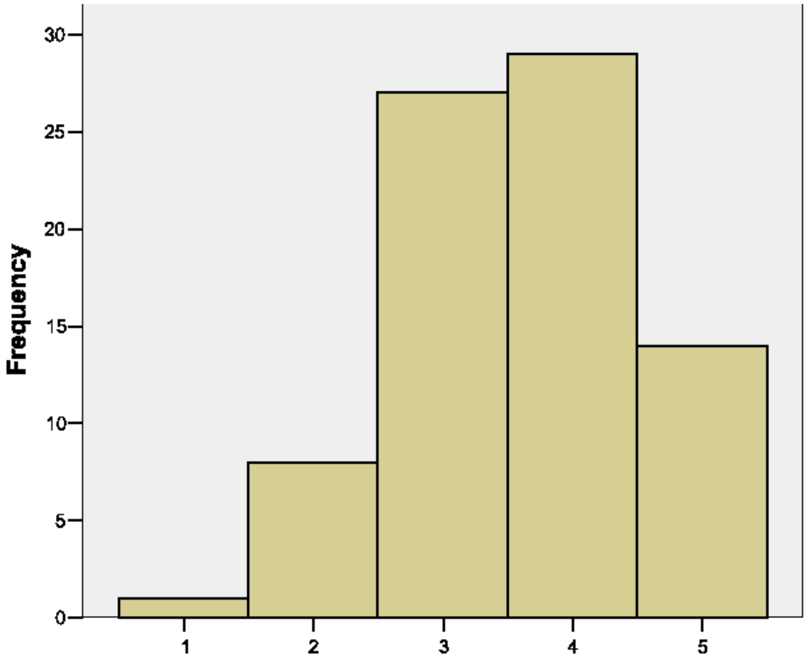
Appendix A



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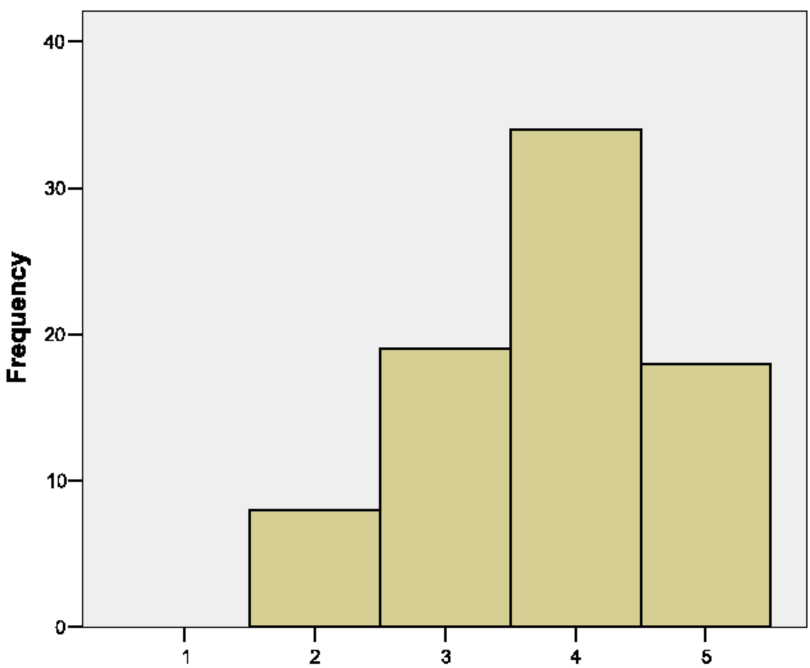

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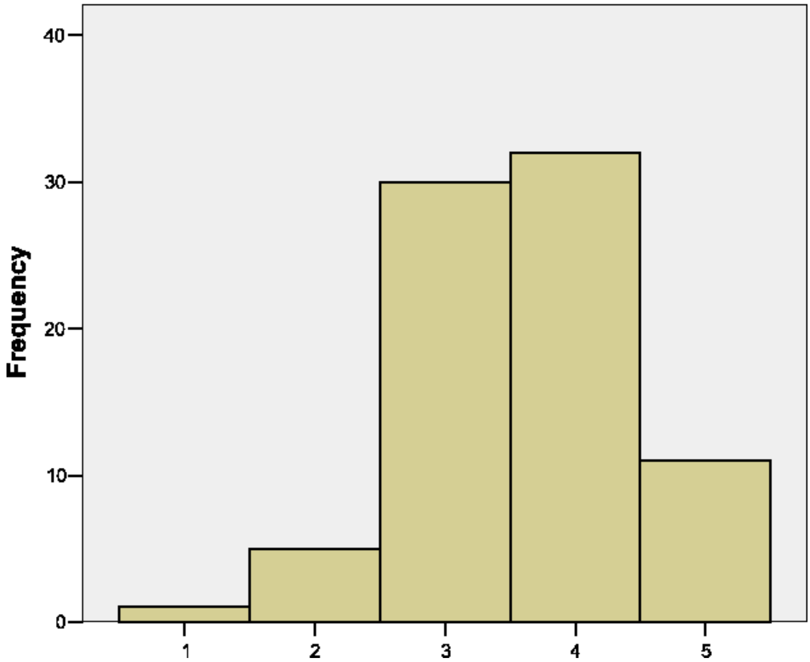

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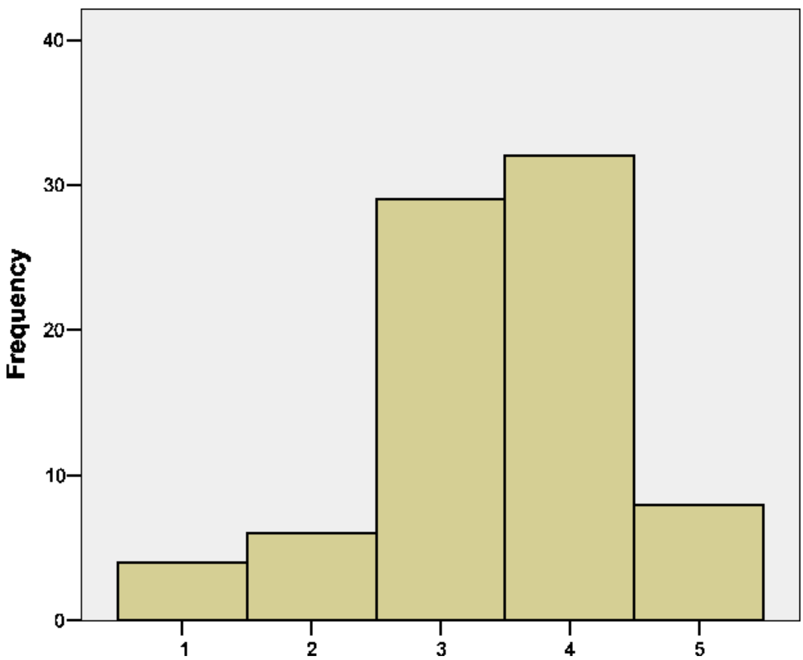

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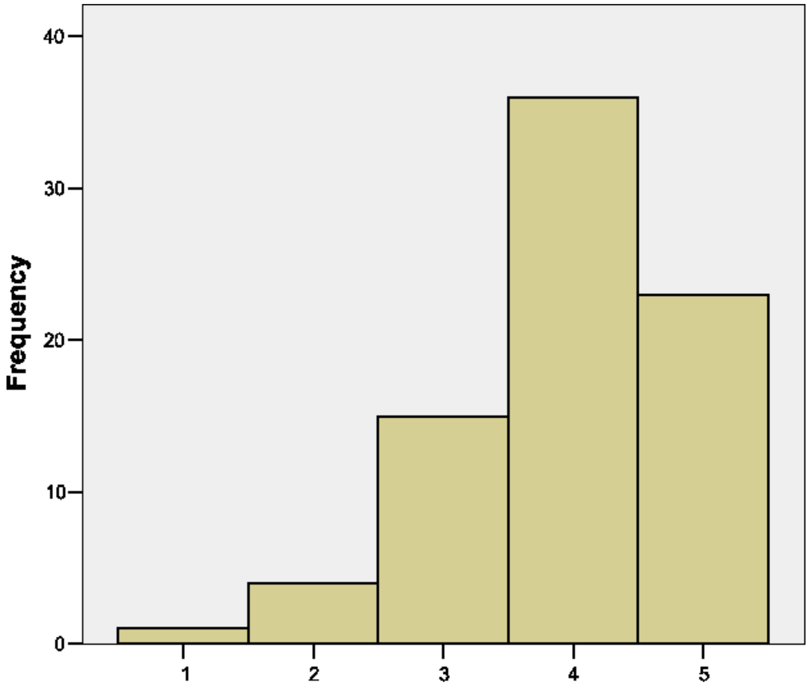

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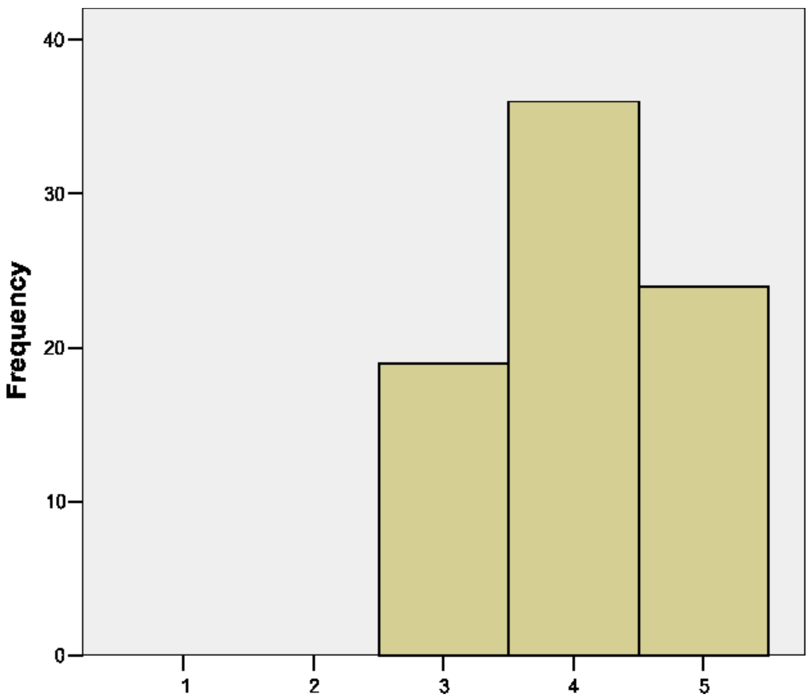

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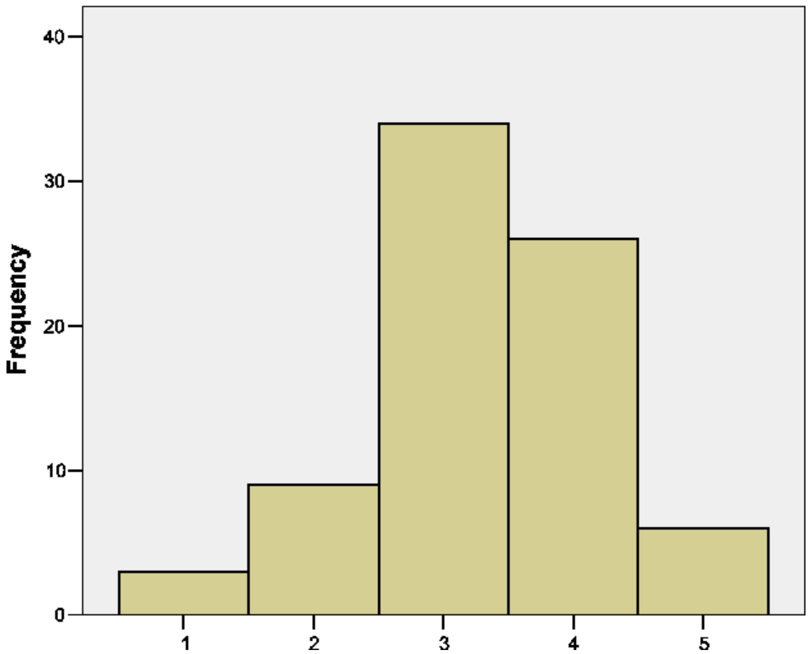

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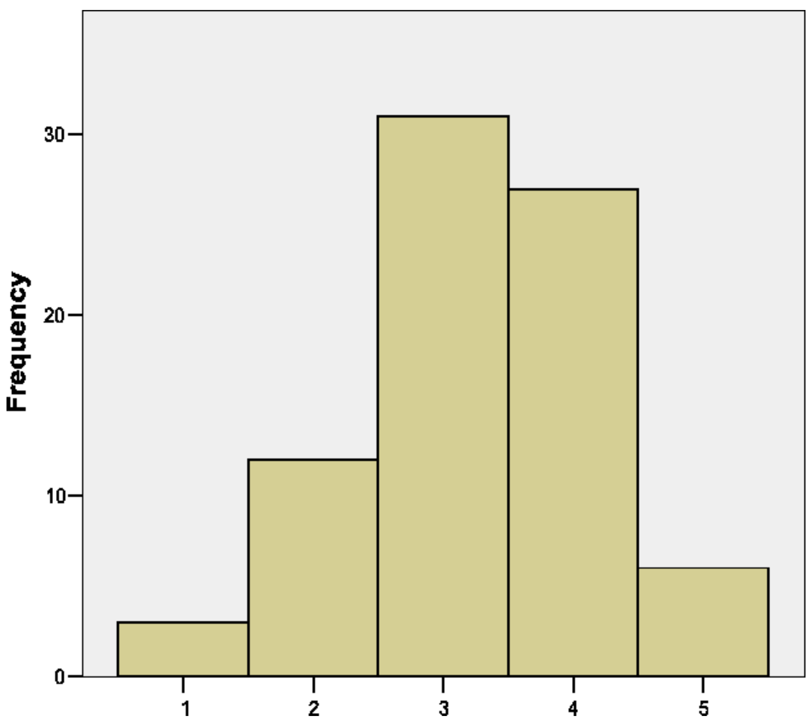

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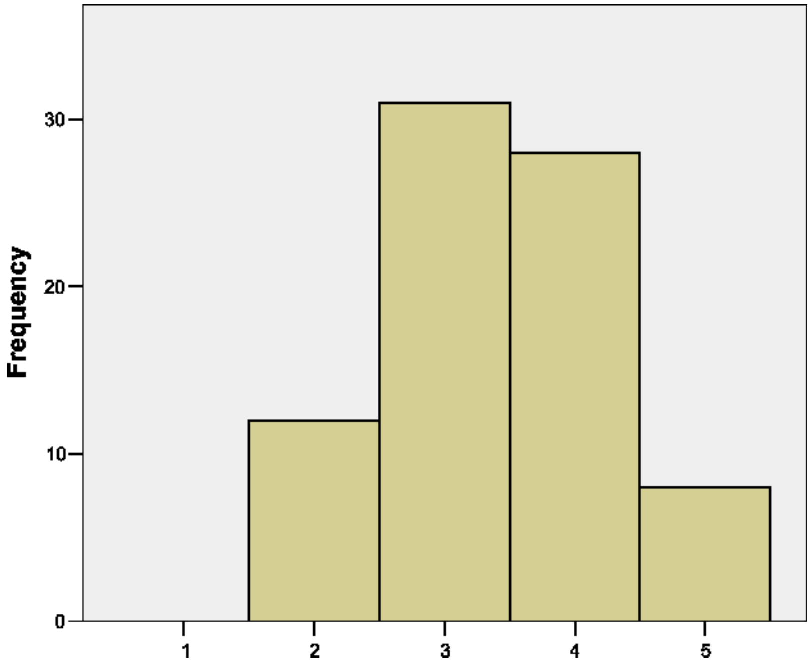

Figure 11. Question 9.

Appendix B

Table 5. Synthesis of support material topics.

TOPIC	SPECIFICATION OF THE TOPIC
Setting the goals of both the activity and of the game. Game rules.	- Production of a serious game to have the players learn the specific assigned syllabus topic (Learning game prototype).
Group work indications.	- identify a moderator; suggestions on how to produce and select ideas.
Preliminary general design intentions for the game.	- competitive or collaborative; multiplayer or individual; based on intrinsic or extrinsic motivation.
Game setting suggestions.	- Specific/generic.
Journey choices. I. Initial situation II. Levels to be passed and related contents III. End of the Journey	- Guided/open. - Possible features (e.g. in person or avatar; starting situation; clarifying goals, etc.). - Where to insert easier and complex tasks to fuel motivation; how to move from basic knowledge towards complexity in a logical progression; naming the objectives to be achieved in a meaningful and motivating manner; how to create motivating challenges to get the players through the game levels; how and when to guide players. - Final challenge characteristics.
Practical suggestions for developing game challenges to have the player acquire knowledge at different levels of mastery.	- Reference was made to Kapp's work: Kapp, K. M. (2012). The gamification of learning and instruction: game-based methods and strategies for training and education. John Wiley & Sons, pages 189-190.
Game economy.	- Intrinsic and extrinsic motivation: strategies to best implement them.

Appendix C

1. Self-assessment document.

Here is a chart that can guide you through the design of the game. Answers should always be "yes" for a quality learning game.		
	Yes	No
Does the game allow the player to acquire ali the content I set out to convey?		
Are the levels attainable only through what has been learned previousiy in the game?		
Does the game create a sense of pleasant immersion and loss of track of time?		
Does the game make you want to strive to get through the levels?		
Do the rewards fairiy compensate for the effort made to achieve the goals?		
Do the ruies work and does the game flow?		
Once the game is set up, it may differ from the choices made at the beginning of the design phase. Do you feel these variations are justified and good for the game?		

2. Mid-term feedback from players.

	not at all	a lele	moderately	quite a bit	extremely
Does the game you experienced allow you to confidentiy acquire the content presented?	1	2	3	4	5
is the presentation of the content done in a way that allows you to proceed through the game in a logica) sequential manner?	1	2	3	4	5
Does the game create a feeling of pleasant immersion and loss of track of time?	1	2	3	4	5
Did you feel enticed to play the game again?	1	2	3	4	5
Do the rewards fairiy compensate for the effort made to achieve the goals?	1	2	3	4	5
Do the ruies work and does the game flow?	1	2	3	4	5
Do you feel that the play time was sufficient to acquire the content present?	1	2	3	4	5

3. Final feedback from players.

Write through keywords which contents you feel you have acquired best.

How would you improve the game to make it more effective at conveying the content? What would you insert, where, and why?

Appendix D

Table 7. Examples of serious games designed by students. Synthesized game dynamics.

Example 1	**Syllabus topic.** Hollier's method. Origin-destination sheet operation and sum of incoming and outgoing flows.
Summarized game dynamics. All participants are divided into groups. For each group a team leader who has "started to follow" the specifically created page with his Instagram account. To foster collaboration and workgroup among group members, interaction with designers was limited to team leaders only. After an introductory explanation, participants had to complete a table through computation of incoming and outgoing flows for each machine. Once passed the level, a challenge was posted on Instagram: "Having calculated the previous values for each machine how would you use them (what formula would you adopt) to best arrange the machines?". Answers were posted on the page, pairing them with fun elements to highlight the inappropriateness or conversely the correctness of the answer. After posting the correct answer (ratio between the sum of incoming flows and the sum of outgoing flows) students had to calculate it. Then, received the right solution, the last question was posted on Instagram: "How would you order these machines in a production line taking into account the ratios you just calculated?". All the answers to the question were published and subjected to participants' evaluation. Once over, the highest-ranking group was rewarded with a surprise package and the publishing of photo/short video on the home page. Some final clarifications on Hollier's method followed.	
Example 2	**Syllabus topic.** Balancing of production lines.
Summarized game dynamics. When balancing production lines, the very high number of variables allows a large number of different solutions. For this reason, the game has been designed to be accessible globally to as many users as possible working on several solutions of the same challenge at the same time. A site was created where any company with balancing problems can enter on the platform a challenge. Who will find the best solution to one of these challenges will place his score - calculated in terms of cycle time, efficiency, dead time, and balancing delay - as the record of that particular challenge. The goal of the players will be to beat the established record.	
Example 3	**Syllabus topic.** Materials flow analysis.
The objective of the board game is to conclude the path by answering questions to get to the end before the other players. The path is divided into steps; each step is associated with a definition that will allow the player to acquire the knowledge to solve the final level. Every few turns, a check of the players' learning will allow to reveal a fundamental formula to solve the final exercise. The player will be asked to answer questions that will allow him to access the next step. To answer each question, 20 seconds will be given, and each player will be assigned an avatar with a different power (useful to advance in the game).	