EXTENDED TAXONOMY OF DESIGN AND INNOVATION GAMES TO IDENTIFY PERSPECTIVES OF DEVELOPMENT AND EVALUATION

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ABSTRACT

Learning innovation and design process is a necessity of the coming decade and games are a potential tool to do so. This paper proposes an extended taxonomy for categorising innovation and design games. The intent is to understand the essential, the similar and the different categories not only for development, but also for evaluation of innovation and design games, and in turn, help educators identify appropriate games for their learning objectives and curricula.

Keywords: Innovation, Design process, Design education, Taxonomy, Educational games

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1 INTRODUCTION

Innovation is identified as a new way of doing things that are commercialised (Porter, 2011). It is the creation of new products, processes, knowledge or services by using new or existing, scientific or technological knowledge, which provides a degree of novelty either to the developer, the industrial sector, the nation or the world, and succeed in the marketplace (Galanakis, 2006). In the 21st century, the need for learning innovation and design process has become a necessity not only for professionals working in various companies but also for future workforces, i.e., graduate and school students. Besides, the application of educational games has also been found to be promising.

Game is no longer seen as just an amusement. Because of their ability to keep the player engaged in the process, the use of games is prevalent for educational purposes. Besides fun, educational games give a learning advantage to the player. Application of educational games seems promising, e.g., to overcome disengagement, to train, to imbibe or to improve skills, to change behaviour, to improve the experience. In last two decades, researchers in the field of design have been exploring the game-based approach to educate and train learners for innovation as well as design process (Outram et al., 2007; Judmaier et al., 2008; Juuti, 2008). Studies for taxonomy to classify perspectives of game development (Cortes Sobrino et al., 2017) and framework to evaluate the degree of coherence of the game elements (Ma et al., 2019) have been recently reported. The aim of this research is to aid researchers, educators and developers in understanding, developing and evaluating educational games in the field of design and innovation.

2 RESEARCH GAP AND PROPOSED METHODOLOGY

Broadly speaking, the areas that need to be considered for educational game taxonomy can be divided into three significant aspects: area of application, development and evaluation. The attempt was made to see whether the current taxonomy covers these three areas and whether there is a scope of extension.

Michael and Chen (2005) defined serious game as a game in which education is the primary goal rather than entertainment; and covered the application of serious games in various fields, such as military, government, education, healthcare and corporate. Cortes Sobrino et al. (2017) proposed a taxonomy for serious games, with three categories: public, purpose and skill, to identify perspectives of game development, and applied the same to classify seventeen educational games of the Design Society Database. However, there still seems to be scope for adding crucial categories that were not discussed or considered in the above taxonomy. Besides, there are other ways of game-based learning, such as, gamification, where game design elements are used in non-game contexts (Deterding et. al, 2011), and simulation game.

Ma et al. (2019) evaluated an existing innovation process board game as a case study, for the degree of coherence of the game elements, with the help of the Serious Game Design Assessment (SGDA) framework (Mitgutsch and Alvarado, 2012) and identified nine existing serious games for teaching innovation processes. However, the evaluation of a game's effectiveness, with respect to its intended purpose, is yet to be empirically validated. Evaluation is a critical activity of any design process and is responsible for directing the decision-making and the eventual outcome of the process.

Thus, the following gaps were identified;

- existing taxonomy (Cortes Sobrino et al., 2017) does not provide a comprehensive view of a game's potential to achieve learning, as it omits crucial considerations regarding various categories and their intended use, and
- neither address the potential application of the same for developing the other two aspects of game-based learning, i.e., gamification and simulation game.
- existing framework (Ma et al., 2019) does not evaluate the effectiveness of the game in terms of its designated purpose,

Therefore, the research question arrived upon for this study is: What are the essential categories that must be included in the taxonomy to be used as criteria for developing and evaluating education games in the field of design and innovation? And the following methodology was used.

For further developing taxonomy - We first reviewed the existing literature and scrutinised the proposed categories in the available taxonomy to further identify other categories. The following keywords were selected to conduct a search: "educational games", "game-based learning", "game taxonomy", "game classification", "game development", "game evaluation", across various data sources, such as Google Scholar, Research Gate, Science Direct and various libraries (Wiley, Springer, ASME, Design Society

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etc.). The identified categories were then added, and an extended taxonomy was proposed for the development and evaluation of games.
For classification - We first made use of the games provided in the above, previous contributions, and added other games from other publications as well as web platforms and market. The games include innovation process, design process, product development process, design thinking, human-centred design, etc. The games were then tagged & classified based on the extended taxonomy.
For reproducibility - Inter-coder reliability was measured, in which the definitions of each category were given to the coder to tag each of the games, with one or more tags from each of the categories. The tags were then compared with the tags that were already assigned to the games by the authors. For evaluating the consistency among the tags, percentage agreement for each category, the overall percentage agreement, and Cohen's Kappa statistics were calculated. Various games were analysed to evaluate the proposed taxonomy's effectiveness and the implications of this taxonomy in the paper.

3 REVIEW OF EXISTING TAXONOMY

Among various existing taxonomies of games available in the literatures, Cortes Sobrino et al. (2017) reviewed two existing taxonomies in the field of serious games, adapted two categories of the G/P/S model (i.e., purpose and public), which was developed by Djaouti et al. (2011) and proposed a new classification canvas with three specific categories: public, purpose and skills. Each category is briefly explained below:

1. *Public/ targeted users: Children, Students and Professional*

The first category shows the type of targeted user for whom the game is developed, e.g., children, students and professionals. (Note: The 'scope' category in G/P/S model includes two subcategories: Market and Public. The games in the field of design and innovation are already market-specific. So, the remaining category was considered by Cortes Sobrino et al. (2017).)

2. *Purpose: Spread a message, Educate and Train*

The purpose of a game might be to spread a message (inform people about a subject), to educate (learning by doing), or to train (to improve cognitive performance or motor skills) (Cortes Sobrino et al., 2017). For instance, the purpose of SBCE game (Kerga et al., 2012) is to educate players on how to delay decisions early in a design phase, and to avoid unnecessary design rework and missing customer goals.

3. *Skills: Conceive, Design, Implement and Operate*

The third category is the competencies/skills associated with Conceive-Design-Implement-Operate, CDIO (Crawley et al., 2007) innovation activities. Here, we argue that the aim of the game should not be limited to skill development only, but must extend to enhance knowledge and develop a certain attitude. For instance, Bath Boat Game (Outram et al., 2007) was developed for enhancing knowledge relating to sourcing and the supply chain, the business of trading in the market, and to develop skills related to computing costs and margins. While retaining the essence of CDIO, instead of the erstwhile skill category, authors have represented the category as stages of the innovation process to which the games contribute. This category is discussed in the next section.

4 EXTENDED TAXONOMY

4. *Stages of the innovation process*

Various games have been developed for innovation, design and design thinking (DT) processes. These games can be classified based on the innovation or design phase it uses. Thus, it is desirable to know the terminologies and differences among the terms. The innovation process is considered to have a broader span than the design process. As noted by Chakrabarti (2019), the innovation process, whereby a system is designed and brought to the society, involves the design of products (Conceive & Design), their processes of realisation (Implementation), the service systems and supply chains (Operation), and the business systems that can bring these to the society. Design is one of the four elements of the innovation process, and can be considered as a subset of it (Figure 1). Design is a process of finding problems from an existing situation and developing a plan for transforming the situation into a preferred one by solving the problems (Simon, 1969). Various prescriptive models of the design process (e.g., Cross (1989), Roozenburg and Eekels (1995), Pahl and Bietz (1996), Eppinger and Ulrich (2015)) are prevalent in engineering academia as well as in industry. For instance, the PDP game (Becker and Wits, 2014) makes use of Eppinger & Ulrich and Pahl & Beitz's approaches. In comparison, DT or Human-centred design

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is a simplified version of 'designerly thinking': a way of describing a designer's methods that is applied into an academic or practical discourse (Johansson et al., 2013). IDEO (Brown & Wyatt, 2010), Stanford DT (Plattner et al., 2009), and SUTD Design Cards (Foo et al., 2017) are examples of various existing DT models. Each DT model is broken down into a number of abstract activity stages. For example, Stanford DT process is divided into five stages: Empathise, Define, Ideate, Prototype and, Test. IDEO has three activity stages: Inspiration, Ideation, and Implementation. Despite the fact that each of these models has different terminology, they have a shared view of the design-thinking process, which can be generalised and classified into three broad stages to avoid ambiguity: data gathering about user needs, idea generation and testing (Liedtka, 2015).

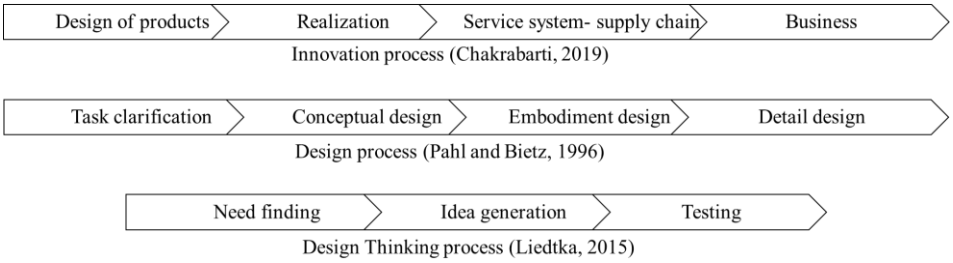

Figure 1. Visualisation of innovation and design process

5. Game approach: Serious game, Gamification and Simulation game

Before developing any game platform, it is essential to know about the approach one should use. Serious game, gamification and simulation game are three different perspectives of educational games. Sometimes it is not clear whether earlier authors discuss about serious games or about a gamified version of learning. Similarly, confusion exists between serious games and simulation games. Michael and Chen (2005) defined serious game as a game in which education is the primary goal rather than entertainment. Gamification, on the other hand, is the use of game design elements in non-game contexts (Deterding et. al, 2011). Gamification is further classified into structural gamification and content gamification (Kapp, 2013). Structural gamification alters only the structure around the content by using game elements such as leader board, reward (points, badges, currency), level-up; while the content remains unchanged. In comparison, content gamification alters the content and makes it more game-like by using game elements such as story, challenge, curiosity, character, interactivity, feedback, or freedom to fail (Kapp, 2013). Serious games are full-fledged games and have complete units (creation of a game as a whole). In contrast, gamification merely uses game elements in an existing learning programme. Both approaches can be used to increase engagement and to solve learning issues. It is important to note that the boundary between "serious game" and "artefact with game elements" can often be blurry (Deterding et al., 2011) as both are trying to solve a problem, motivate, promote learning and use game-based thinking and techniques (Kapp, 2012). Also, if an educator introduces more game elements to fulfil various educational objectives, the gamified version becomes more like a serious game.

Simulation can be defined as a "representation of reality or some known process/phenomenon" (Ochoa, 1969). It is a mathematical or algorithmic model with an appropriate set of constraints that allows predictive analysis of the system (Deshpande and Huang, 2011) and allows learners to experience the consequences of their decisions with no/ less cost of error which may not be possible in reality. When the game elements such as fantasy, rules, challenge, or winning condition are added to the simulation, it becomes a simulation game (Crooltall et al., 1987).

6. Type of platform: Digital or Non-digital

Classification of educational games based on the platform they use was already carried out by (Battistella, 2015), which can be directly adaptable for the innovation games. Based on the platform they use; innovation games can be classified into digital and non-digital games. The digital platform includes the use of computers, table, phone, console etc. Non-digital platforms, on the other hand, are developed with the use of various resources such as board, cards, props. The significant advantage of developing digital games over a non-digital game is that the content can be accessed from anywhere and at any time. It is convenient to avail of the updated content on a digital platform. Also, online content is easy to manage, collect and analyse. However, in comparison to digital games, many non-digital games do a better job in developing imagination, creating better social experience and communication, and practising competencies in a realistic environment (Battistella, 2015).

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7. Placement of use: During learning or After learning (as a reinforcement)

The placement of a game can be during training (learning/ training occurs through a game) or after training (participants first become familiar with the process prior to playing the game, and then undergo reinforcement of learning through practising the game). For example, a new Product Development Process (PDP) game was designed to reinforce learning of the organisational aspects of the PDP (Becker and Wits, 2014). Generally, gamification techniques and simulation games are used during training, whereas serious games can be used during or after training sessions.

8. Level of evaluation: Reaction, Learning, Behaviour and Results

As noted by Emmerich and Bockholt (2016), two types of evaluation models exist: some models evaluate the quality of the game during or after the development phase; and contributes to further development and modifications (e.g., ADDIE models (Molenda, 2003), Serious Game Design Assessment (SGDA) framework (Mitgutsch and Alvarado, 2012)). Other models use empirical study (e.g., interviews, surveys, testing) to investigate the game's actual effects regarding fulfilment of its purpose. Kirkpatrick (2006) developed an evaluation model for training programmes in companies, which got widely adopted as a game evaluation technique. The model has four levels of evaluation: reaction, learning, behaviour and result. The same model can be adapted for the evaluation of innovation and design games (Table 1). Reaction is the first level that measures the participant's satisfaction. A positive reaction may not ensure learning, but an adverse reaction almost certainly reduces the possibility of its occurring (Kirkpatrick, 2006, pp22). The second level is learning, which measures the change in attitude, improvement of knowledge, and/or increase in skill, as a result of playing a game. The third level is 'behaviour' which measures the degree to which acquired learning transfers to participants' future performance. The fourth level is 'results' obtained by the participants at the end of playing the game. In the education context, besides these four levels, Shadish's work (Shadish et al., 2002) suggests common types of study and research designs which can be used for testing of the effectiveness of a game.

Table 1. Exemplifying four levels of evaluation

Level	**Examples of methods & tools**	**Examples in the context of innovation and design games**
Reaction	Reaction form, feedback form, questionnaires	Perceived use of the game in learning, fun, engagement etc.
Learning	Pre & post-test, interviews, observation	Effect of the game on learning conceptual knowledge, process knowledge, decision-making skills, problem framing skills, collaboration skills, business skills, etc
Behaviour	Interviews and observation over the period	Participants' mindset during future design exercises, measurement of long-term effects of the game
Results	Evaluation of the effect occurred by the participant	Design outcomes: requirements, ideas, concepts, prototypes, solutions etc., Impact on the organisation outcome (e.g. profit)

9. Other features

Besides the above classification, each game has its own rules, procedures, winning state, and resources. Also, educational games can be classified based on the type of activities the game has (e.g., puzzle, allocating resources, strategising, building, exploring, role-playing, time pressure) (Kapp, K.M., 2013). Based on the involvement of players, a game can also be classified as a single-player or multi-player game. Games can be classified based on activity (physical exertion, physiological, mental), modality (visual, auditory, haptic, smell, etc.), interaction style (keyboard/mouse, movement tracking, eye gaze, joystick etc.), environment (social presence, mixed reality, virtual environment, etc.) (Laamarti et al., 2014). Games also can be classified based on the type of learning objective it fulfils (Kapp, K.M., 2013). (i.e., cognitive, psychomotor & affective (Bloom, 1956); verbal information, intellectual skills, cognitive strategies, attitudes & motor skills (Gagne, 1972)).

5 CLASSIFICATION OF GAMES BASED ON AN EXTENDED TAXONOMY

For classification, we identified a total number of 20 games available in literature or on web platforms. Some games do not provide all the information about the game attributes. In the case where literature does not include all the categories mentioned in the taxonomy, we have marked the categories as NA. A few

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games from the previous taxonomy were not found related to design and innovation, and therefore have been eliminated from the list. Even if a game is meant for general public, the classification of games for the targeted user was considered based on participants involved in the empirical testing of the game. Table 2 depicts extended classification of existing game. The games intended to use for the academic construction of the professional designer's practice, were further classified into task clarification, conceptual design, embodiment design and detail design. Whereas the games intended to use beyond the design context (i.e., design thinking) were further classified into data gathering about user needs, idea generation and testing.

Table 2. Extended classification (Legend: SS: service system, SC: supply Chain, T: task clarification, C: conceptual design, E: embodiment design, D: data gathering about user needs, I: idea generation, T: testing, NA: information not available; green highlight: design process stage, orange highlight: design thinking process stage)

	Game approach			Platform		Public			Placement of use		Purpose			Participants' Involvement		Innovation Stages				Evaluation level				
Game	Gamification	Serious Game	Simulation	Digital	Non-Digital	Children	Students	Professional	During	After	Spread message	Educate	Train	Single Player	Multiplayer	Design	Realisation	SS & SC	Business	Reaction	Learning	Behaviour	Results	
SBCE(Kerga et al., 2012)		●			●			●	●		●	●			●	● T, C				●				
PDP (Becker and Wits, 2014)			●		●		●			●		●			●	● T, C, E					●			
Bath Boat Game (Outram et al., 2007)			●		●		●			●		●	●		●		●	●	●	NA				
SuLi (Judmaier et al., 2008)			●	●		●			●			●			●		●			●	●			●
The simulation game (Hölttä and Eisto., 2011)			●	●			●		●				●		●			●		●	●			
Innopoly (Berglund et al., 2011)			●		●		●		●				●		●	● T, C			●		●			●
18-Wheeler (Juuti, 2008)			●		●		●	●	●			●	●		●	● T, C			●	●	●			●
Apollo 13 (Juuti and Lehtonen, 2012)			●		●		●		●			●	●		●	● T, C			●	NA				
Gamestorming (Meuris et al., 2013)		●			●		●		●				●		●	● C					●			●
EDIPS (Uei et al., 2014)			●		●		●	●	●			●	●		●			●			●			
DBox (Bhatt et al., 2019)	●				●	●			●			●	●		●	● D,I,T				●	●			●
Lino (Libe et al., 2020)		●			●	●			●			●	●		●	● I, T				●				●
STORM (Rosa et al., 2018)		●			●		●	●	●				●		●	● I				●	●			
TILES(Mora et al., 2017)		●			●	●	●		●		●	●			●	● I				●	●			●
Crossroads (Bogers and Sproedt, 2012)			●		●		●			●		●			●				●		●			●
CONSORTiØ (Ma et al., 2019)		●			●		●			●		●			●	● T, C			●	NA				
Creanov (Diaz, 2017)		●			●		●	●	●				●		●	● I				NA				
RIPPPLR (2016)			●		●	NA			●				●		●	● I				NA				
DT board game (2019)		●			●	●			●			●			●	● I, T				NA				
Khandu (2016)		●			●	●			●			●	●		●	● I, T				NA				

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Results of an intercoder reliability test with percentage agreement for each category are as follows: Game approach: 90%, Type of platform: 95%, Public: 91.2%, Placement of game: 95%, Game purpose: 75.4%, Involvement of participants: 100%, Innovation process stages: 87.5%, Evaluation level: 83.9%. Overall percentage agreement was found to be 87.5%, whereas Cohen's Kappa statistics was 0.76 (substantial agreement). The minimum agreement was found for the "game purpose" category (i.e., 75.4 %). This was due to the lack of explicit information available in a few of the literatures, and thus resulted in inconsistency. Later, the discrepancies for each category were discussed and resolved by taking corrective actions in the tagging. The categories selected for the classification are shown in Table 3.

Table 3. Identified categories for classification (Legend: ○: Radio button, □ Checkbox)

Categories
Game approach: ○ Gamification ○ Serious game ○ Simulation game
Type of platform does the game require: ○ Digital ○ Non-digital
Public/ targeted user: □ Children □ Students □ Professional
Placement of game: ○ During ○ After
Game purpose: □ Spread a message □ Educate □ Train
Involvement of participants: ○ Single player ○ Multi players
Innovation process stage: □ Design □ Realisation □ Service system-supply chain □ Business
Design stage: □ Task clarification □ Conceptual design □ Embodiment design □ Detail design
Design Thinking process stage: □ Data gathering about user needs □ Idea generation □ Testing
Evaluation level: □ Reaction □ Learning □ Behaviour □ Results

6 DISCUSSION

Based on the review of games with respect to extended taxonomy, key findings are discussed below in which the results are referring to Table 2.

- The types of public category are not mutually exclusive. For instance, 18-wheeler (Juuti, 2008), a simulation game, was tested for company engineers as well as university students. Thus, a game can be developed for a broad range of users or for specific, targeted users. For instance, a game can be developed for primary or secondary school children. Further, students can also be graduate students or researchers. Also, a game can target a specific age or occupation.
- The majority of simulation games impose rules as a game element (contain no tangible game elements).
- All games are multi-player games. This may be due to the fact that most innovation and design processes involve team activity. However, this also opens up the scope for developing single-user games for design and innovation.
- For serious and simulation games, the duration of play varies from 1 hour (e.g., Gamestorming) to 6-12 days (e.g., SuLi). This is because some games focus on a single activity or a few activities within a longer process, while others focus on the entire process.
- The third level of evaluation (change in behaviour) is not done in any game. This is an important gap that opens up developing scope in this direction.
- Some innovation games are developed for a specific phase of the process. For instance, Bath Boat Game (Outram et al., 2007) contributes to the last three stages of the innovation process (business, manufacturing, and supply chain issues). In contrast, the buyer-supplier relationship game contributes specifically to the business stage. SBCE game facilitates the test-design-build approach at the early stages of design when concepts are generated and selected. Some DT games cover all the phases of the process. For example, the "IISC DBox" (Bhatt et al., 2019) was developed to inculcate design to a learner covering all three stages (i.e., data gathering, idea generation and testing). The Rippler is a game that helps in generating ideas during the brainstorming process and thus covers only the idea generation stage, whereas Lino (Libe et al., 2020), a DT game, covers both the idea generation and testing stages. For both the above games, problems are pre-defined or given before the game.
- There is an overlap among the game approaches: serious games, simulation games and gamification (Figure 2a). SBCE game is tagged as a serious game. As a rule, SBCE game sets the penalty of redesigning (as redesigning increase development cost and development time) and draws real-world

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rules. Thus, it contains simulation element as a rule. Similarly, as a rule, IISC DBox, a gamified version, provides rewards to the players for identifying outcomes with quantity and variety (as quantity and variety have a direct correlation with the novelty of the solution), and draws real-world rules. Thus, it contains simulation element as a rule. Also, if an educator introduces more game elements to fulfil the educational objectives, the gamified version becomes a serious game.

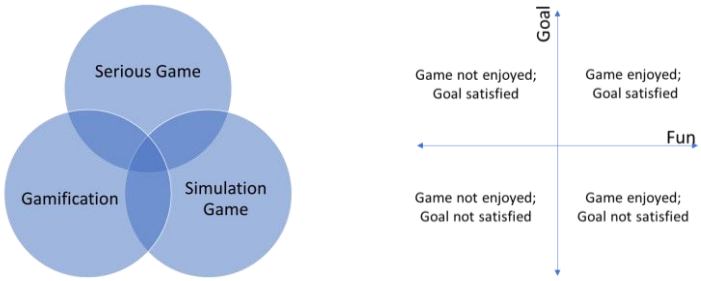

Figure 2. Representation of (a) game approaches and (b) game outcomes

6.1 Challenges in game evaluation

Evaluation is essential for checking the effectiveness of game on its intended outcomes. For instance, if a game is developed to improve a learner's understanding on a particular topic, evidence must be gathered to assess the impact of the game on the improvement of the learner's understanding on that topic. Apart from a game's effectiveness on the fulfilment of its goals, its impact on the learner's experience (fun, engagement etc.) also needs to be tested. In the evaluation of gamestorming (Meuris et al., 2013), the effectiveness of gamestorming method over the traditional method of brainstorming was tested empirically. However, its effect in terms of fun or motivation was not assessed. The game can be effective only if it satisfies the goals, and the learner enjoys it (Figure 2b). If the learning goals get satisfied, but the game is not enjoyable for the learner, it becomes an activity rather than a game. On the contrary, if the game gives enjoyment but does not achieve the intended learning goal, then it just becomes a fun activity. Thus, evaluation of a game must be done in terms of its ability to engage participants in the learning process as well as its ability to fulfil learning goal/s.

Another challenge is to assess whether the learning goals are fulfilled because of the game or because of learning content itself. For instance, in the game Lino, while the outcomes generated by students were found to be creative, it was unclear whether the generation of creative outcomes was due to the methods used or because of the game elements used. Similarly, while Creanov (Diaz, 2017) argues that the game was tested on 400 students, it remains unclear whether the innovative outcome generated was due to the effectiveness of the method, the game elements or both. At this stage, data from observation and participants' reactions may help judge the effectiveness of game elements.

7 LIMITATIONS & CONCLUSION

The list of classified games is not exhaustive. The classification has been made based on a set of broad aspects that can further be classified into subdivisions. For example, for the evaluation category, the type of research designs used under each evaluation level is not shown. In addition, the frameworks used for the development of the games are not currently discussed.

We argue that the extended taxonomy proposed in this paper allows gaps to be identified in the current status of the existing game taxonomy, thereby gives a better opportunity to develop and evaluate future games for innovation and design processes. The categories used in this classification scheme are generic enough to be applicable to all three types of educational game approach (i.e., gamification, serious games, and simulation games), thereby allowing one to classify any game easily. It could bring the research in the above fields (i.e., gamification, serious games, and simulation games) together for knowledge exchange. The categories given in the extended taxonomy (i.e., Game approach, platform, public, involvement of participants, innovation stages) can enable to think about various aspects and can guide educator in the development of the game such that game can be used effectively to satisfy the learning objectives. Also, the taxonomy provides evaluation criteria that can help researchers to analyse and evaluate the results of game-based learning. The taxonomy has the potential to guide researchers, educators and developers working in the field of educational games for innovation and design, by providing terminological coherence, direction for developing and evaluating games, and identifying the

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suitability of a given game for a given curriculum. We propose the extended taxonomy for the aim of making it useful for the development and evaluation of games; the validation (e.g., in terms of its applicability and ease of use) can be done through case studies which is a part of future work.

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