How gamification impacts physics?

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Abstract

With the rapid development of science and technology, the importance of physics increases equally because "knowledge of basic natural sciences contributes to technological progress and ensures sustainable development" [1,2]. Physics is one of the foundational school subjects in preparing students for the challenges of the 21st century. This makes improving students' learning outcomes in physics essential to modern education. To that end, clear articulation of positive educational goals, streamlined teaching processes, and diversified teaching methods should eliminate routine, unproductive, and tedious practices. Furthermore, lifelong physics learning requires more than foundational knowledge and skills. It largely depends on the attitude that students develop towards physics. Physics education practices should ensure that students completing primary education understand and actively participate in discussions of science and technology issues and make responsible and informed decisions [3]. In accomplishing these goals, games and gaming practices have great potential as they directly and strongly engage participants in developing and co-creating the outcomes, both individually and collaboratively. Introducing game elements in non-game environments is called gamification, which is a broad term that includes many variations and applications. This complexity makes applying gamification in education a challenge, especially in a physical-science-related field. This research aims to provide an overview and analysis of the studies related to gamification use in physics education. Our results show that gamification in physics education is seldom used, especially considering that our references include all articles available in the databases. Given that gamification elements have been applied most frequently in computer science, while other STEM areas have been neglected in this respect, our findings point to one wide area with great educational potential that has not been explored yet.

Keywords: *Physics, education, gamification, game-based learning, review*

1. Introduction

Students' difficulties in learning physics concepts are frequently caused by preconceived ideas that can be described as misconceptions, alternative conceptions, or mental models. These intuitive beliefs of students about physical phenomena are derived from inadequately understood everyday experiences. They are usually not aligned with models accepted by the scientific community [5], and are very resilient to change [4]. The potential of gamification in facilitating physics learning lies in the successful educational and entertainment practices already deployed in many other spheres of life such as economics, health, entertainment, and non-traditional education. It is known that structured games can deeply engage students, develop their creativity, and bridge their educational process with applications in various areas of everyday life.

1.1 Gamification

The concept of gamification is broad and complex but based on the existing literature, we can say that the generally accepted definition is: "the use of game elements in a non-gaming context" [6]. The main idea of gamification is using game strategies, game mechanics, and aesthetics to motivate and engage participants. In this sense, gamification stands in contrast to game-based learning (GBL), which complements traditional teaching with the use of technology [8]. We also differentiate gamification from the concepts of serious games, which focuses on making simulations of the real world.

Viewed through an education lens, gamification can be integrated into the learning process through the traditional game mechanics elements such as badges, points, rankings, levels, and rewards. By adopting these game elements in a context that is typically not considered entertaining, we can make the educational processes much more exciting and dynamic for students [7].

1.2 Elements of gamification

When we generally talk about gamification, we typically associate it directly with the concept of play, which is one of the primary ways of development from the earliest age onward. The use of the game in education is not something new, but not every use of the game is gamification. In a school setting, it is important to strategically map the game elements to the learning process to make it easier for children to learn.

There are several frameworks that systematize the key elements of gamification. Fui-Hoon et. al. [9] describe five basic principles of gamification as namely: goal orientation, success or achievement, encouragement, competition, and fun orientation. Author Jane McGonigal (2015) in her book *Superbetter* asserts that learning to be gameful in the face of extreme stress and personal challenge brings into our real life psychological strength that we naturally display when we play games (such as optimism, creativity, courage, and determination). She states basic principles of gamification through seven categories, i.e. "seven rules to live by". Those are: challenge yourself, collect and activate power-ups, find and battle the bad guys, seek out and complete quests, recruit your allies, adopt a secret identity and go for an epic win [10]. Chou (2014) constructed complete framework to analyze and build strategies around the various systems that make games engaging. He states that almost every successful game appeals to certain Core Drives within us that motivate a variety of our decisions and activities. He also elaborates how different types of game techniques motivate people either through inspiration and empowerment, or through manipulation and obsession. His gamification design framework is called Octalysis, based on the eight Core Drives or aspects of the game design and analysis [11]. The eight Core Drives reprezented in Octalysis are: (1) Epic Meaning & Calling, (2) Development & Accomplishment, (3) Empowerment of Creativity & Feedback, (4) Ownership & Possession, (5) Social Influence & Relatedness, (6) Scarcity & Impatience, (7) Unpredictability & Curiosity, ˙(8) Loss & Avoidance.[11] Each of the core drives is associated with a large set of specific gaming strategies. The most commonly used ones in educational settings are: points, levels, challenges, badges, scales, awards, progress bars, stories, avatars and feedback [9,12,13].

1.3 Questions and objectives

While the application of gamification in different fields has been widely researched, it did not find a broad application in physics education. We find this opportunity promising and significant. In this paper we describe and synthesize available information to help understand the current approaches. Available studies indicate existing interest in the application of gamification in education, but most often them are focused on higher education. [14,15]

The aim of this research is to conduct a systematic review of studies that have developed a methodology of gamification in physics education based on established criteria. For that purpose we seek to answer the following research questions:

RQ1 What is the time distribution of studies investigating the application of gamification in physics education

RQ2 What are the most commonly used elements of gamification in selected studies

RQ3 What are the advantages and disadvantages of the application of gamification in selected studies

These research questions were created in order to establish the known potentials and pitfalls in implementing gamification elements in physics education and to identify the most successful applications, if any, in this field.

2. Methodology

Our review of the published articles was guided by the PRISMA protocol and recommendations for the systematic literature review [16]. To compile a list of papers applicable for this review, in accordance with the protocol mentioned above, we searched two large databases of scientific materials: Web of Science and Scopus. We analyzed all available materials in both databases, which means articles published from 1950 to 2021. We did not set the lower limit of the search time interval. However, as a term, gamification originated in the digital media industry and became widespread and accepted only in the second half of 2010. At that time, thanks to the development of the Internet and the DICE conference via video, it went viral [6]. The search strings we used to characterize the study of gamification in physics education were: gamification AND physics AND school. We applied the search through the title, abstract, and keyword fields. To select the documents applicable for our review, we have defined in advance the following criteria and exclusion sequence:

- Regarding language, we took only the studies written in English (criterion 1).
- Regarding the format, we excluded papers on websites, blogs and newspaper articles as well as parts of books (criterion 2).

- Regarding the research area, we have eliminated studies that are focused on socio-educational programs in informal contexts, such as public health education programs and the like (criterion 3).
- Regarding the research questions, documents that did not include elements of gamification in the context of physics education were also excluded, as well as those in which gamification was equated with GBL or serious games (criterion 4).

To eliminate overlaps, we used the EndNote application to compare the articles obtained through the criteria mentioned above. Those articles that were not directly related to research issues or did not meet all the inclusion criteria were also subsequently eliminated.

3. Results and discussion

Searching by strings, we singled out 114 research articles. Applying the first three criteria resulted in the list of 22 articles and the subsequent EndNote comparison eliminated four additional papers as duplicates. The resulting 18 papers were analysed through criterion 4, resulting in the selection of seven full-text articles that met all of the eligibility criteria. Table 1 presents the key findings associated with each of these seven papers analyzed in depth.

Author	Education level	Year	Gamification elements	Result (+ = -)
[17]	University	2019	Rank, points, narrative, timer	+
[18]	High School	2020	Points, badges, leaderboards	+
[19]	University	2020	XP, quests, levels, leaderboards, feedback	+
[20]	High School	2019	Quest, strategy	+
[21]	University	2021	Challenge, skills, points, rules, badges, leaderboards	+
[22]	Graduated	2021	Feedback, progress bar	+
[23]	University	2021	Timers, levels, XP, leaderboards, badges, feedback	+

Table 1. Content

The first characteristic of the selected papers that stand out is that all of them were published within the last two years, while our search spanned the period starting from 1950. This indicates that the gamification application in the realm of physics education is a very novel endeavor. Table 1 also presents the gamification elements used in each of the analyzed studies. By comparing these elements with the Octalysis framework, we find that utilized elements largely target only a small number of the Core Drives. In particular drive 2 (Development & Accomplishment) and drive 3 (Empowerment of Creativity & Feedback). This narrow band currently used leaves a broad space for incorporating a much larger range of motivational venues in developing gamified teaching strategies.

We consider the results of the analyzed studies positive if they report improved academic achievement, and/or engagement, and/or motivation due to the gamification elements incorporated in the teaching process. We found that all of the analyzed studies showed that gamification had positive effects on the outcomes of students' learning and motivation. Yacobson et. al. [22] reported significant improvement of students' intrinsic motivation, self-determination, self-efficacy, grade accomplishment and career motivation which are the five components of motivation. In Forndran and Zacharias' study [17], gamification was applied to the topic of electric resistors and offered to 2nd-year college students majoring in physics and engineering. The study also incorporated narrative-based approach revolving around electric power consumption as part of the gamification strategy. Participants very favorably rated of all aspects of the experimental intervention, with 96% approval rate for the storytelling aspect, 83% approval for the competition and collaboration features, and 90% approval for the point-based advancement and comparison system. The key downside of the intervention, as perceived by students, was related to the time required to complete the assignments [17].

Andrade et. al. [18] showed that the strategy of gamification aspects yield the best results when combined with other active learning methodologies such as project learning and they can especially enhance learning in virtual environments. For example, according to the authors, the introduction of gamification elements through the online learning platform had a positive effect on the perceived usability of the system and the students’ engagement level in the learning process. Moreover, groups interacting with the gamified questioning-based technique showed significant gains in their learning performance, as opposed to the null improvement that the control groups showed [18].
Dela Cruz et. al. reported positive results in terms of the students’ self-efficacy and career motivation after implementing gamification. They also report the positive effect of gamification in terms of grade pursuit motivation because with gamified systems, students give even more importance to their grades

than in the traditional setting. This further reflects on their improved performance in the subject. Authors attribute this additional motivation to the fact that elements of games such as leaderboards and competition allow students to be more aware of their grades and how they fare in comparison with others [19].

Research further shows that gamification strategies combined with the elements of augmented i.e. virtual reality can additionally contribute to the formation and development of students' cognitive interest and motivate their self-educational activities [20]. Ahmed & Asiksoy successfully applied gamification elements to enable students to conduct physics lab experiments on their own without any external interference or involvement and also integrate their creativity in the process of conducting the required experiments [23]. In their study, of all of the applied gamification elements, the badges and levels were found to have the most significant impact on students' improvement on innovation skills.

In general, the results of our findings suggest that gamification can and does have significant positive effects on students' motivation, engagement, and academic success. However, it is insufficiently researched as a strategy in general, and especially at the primary and secondary education levels.

4. Conclusion

This research presents a systematic analysis of the application of gamification in physics education. We found that gamification elements can be implemented as triggers of motivation, engagement, and academic success of physics learners. We also found that the concept of gamification is frequently mistaken for the notion of GBL and serious games, and to maximize the positive aspects of each of these different activities, they should be clearly delineated in educational practice and research. Our findings suggest that gamification elements have a great promise in guiding the development of new physics education strategies both by teachers and curriculum developers. At the same time, optimizing the best gamification practices is a broad area of possible new advancements and an uncharted new frontier for the physics education research community.

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