



Learning analytics for enhancing the usability of serious games in formal education: A systematic literature review and research agenda

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Abstract

In recent years, the interest in the use of serious games as teaching and learning tools in traditional educational processes has increased significantly. Serious Educational Games (SEG) and Learning Analytics (LA) are gaining increasing attention from teachers and researchers, since they both can improve the learning quality. In this article, we aimed to examine, summarize and characterize the current state of the art related to the application of LA to SEGs through a systematic literature review based on a methodological instrument called PRISMA. A qualitative analysis was performed in which 80 significant papers were selected from the ScienceDirect, SpringerLink, Web of Science, and IEEE-Xplore databases. From this analysis, we identified the main features of an efficient use of SEGs in terms of success factors and learning outcomes; we also discussed the benefits and challenges of integrating LA approaches into these environments. Consequently, a new multidimensional taxonomy for using SEGs to categorize these major features was proposed. The findings of this review reveal that SEGs have a beneficial effect on students' behavior, cognition and emotion; but more future works and empirical studies investigating data science techniques are needed to improve the usability of educational games. This research and the suggested guideline recommendations may be of value to researchers and practitioners willing to deploy SEGs contributing thus to the continuous improvement of digital learning in formal education.

Highlights

- A process of a systematic literature review for summarizing the findings of existing studies related to the use of learning analytics and serious games in formal education.
- The review proposes a new multidimensional taxonomy of several technical, pedagogical, game and contextual features useful for researchers and educators interested in integrating serious games into classrooms.

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- Identifying research gaps and challenges of investigating learning analytics within educational games that need to be explored to improve their usability.
- Proposing specific guideline recommendations for facilitating the deployment of serious games in traditional educational processes.

Keywords Teaching and learning · Formal education · Serious games · Data science · Learning analytics · Systematic literature review

1 Introduction

The global pandemic of coronavirus disease (COVID-19) has further accelerated the use of innovative technological tools in an unprecedented way in almost all domains. In particular in the field of education, emerging technologies such as social and collaborative learning tools, intelligent and adaptive tutoring as well as augmented and mixed reality applications, are deployed extensively in traditional educational processes by examining the relationship between digital and learning (Klašnja-Milićević et al., 2017) (Hantoobi et al., 2021). In recent years, the interest in studying the impact of serious games on learning outcomes in formal education has increased (Cheng et al., 2015) (Hainey et al., 2016). In fact, many research works show that integrating serious games, as a complementary learning resource, into the educational process has the potential to improve learners' learning experience (knowledge acquisition, content understanding) as well as their satisfaction (motivation, engagement) (de Freitas, 2018) (Fokides, 2018). Findings from several studies suggest also that serious games for education, so-called *Serious Educational Games* (SEG), can improve students' learning achievements (Vlachopoulos & Makri, 2017) (Lamb et al., 2018) (Giannakoulas & Xinogalos, 2018).

However, despite these benefits, the adoption of SEGs in formal education is still limited and is not always a guarantee of its success on all levels (pedagogical and motivational) (Tseklevs et al., 2016) (Hainey et al., 2016) (Alonso-Fernández et al., 2019). One challenge for the successful deployment of SEGs is how to measure the learning progress and outcomes achieved by students during their interaction with such environments. Traditional assessment methods like pre/post-questionnaires, qualitative interviews, observations, and notation grids (Smith et al., 2015) (Calderón & Ruiz, 2015) (Barr, 2018) are not suitable for SEGs since they are too intrusive impacting thus negatively learners' engagement. SEGs are interactive learning environments which can therefore produce large amounts of player-game interaction data (Alonso-Fernández et al., 2019).

Over the last decades, important technological advances have been achieved in the artificial intelligence and education areas, which investigated aspects contributing to improve the game usability (Serrano-Laguna et al., 2014). The emerging discipline of *Learning Analytics* (LA) and *Educational Data Mining* (EDM) has the capability to provide continuous non-intrusive assessment for SEGs, so-called *stealth-assessment* (V. Shute & Ventura, 2013), by collecting and interpreting pertinent information from heterogeneous data sources including sensor data and

real-time game data (Massa & Kühn, 2018). The LA and EDM communities are concerned with investigating big data about learners by applying different data science techniques and methods (data mining, machine/deep learning, analytics and statistics) to teaching and learning in order to provide better support both to students and teachers. (Vahdat et al., 2015) have made a distinctive difference between LA and EDM in terms of origins, key applications, and main objectives. In this article, the two terms are interchangeably used because the methods relevant to the educational field are utilized by both communities.

The topic of applying LA to serious games in the educational context has been widely researched (Vlachopoulos & Makri, 2017) (Schneider & Lemos, 2020) (Theodoropoulos & Lepouras, 2020) and reviewed.

(Petri & Gresse von Wangenheim, 2017) (Alonso-Fernández et al., 2019) (Tlili & Chang, 2019). Although some scholars have made the effort to specifically review and examine the effectiveness of SEGs using data science techniques (Alonso-Fernández et al., 2019), data analytics approaches (Tlili & Chang, 2019), LA interactive dashboards (Schneider & Lemos, 2020), or artificial intelligence methods (Yannakakis & Togelius, 2018), the *usability of SEGs* as well as the *benefits and challenges of applying LA to game data*, specifically in formal educational settings, have not been examined in detail. For example, (Vlachopoulos & Makri, 2017) collected studies from 2006 to 2016 to study the positive effects and learning outcomes of using serious games in higher education settings but didn't examine the effect of applying LA to improve the usability of SEGs. Therefore, this systematic literature review focused on formal education settings and aimed to explore (1) whether the use of SEGs could improve learners' performances, and (2) how further research on incorporating LA into SEGs can be conducted in order to enhance their usability. In addition, the present study attempts to propose a new multidimensional taxonomy for characterizing the exploitation of serious games in education; consisting of three dimensions namely: success factors, learning outcomes, and game learning analytics. Such a proposal would allow educators and researchers to better understand the major aspects that should be considered in the deployment and assessment of serious games in the educational system.

The remaining parts of this article are organized as follows. In Sect. 2, we provide a background of this work related to LA and SEGs fields. In Sect. 3, we present the adopted research method to conduct the systematic literature review. In Sect. 4, we expose the results analysis of this study in order to answer our research questions. In Sect. 5, we discuss the major findings; and we suggest future research opportunities as well as specific guideline recommendations for facilitating the deployment of SEGs in educational processes. Finally, in Sect. 6, we conclude the study with general notes.

2 Background

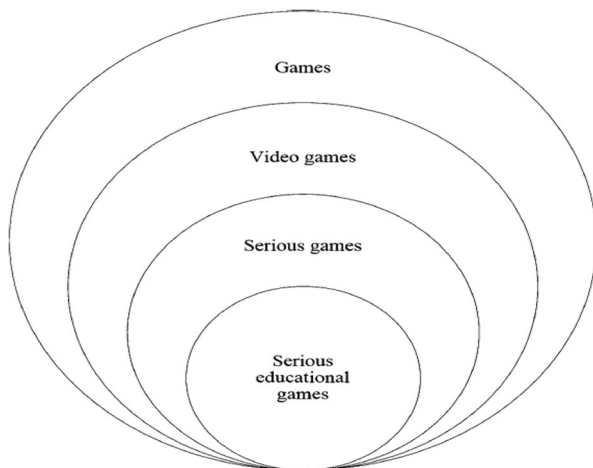
In this section, we introduce common concepts related to SEGs and LA fields. First, we present some general information about game-based learning processes. Afterwards, we define relevant LA aspects useful for understanding the context of this article.

2.1 Serious games

In the literature, there are several studies that proposed definitions of the term “serious game”. Serious games, as introduced by (Abt, 1987) in his book, are “*games designed for a primary purpose other than pure entertainment*”(Abt, 1987). (Zyda, 2005) has proposed a more specific definition in his article “From Visual Simulation to Virtual Reality to Games”, in which presents serious game as: “*a mental contest, played with a computer in accordance with specific rules, that considers entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives*”(Zyda, 2005). More recently, Alvarez and his colleagues (Djaouti et al., 2011) have characterized serious game as follows: “*a computer application, whose initial intention is to combine coherently the serious aspects (Serious) in a neither exhaustive nor exclusive manner, with instruction, learning, communication or further on information, assorted with the playing aspect of Video Games (Game)*”(Djaouti et al., 2011).

Nowadays, serious games are applied successfully in several domains (healthcare, education, military and defence, ecology etc.) with different purposes (teaching/learning, training, raising awareness, changing attitudes and behaviours etc.), and their target audiences include all ages (Daoudi et al., 2021). Serious Educational Games (SEG) are, as shown in Fig. 1, a specific form of serious games that incorporates a directed pedagogical approach to not only train activities but also to teach educational content (Annetta, 2008). These applications are used at all educational stages including primary, secondary and higher education (Hainey et al., 2016) in a wide spectrum of academic disciplines and subjects such as computer architecture (Tlili et al., 2015) (Hsu & Lin, 2016), mathematics (Ke, 2014) (Chadli et al., 2019), science (V. J. Shute et al., 2016) (X. Yang et al., 2021), computational thinking and programming concepts (Giannakoulas & Xinogalos, 2018) (Theodoropoulos & Lepouras, 2020), as well as language learning (T.-Y. Liu & Chu, 2010) (Suh et al., 2010) (J. C. Yang et al., 2010). SEGs are considered as an alternative to traditional

Fig. 1 Positioning SEGs (Annetta, 2008)



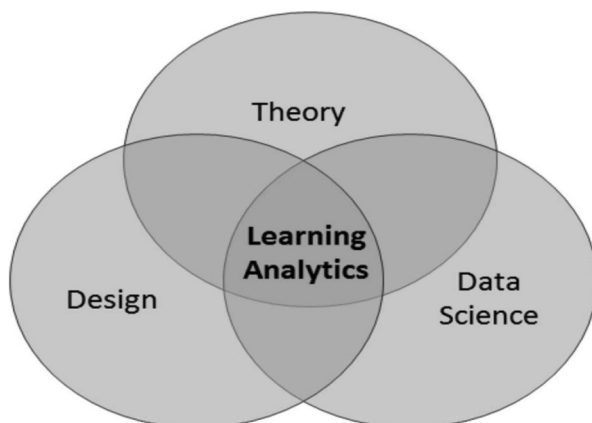
teaching methods that can contribute to improving student motivation, promoting learning, increasing task engagement, and higher specific skills such as problem-solving and collaboration (Petri & Gresse von Wangenheim, 2017) (Lamb et al., 2018) (Gómez & Suárez, 2021).

2.2 Learning analytics

The commonly used definition of Learning Analytics (LA) is proposed by (Siemens & Long, 2011). Authors defined LA as: “*the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs*” (Siemens & Long, 2011). Hence, LA aims to collect and analyze different forms of digital data about learners using data science and artificial intelligence techniques in order to address relevant questions related to their learning activities (Siemens, 2013). (Gašević et al., 2017) proposed, as shown in Fig. 2, a consolidated model of LA composed of three disciplines namely: *data science, theory, and design*. *Data science* provides analysis methods and algorithms such as machine/deep learning, natural language processing, computer vision, and data mining. *Theory* concerns all theories related to the education sciences, cognitive psychology, and sociology. Finally, the *design* discipline includes learning design, ergonomics (interaction and visualization) as well as study design (Gašević et al., 2017).

LA is mainly used to understand how people learn in the context of educational systems including learning management systems, intelligent tutoring systems, massive open online courses, and serious games. LA offers new tools to discover knowledge from a wide variety of types of digital data coming from different data sources like raw log files (interaction traces), as well as multimodal streams such as facial expressions, and other sensor data (Massa & Kühn, 2018). There exist different applications of LA. These applications can be classified according to the targeted end-user namely: *students/learners, educators/teachers, researchers, and administrators* (Vahdat et al., 2015). In fact,

Fig. 2 Consolidated Model of LA as Proposed by (Gašević et al., 2017)



learners' modeling is a process aiming to analyze and to represent the most important features characterizing the learners' activities such as the acquired knowledge, the personality traits, and the emotional states (Papa Mitsiou & Economides, 2014). For *educators*, data analysis and visualization by providing reports that contain useful information about different learners' aspects can help them to make decisions to improve their teaching performance. Concerning *researchers*, making discoveries in a learning context can help them to have a better understanding of learners' interactions with educational environments and eventually to propose new methods for evaluating their pedagogical effectiveness and personalizing the learning experience. Finally, LA methods and techniques can be exploited by *administrators* to evaluate the best way to organize institutional resources (human and material) and their educational offering. There are also multiple methods and techniques of LA for each of the various applications cited above. These methods are the same as those in the data science field like classification and regression, clustering, association rules mining, and social network analysis (Papa Mitsiou & Economides, 2014).

Figure 3 represents our comprehensive classification synthesizing all main elements of LA cited above. This classification aims to respond to five main questions related to the LA domain. These questions are respectively: (1) What are the main computer-based educational systems familiarly studied in the LA field? (2) Who are the stakeholders considered in LA? (3) Which type of data sources can be exploited to make new discoveries? (4) What are the different applications of LA? And (5) What are the main methods/techniques allowing us to explore data?

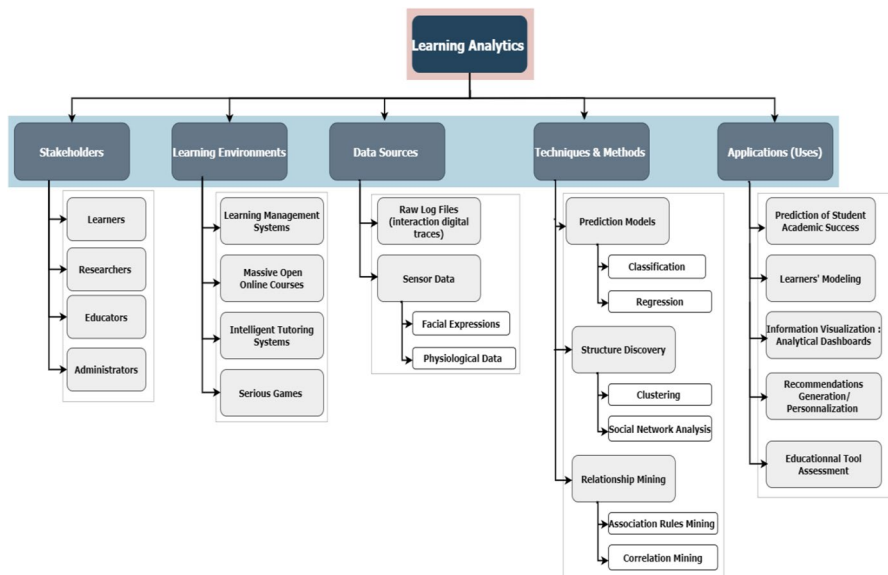


Fig. 3 Our Classification of LA

As mentioned in the Introduction section, our main motivation lies in the fact that SEGs are already, to a certain degree, integrated into classrooms, yet a *systematic review* specifically tackling the issue of *assessing and improving the usability of SEGs by applying LA* is still lacking. Therefore, this study aims to address this gap with a systematic literature review that explores the existing approaches, purposes and contexts in investigating LA for SEGs. Next section describes the different steps of the studies selection process.

3 Research method

The methodological approach of this review is known as a “*Systematic Literature Review*”(SLR). The aim of a SLR is to identify, summarize, interpret and classify the key elements of existing studies in a given topic or area according to a specific research question (Liberati et al., 2009). In addition, a SLR can be useful for identifying and analyzing potential research gaps that may be further developed. For this review, we followed the process with the following steps: (1)definition of research questions, (2)conducting the research by defining the search terms, (3)examination of articles using inclusion and exclusion criteria, and finally (4)presentation and synthesis of the main characteristics and major findings of the included studies. This process follows the *Preferred Reporting Items for Systematic Reviews and Meta-Analysis for Scoping Reviews (PRISMA-ScR)* to improve the methodological quality (Liberati et al., 2009).

3.1 Research questions

The aim of this SLR is to analyze, characterize, and synthesize the existing empirical evidence on the use of both LA and serious games in the educational context. For this aim, we explore the following general Research Question (RQ): what is the current scientific knowledge about the application of learning analytics to serious games in formal education? This global RQ is operationalised by the following sub-questions shown in Table 1:

Table 1 Research Questions

ID	Research Question
RQ1	What are the different pedagogical, contextual and game features addressed during the use of serious educational games?
RQ2	How learning analytics can contribute to measure, evaluate and improve the usability of serious games in formal education?

3.2 Databases searched

The electronic databases searched in this literature review include IEEE (Institute of Electrical and Electronics Engineers)-Xplore, ScienceDirect, Web of Science, and SpringerLink. In order to include significant articles, we selected the search terms, as presented in Table 2, structured in two segments: one for SEGs and one for LA. The first segment includes terms for serious games and all its synonyms when they are used in the field of education. The second segment includes several alternative terms for learning analytics. The selected search terms were applied to the title, keywords and abstract of each article.

3.3 Inclusion and exclusion criteria

The process of literature searching was carried out between January and March 2021, and the time period of publications was between 2010 and 2021. The purpose of this step is to identify the relevant articles that answer the research questions by examining the title and the abstract for each article. To this end, we apply the inclusion and the exclusion criteria shown in Table 3 to decide on its pertinence. Table 4 presents the result of the search process and significant publications that met the inclusion criteria for each database.

As shown in Table 4, the adopted search terms identified a big number of articles (536) proving the high-growth of interest in using serious games for

Table 2 Search Terms

Segment	Search terms
Serious Educational Games (SEG)	Games-based Learning OR Educational Games OR Learning Games OR Serious Games
Learning Analytics (LA)	Artificial Intelligence OR Data Science OR Educational Data Mining OR Data Analytics

Table 3 Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Journals, conference articles or book chapters published between 2010 and 2021	The article is not in the English language
The article provides a literature review or an analysis of empirical evidence about applying LA to SEGs	Articles whose full text is not available online
The article addresses the topic of using serious games in the context of formal education	The article discusses aspects not in relation to our research topic

Table 4 Search Results and Number of Relevant Articles that met the Inclusion Criteria for each Database

DataBase Searched	Number of articles identified in the search process	Number of included articles (meeting inclusion criteria)
Web of Science	72	7
IEEE-Xplore	63	8
ScienceDirect	218	37
SpringerLink	183	28
Total	536	80

education during this time period. Only 80 articles were identified as significant to this literature review. Clearly most articles were found in the ScienceDirect database with SpringerLink, and Web of Science the next most popular, followed by IEEE-Xplore.

3.4 Selection and synthesis of the publications

The selection of publications followed a three-steps process, as proposed by the *PRISMA* guidelines and shown in Fig. 4 (Liberati et al., 2009). In the first step, after removing duplicates, the title was screened for topic relevance. In the second step, and if the title is in line with our objectives, the abstract was read. In the final step, we read the full text of publications identified in the second step to select relevant studies that meet the inclusion criteria.

Next section examines and synthesizes the findings described in the included studies by answering our research questions.

4 Results analysis

In this section, we start by presenting a descriptive analysis of a representative list of the most cited articles included in our work, then we examine the existing literature in two main stages. First, we classify the different pedagogical, contextual and game features addressed during the use of SEGs (RQ1). Second, we show how learning analytics can contribute to measure, evaluate and improve the usability of serious games in education (RQ2). Consequently, we propose a multidimensional taxonomy for using SEGs in order to provide a comprehensive overview of current knowledge on this topic (RQ1 & RQ2).

4.1 Descriptive analysis of the selected studies: An overview

Table 5 illustrates the major information of the most cited studies in terms of objectives, study type, methods used for data collection and analysis, and results/ conclusions. This summary is valuable to present the major findings of the selected studies in an understandable and simple manner. As shown in Table 5,

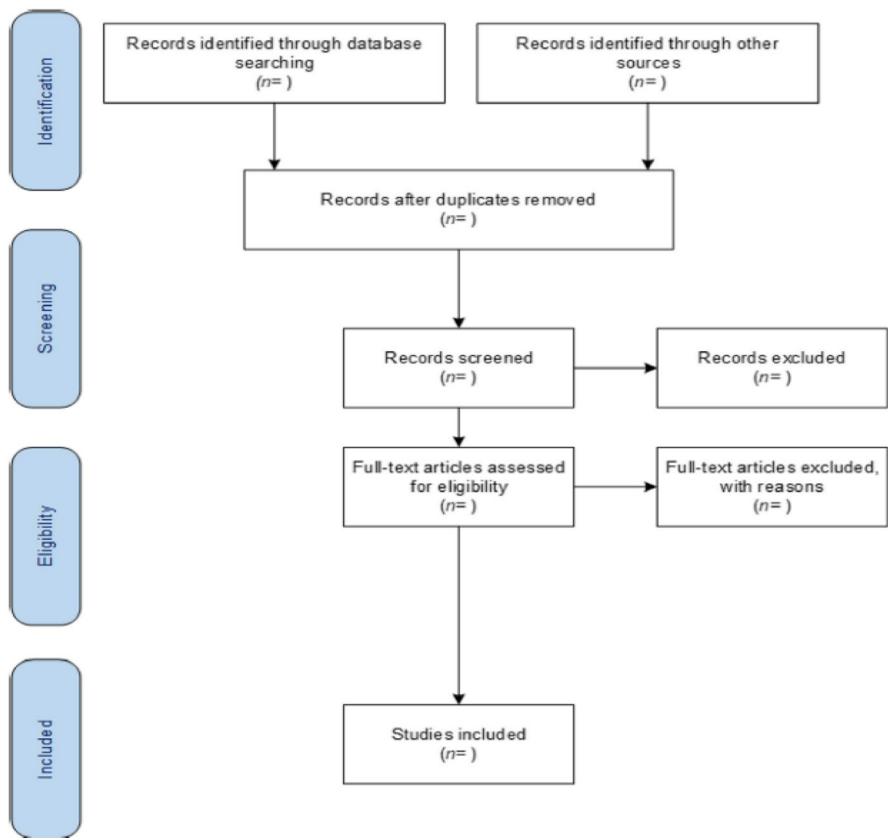


Fig. 4 PRISMA Flow Diagram for the SLR Process (Liberati et al., 2009)

many works have been conducted to analyze and discuss several aspects about using serious games in educational processes. The majority of them present empirical evidence obtained through the integration and assessment of serious games in real class settings. The most commonly explored conceptual framework was self-determination theory for motivation (Fulya Eyupoglu & Nietfeld, 2019) and Flow theory for engagement (Csikszentmihalyi, 1990). Data collection and analysis was performed generally through the elaboration of pre/post-questionnaires, interviews; and the data analysis results showed the benefits of using educational games in the teaching/learning process in terms of cognitive, emotional and behavioral outcomes. Recent research works have been proposed to integrate LA into SEGs in order to improve the process of design, implementation and assessment of serious games in the educational system as introduced by (Malliarakis et al., 2014) (Nguyen et al., 2018) (Alonso-Fernandez et al., 2021).

Table 5 Summary Table of the Most Cited Articles Included in our Review

Article	Objectives	Study type	Methods	Results/Conclusions
(Alonso-Fernández et al., 2019)	Classification of objectives, analysis techniques and stakeholders and from the applications of data science to game learning analytics data	Literature Review	Systematic literature review	-Most studies focus on learners' behaviors assessment by applying classical methods -Need of Game Learning Analytics with rules and open datasets
(Assaf et al., 2019)	Improving the acceptability of educational games in classrooms by analyzing teachers' perceptions about the use of serious games in formal education	Empirical	Survey	-Teachers' opinions and attitudes constitute an important contextual factor influencing the success of game-based learning experiences in the educational system
(Provelengios & Fesakis, 2011)	Analyzing the learning effectiveness of a serious game called "Food Force" about the global problem of hunger and the importance of humanitarian aid for primary education students	Empirical	Questionnaires and group interview	-The game has a positive impact on students' views and attitudes
(Alonso-Fernández, Calvo-Morata, et al., 2020; Alonso-Fernández, Martínez-Ortiz, et al., 2020)	Conducting an evidence-based evaluation of a serious game's effectiveness of bullying awareness for players between 12 and 17 years old	Empirical	Game learning analytics and data mining techniques using the xAPI-SG standard and traditional evaluation methods (pre/post-tests)	-Building prediction models of bullying awareness increase
(Hainey et al., 2016)	Synthesizing empirical studies related to the integration of serious games in Primary Education in terms of learning outcomes	Literature review	Systematic literature review	-Providing a repository of computer games useful for primary education -Classification of different learning outcomes

Table 5 (continued)

Article	Objectives	Study type	Methods	Results/Conclusions
(Malliarakis et al., 2014)	Proposing a conceptual framework to guide the integration of learning analytics mechanisms in game-based learning and which components should be taken into consideration when gathering and analyzing data	Empirical	Game learning analytics	-Implementing the framework within a MMORPG for teaching computer programming concepts in secondary education
(Kang et al., 2017)	Identifying and exploring learning behavior patterns of players within a serious game to learn problem-solving strategies	Empirical	Sequential pattern mining and statistical analysis	-Providing an analytical approach to understand in-depth the learning pathway of students' performance using gameplay data
(Nguyen et al., 2018)	Implementing a framework to incorporate learning analytics into serious games specialized for people with intellectual disabilities. It consists of three central components: learner profiling, learning adaptation and learning evaluation	Empirical	Game learning analytics	-The framework can be useful for the design, realization, evaluation and adaptation of serious games at the individual or collective level
(Gómez & Suárez, 2021)	Collecting, synthesizing, and mapping existing evidence related to the design and the effect of using serious games in higher education	Literature review	Systematic scoping review	-Studying pedagogical and technical factors of the design and the exploitation of serious games in higher education -Serious games have a positive impact on students' learning and achievement

Table 5 (continued)

Article	Objectives	Study type	Methods	Results/Conclusions
(Petri & Gresse von Wangenheim, 2017)	Exploring the evaluation process of games for computing education	Literature review	Systematic literature review	-Most evaluations are carried out without a suitable scientific rigor -Considering a more rigorous evaluation approach of serious educational games
(Mawas et al., 2020)	Investigating the impact of an educational game used to teach Science, Technology, Engineering, and Mathematics (STEM) subjects for primary school students by comparing the learning performance of the game-based approach with the traditional teacher-based approach	Empirical	Post-questionnaires and game review survey	-Evaluating the user experience while playing serious games and their usability in the educational context

In short, the descriptive analysis detailed above helped us to have an overview on the main contributions of the most cited studies, and consequently, enabled us to respond to our research questions as reported in the following subsections.

4.2 RQ1: What are the different pedagogical, contextual and game features addressed during the use of serious educational games?

In order to address the first research question, the major features discussed in the included articles can be categorized as follows: *success factors* and *learning outcomes*.

4.2.1 Success factors

The study of practices that influence the success of gameful learning experiences is one of the critical global issues that needs attention from researchers, educators and game designers/developers. By performing a systematic review of prior studies, we have uncovered a set of practical success factors contributing to an efficient use of serious games in traditional educational processes (Popescu et al., 2011) (Ravyse et al., 2017). These factors, including pedagogical, game and contextual ones, are able to improve users' satisfaction (teachers and students):

- *Pedagogical factors*: focus on examining the pedagogical concerns of the serious game as a learning tool. Hence, the pedagogical aspects coupled with the use of SEGs can be analyzed in terms of the following four factors: relevance of pedagogical content, scenario realism (credibility), clarity of pedagogical objectives, and players' progress (learning effectiveness) (Popescu et al., 2011).
- *Game factors*: focus on examining the game-play features of the serious game itself such as game type (simulation, adventure, strategic, puzzle etc.), game vehicles (computer, mobile, web-based or video console), player design (single, multiplayer: collaborative or competitive), game design and aesthetic (immersion environment 2D, 3D, virtual reality, interactivity etc.) (Ravyse et al., 2017).
- *Contextual factors*: it is important also to study the detail of how SEGs are incorporated into the student's learning process. Hence, the experimentation conditions (face-to-face or distance learning, game duration, teacher's role), the different educational institutions types, and the learners' individual traits can all influence the success of the learning process (Popescu et al., 2011). For instance, learners' special characteristics like their prior knowledge on the studied subject, their personality traits, as well as their current mood have a considerable effect on learners' achievement. The SEG, as with other digital educational resources, promotes learning provided that it is integrated into classrooms in a relevant and intelligent manner (insertion of the tool at the right time, for an appropriate period of time, in a specific teaching strategy aiming given students with a particular learning objective).

4.2.2 Learning outcomes

Many research works have been proposed to study the positive impacts and outcomes related to cognition, affect, and behavior change during integrating SEGs into classrooms (Hainey et al., 2016) (Vlachopoulos & Makri, 2017) (Lamb et al., 2018) (Yu et al., 2021). They classified learning outcomes into three main categories namely: cognitive outcomes, behavioral outcomes, as well as affective and motivational outcomes as follows:

- *Cognitive outcomes*: numerous existing studies discuss the impact of game-based learning sessions on various cognitive skills like knowledge/skills acquisition, critical thinking, problem-solving, content understanding, and decision-making (Hainey et al., 2016) (Lamb et al., 2018).
- *Behavior change outcomes*: behavioral objectives refer to the enhancement of relational abilities and social/soft skills like collaboration/coordination, communication/interactivity, feedback, reflection, and leadership; as well as the improvement of organizational skills, project management, and teamwork (Vlachopoulos & Makri, 2017) (Lamb et al., 2018).
- *Affective and motivational outcomes*: several studies focus on the affective outcomes of deploying SEGs in educational settings. Most of them looked at intrinsic motivation (Habgood & Ainsworth, 2011), Flow experience or engagement (Daoudi et al., 2021) and user satisfaction (Yu et al., 2021). In fact, it is crucial to investigate both engagement and intrinsic motivation in SEGs since intrinsic motivation is positively related to engagement (higher motivation contributes to achieving higher engagement and vice versa) and player' engagement has a positive and significant impact on student satisfaction (Yu et al., 2021). There are also other works interesting in other positive feelings like enthusiasm, self-assessment, confidence, excitement, enjoyment, and self-efficacy (Vlachopoulos & Makri, 2017).

4.3 RQ2: How learning analytics can contribute to measure, evaluate and improve the usability of serious games in formal education?

Despite the heterogeneity of the reviewed studies, we have been able to identify some common points and results about the usability of serious games in formal education. In fact, the main objective when analyzing digital traces collected from SEGs is educational tool assessment, especially its usability. In the context of human–computer interaction, the software usability¹ is described as, according to the ISO 25062:2006 definition, “the degree to which a software can be used by specified users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use”. Hence, the usability is a multidimensional concept defined by three quality components namely:

¹ <https://www.iso.org/obp/ui/#iso:std:iso-iec:25062:ed-1:v2:en>

- *Effectiveness*: refers to the accuracy and completeness with which users achieve specific goals.
- *Efficiency*: refers to the achievement of the goals with a minimum of resources in terms of time, energy etc. So, users can perform tasks quickly through the easiest process.
- *Subjective satisfaction*: refers to the user experience (positive attitudes/emotions towards the use of the tool).

The usability of serious games is a key factor in predicting successful deployment of that educational tool in classrooms (Abdellatif et al., 2018). It contributes to improving the utility and the acceptability of SEGs from pedagogical (reflexivity, adaptability), technical (gamification, gameplay), and contextual (context of use) perspective. Indeed, many studies reported that LA application to SEGs could increase the usability of these games in traditional classrooms (Nguyen et al., 2018) (Alonso-Fernández et al., 2019). LA techniques can be useful for, on the one hand, automating the analysis and modeling process of educational data for purposes of understanding and explanation; on the other hand predicting students' behavior in learning situations for purposes of personalization (Kiili et al., 2018) (Nguyen et al., 2018) (Alonso-Fernández et al., 2019). In order to illustrate the findings of the recent works investigating the application of LA to game data in the educational context, we propose to present a summary of their major characteristics as shown in Table 6. These characteristics include the objective of applying LA to SEG, the collected data (ex. game metrics/traces, pre-/post-tests) as well as the evaluation methods/techniques used in the study.

Based on this summary, the major elements treated in the included studies can be categorized as follows *objectives of LA*, *analysis criteria*, and *game learning analytics approaches*. Such a proposal aims to address the second research question.

4.3.1 Objectives of applying LA to SEGs

According to the selected studies, applying LA to SEGs has several objectives including:

- Understanding how students learn using games and modeling their behaviors (affective, social and cognitive states) during gameplay (Hou, 2012) (Kerr & Chung, 2012) (Cheng et al., 2015) (Minović et al., 2015) (Israel-Fishelson & Hershkovitz, 2020);
- Implementing teaching support to improve the process of teacher inquiry (Rodríguez-Cerezo et al., 2014) (Sergis & Sampson, 2017) (Kiili & Ketamo, 2018);
- Conducting formative and summative assessments of students' learning based on in-game data (stealth assessment) (Serrano-Laguna et al., 2014) and game evaluation (Freire et al., 2016) (Abdellatif et al., 2018);
- Predicting learning results based on students' interactivity (Loh & Sheng, 2015) (Kouraki et al., 2017) (Rowe et al., 2017) (Hernández-Lara et al., 2019);

Table 6 Summary Table of the Recent Studies Investigating LA in SEGs

Article	Objective of applying LA to game data	Game metrics or parameters	Evaluation methods/techniques
(Thili et al., 2015)	Evaluating the efficiency of a game for teaching computer architecture	-Time spent during playing -Game learning activities (Quiz, collecting items, buying, battle, shooting) -Scores obtained in each game learning activity -Game paths -Pre/post-tests	-Paired t-test -Classification methods using SPSS as a LA environment
(Serrano-Laguna et al., 2014)	Assessing educational video-games (learning contents, learning progress and learning gain) based on different types of traces to improve game usability	-Game start (connection information) -Game end (information about the end reached) -Game Quit (contextual variables like completion status) -Input traces (button pressed, moved, clicked) -Phase changes (levels, missions)	-Identifying and classifying set of generic traces and reports -Elaborating game-specific assessment rules based on combinations of generic traces -Real-time visualizations (analytics dashboards)
(Nguyen et al., 2018)	Proposing a systematic framework for learner profiling, learning adaptation and evaluation specialized for people with intellectual disabilities	-Demographic data of the learner -Dynamic gaming data: interactive actions on objects/avatars, timestamp of beginning and end of the game - Session, sequences of navigating between scenes, navigation frequency and time stamp of accessing each learning objectives and scenes	-Analytical algorithms for recommendation and personalization, behavior modeling and visualization including Machine Learning and Data Mining
(Malliarakis et al., 2014)	Helping teachers have an overall overview of the students' progress, problems and interactions during playing an educational game for computer programming	-Activity metrics -Session time/ last access -Answers in multiple choice questions -Interactions/chatting	-LA methods (Machine Learning, Educational Data Mining, Statistical Analysis) -Mathematical model

Table 6 (continued)

Article	Objective of applying LA to game data	Game metrics or parameters	Evaluation methods/techniques
(Hernández-Lara et al., 2019)	Improving teacher assessment of student learning in the context of business simulation games by studying collaboration, interaction and communication during playing	-Online discussion forums	-Data Mining algorithms such as Natural Language Processing
(Alonso-Fernández, Calvo-Morata, et al., 2020; Alonso-Fernández, Martínez-Ortiz, et al., 2020)	Predicting students' knowledge after playing a serious game for teaching first aid techniques	-In-game interactions -Pre/post-questionnaires	-Data Mining using RStudio: predictions models such as regression and decision trees
(Freire et al., 2016)	Improving the practical applicability of serious games in education by exploring the potential of data-driven approaches including game learning analytics	-Players' interaction logs	-Data Mining and visualization techniques
(Kiili et al., 2018)	Evaluating the effectiveness and usefulness of a game-based rational number training	-In-game metrics: effective playing time, maximum level achieved, collected coins, overall game performance -Pre/post-tests	-Regression and correlation models -Multivariate analysis of variance (MANOVA)
(Kang et al., 2017)	Better understanding of the learning pathway of students' performance and problem-solving strategies of students in a serious games context	-Gameplay data: types of actions, times-tamp, notes	-Sequential pattern mining -Statistical analysis

- In-game personalization and adaptation by providing an appropriate level of challenge according to learners' competencies level (Kiili et al., 2018) (Mostefai et al., 2019); and
- Validating the actual educational and game designs or finding possible improvements in game design as well as the cost efficiency of using games in education (Freire et al., 2016).

4.3.2 Analysis criteria

By examining the included studies, we observed that a wide variety of analysis criteria are considered to assess serious educational games. We report in the following the most frequently evaluated analysis criteria:

- *Learning achievements*: learning gain resulting from using SEGs is the main concern within the majority of selected studies. In fact, the evaluation of such criterion refers to the enhancement of competence level while comparing the players' competence degree after the game session with their competence degree before playing the game (Hakulinen, 2011) (Earp et al., 2015).
- *Affect*: several studies have been proposed to evaluate the player experience during gameplay in terms of sentiments, emotions and attitudes. Emotion is a key multidimensional concept composed of four main aspects namely: (1)subjective experience (feelings of pleasure or displeasure including engagement, motivation, frustration or boredom), (2)cognitive aspects (attention to relevant stimuli), (3)physiological aspects (heart rate, temperature, muscle tension) and (4) behavioral aspects (facial expressions and specific action tendencies) (Habgood & Ainsworth, 2011) (Vlachopoulos & Makri, 2017) (Abdellatif et al., 2018) (Rahimi et al., 2021). There are also others works interested in analyzing and evaluating criteria related to the usability concept such as ease of use, learnability, efficiency, understandability, usefulness, and acceptance (Erhel & Jamet, 2013) (Ravyse et al., 2017).

4.3.3 Game learning analytics approaches

Over the last few years, several research works have proposed approaches, methods and strategies using large-scale educational data (text chat, video records, raw log files) to improve the game usability and make discoveries about learning. Game Learning Analytics (GLA), as an application of LA to game development and research, is the analysis and the extraction of knowledge from data obtained from the interaction of players with serious games (Alonso-Fernández et al., 2017). GLA combines the educational goals of LA with technologies that are commonplace in Game Analytics (GA) to better assess and understand how games affect education and training (Alonso-Fernández et al., 2017). It could import considerable advantages for education, including assessment and improvement of learning performances, early detection of students at risk of dropping out or academic failure, increased engagement of learners, giving real-time feedback, and personalization of

learning experience. In what follows, we describe three main GLA approaches and methods developed in the reviewed studies:

- *Prediction approach*: a major task supported by this approach is to predict the learners' performance and knowledge behavior, or to predict final learners' grades based on digital data collected during game-based learning sessions. This approach is based on Machine Learning algorithms including classification and regression (Siemens, 2013) (Klašnja-Milićević et al., 2017) (X. Yang et al., 2021).
- *Structure discovery approach*: it is possible to identify relevant relations and patterns between learners' competence levels, times of using the learning environment, and their grades based on game data. The most common methods include clustering, factor analysis, and social network analysis (Klašnja-Milićević et al., 2017).
- *Relationship mining approach*: it is possible to determine a relationship between the game usability and the players' performances based on data gathered from the interaction between the learner and the game (Klašnja-Milićević et al., 2017). This approach includes several methods such as association rule mining, correlation mining, and sequential pattern mining (Siemens, 2013).

4.4 Towards a multidimensional taxonomy for SEGs (RQ1 & RQ2)

In order to provide a clear and comprehensive overview of the available evidence on our topic, we developed a multidimensional taxonomy for using serious games in formal education as shown in Fig. 5. In fact, the proposed taxonomy aims to resume

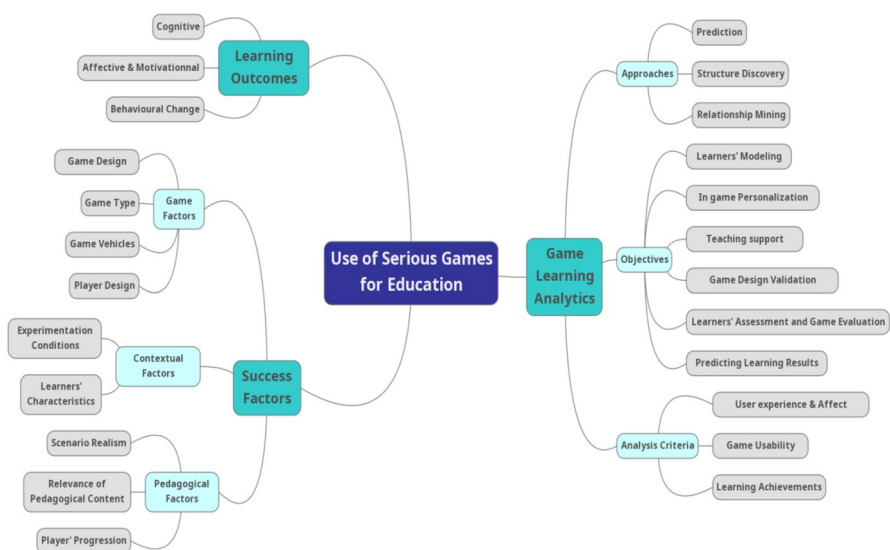


Fig. 5 Our Proposed Taxonomy for Using SEGs

the main elements analyzed in previous subsections related to RQ1 and RQ2. These elements consist of three major dimensions namely: the dimension of *success factors*, dimension of *learning outcomes*, and the dimension of *game learning analytics*. Each dimension contains various sub-dimensions that were identified in the selected studies. This global view of using SEGs may be a valuable foundation for conducting more future research in order to encourage the serious game deployment in real class settings.

On the basis of the work analysis detailed above, we propose in the next section a discussion of our major findings as well as a research agenda for the progress of the learning analytics field within serious educational games.

5 Discussion

This section first presents a summary of the findings, then discusses these findings in order to open up powerful research opportunities.

5.1 Summary of the findings

In this article, we presented a SLR process that examines works interested in the use of both SEGs and LA in formal education. A total of 536 articles were screened. Then 411 studies were excluded at the level of title and abstract, and 45 studies were further excluded after screening the full texts. As a result, a final set of 80 studies met the inclusion criteria and was entered for this review. Overall, similar to the results of previous systematic reviews (Vlachopoulos & Makri, 2017) (Alonso-Fernández et al., 2019), our findings supported a significant interest in deploying serious games in educational settings and applying LA to game data.

One of the objectives of this SLR was to examine the learning outcomes and effects of adopting SEGs in classrooms. The most commonly analyzed effects with such learning systems was knowledge acquisition, followed by affective and motivational skills as well as perceptual and cognitive skills. Hence, the most of the included works focused on exploring and evaluating the effectiveness of SEGs from the angle of cognitive outcomes (Erhel & Jamet, 2013) (Lamb et al., 2018) (Kiili & Ketamo, 2018) (Giannakoulas & Xinogalos, 2018). In addition, our findings show that there is a growing need to investigate elements contributing to the successful deployment of serious educational games in traditional classrooms (Ravysse et al., 2017). Moreover, the most often adopted GLA approaches are machine learning and data visualization (Alonso-Fernández et al., 2019). Indeed, the majority of the articles were looking at the student modeling, teaching support as well as personalisation and adaptation while implementing LA within SEGs (Minović et al., 2015) (Mostefai et al., 2019).

The multi-dimensional taxonomy suggested in this study, looking at the main success factors, the learning outcomes, and the game learning analytics, enabled us to provide a classification for categorizing and understanding different aspects of using serious games in formal education. The main contribution of this taxonomy

is to guide both researchers and educators about considering key dimensions to support the deployment of SEGs in the educational system. This taxonomy should contribute significantly towards the research needed to drive development of LA as well as the use of serious games in distance education.

Despite the many benefits of GLA, the application of learning analytics to educational games involves different ethical issues and technical challenges (Siemens, 2013). These critical challenges still remain and need to be resolved by researchers to achieve the success of the field. For example, there are few works that investigate the integration of LA within serious games in traditional educational processes to give effective real-time feedback for both learners and teachers (Hernández-Lara et al., 2019). Indeed, the design of serious games that incorporate a learning analytic system (automatic data collection, analysis and visualization) is a costly and complex task. In addition, we identified that little work has been done to consider background information about learners like demographic data (sex, age, gender, nationality, religion, culture), previous experiences with digital games, prior knowledge on the considered subject, or personality traits. In fact, such learner characteristics can provide useful contextual variables for GLA that have an important impact on the success of the learning experience as well as the persistence in the game (M. Liu et al., 2016). Moreover, the majority of evaluation works are run with a small sample size (between 3 and 20 participants), without duplication of experimentation, using generally traditional data analysis and visualization techniques such as histograms and scatter charts (Schneider & Lemos, 2020). There is also an absence of research works looking at advanced aspects of learning using SEGs namely learners' metacognitive skills such as self-regulation, self-reflection, and self-awareness (Kouraki et al., 2017).

In summary, these findings can be interpreted in order to extract future opportunities for conducting advanced research and exploring new directions as discussed in the next subsection.

5.2 Discussion of findings for future directions and guideline recommendations

The results showed that LA could import considerable advantages for education, including improvement of learning outcomes, early detection of students at risk of failure, increased engagement of learners, giving real-time feedback, and personalization of learning experience (Banihashem et al., 2018). However, there are many technical and ethical issues related to the use of both LA and SEGs in educational settings. Such issues need to be overcome for a successful implementation of LA in SEGs and enhancing thus the usability of educational games. In this subsection, we propose some research directions of integrating LA within educational games that need to be explored in future works; and then we provide specific guideline recommendations for facilitating the deployment of SEGs.

- Future Directions:

First, developing assessment approaches, based on prediction models using real-time game data to infer and refine GLA variables, can be a relevant contribution to

predict the game impacts on learners and thus to facilitate large scale deployments of SEGs. The obtained assessment results, which can be visualized through analytical dashboards, will be useful to provide personalization to individuals' learning needs (pedagogical needs of teachers and students' profiles). In fact, exploring more information visualization tools by designing interactive LA dashboards may enable, on the one hand, educators to provide personalized, formative, and summative feedback, to better understand the students' learning process, and to promote their metacognitive development (Lamb et al., 2018). On the other hand, integrating a LA dashboard into an educational game allows learners to understand their game-play performance changes, as well as their abilities and difficulties (Schneider & Lemos, 2020).

Second, more research should be conducted exploring multi-modal data collection from sensors at real-time to analyze the emotional state of learners and to evaluate their engagement during playing with all its dimensions: social, behavioral, affective and cognitive. Indeed, real-time data analysis enables teachers to perceive immediately how students play, their actions and progress, as well as the problems or difficulties they face (Sergis & Sampson, 2017). This information guarantees a more personalized learning experience for students.

Besides, further studies are needed to realize comparisons between single and collaborative play and more research works are required to explore the pedagogical advantages of implementing LA in collaborative SEGs. Indeed, we note that there is an insufficiency of multiplayer serious games integrating learning analytics. Such conclusion shows not only the necessity of developing games that promote collaboration, but also that incorporating LA is useful to better understand collaborative learning activities and learners' social interactions (Hainey et al., 2016).

In addition, managing the mental health of students is one of the most significant challenges we face in digital education (Ahern, 2018). Indeed, many students experience concentration difficulties and problems in their studies due to several factors including the stress, anxiety, and inability to access online education. There is a positive relationship between well-being and academic success: well-being is a crucial situation for gaining success and success is a vital condition for achieving well-being. That is why it is essential to focus on supporting student mental health and wellbeing especially in times of crisis (such as the COVID-19 pandemic) by applying LA in distant educational systems. The application of LA is an interesting research that offers learners and teachers techniques and advice for self-regulation of emotions and the development of resilience, based on a therapeutic education approach designed by professionals in ergonomics and work psychology. Besides, involving the different actors (parents and teachers) can be very useful to support students by providing them with social and psychological well-being (Ahern, 2018).

Another important issue is to consider critical ethical aspects of data protection like security, privacy, and anonymization related to the collection of massive amounts of educational data (Freire et al., 2016). The question is whether LA has access to personal data about students and their social structure (Banihashem et al., 2018). In fact, there is a considerable lack of studies that explore how learners' personal information is secured during gathering data from SEGs, a problem that requires further attention. (Pardo & Siemens, 2014) have proposed also that it is indispensable to develop legislation methods for data collection in order to avoid the problem of students' privacy violation.

- **Guideline Recommendations:**

Among the major obstacles that occur while exploiting serious games in classrooms is the imprecision of the teachers' role definition and their low familiarity with using this type of learning tool (Cheng et al., 2015). Therefore, it will be important and beneficial to produce, disseminate and share educational resources to train and support future teachers towards the deployment of serious games for greater efficiency. Such resources can include different forms such as pedagogical usage scenarios, and user manual/guide. This recommendation must be addressed if we wish to clarify and enhance the educational effect of SEGs on students' learning, and consequently to recognize the potential of serious games as teaching and learning tools in formal education.

In order to create game-based educational systems that are effective in real classrooms, we need to mobilize researchers from different disciplines (computer science, educational science, psychology and cognitive ergonomics) around methodologies for studying the acceptability of SEGs from an interdisciplinary and user-centered perspective. We also suggest, as proposed by (Hainey et al., 2016), a more collaboration between researchers and other stakeholders, namely game designers/developers and educators to identify best usages of SEGs aiming to improve learners' achievements. This will be a crucial but challenging issue needed to surmount in order to promote the integration of serious games into the educational system and to increase user satisfaction (both teachers and students) for an optimal user experience.

By taking into account the works included in the current study, we invite researchers to deal with large-enough sample sizes to draw generalizable conclusions about the integration and the evaluation of SEGs in real class settings and thus to increase the validity of their works. In short, we believe that the three points cited above are a set of practical guidelines and useful recommendations for all stakeholders that need to be considered in order to ensure successful gameful learning experiences.

6 Conclusions and limitations

This article has presented a SLR process on the use of SEGs and the application of LA in the education field over a 10 years period (from 2010 to 2021). The goals of this article were: (1) to build an idea of previous research by identifying the main features of using SEGs; and (2) to identify future directions and guideline recommendations concerning the implementation of LA within serious games in the educational context. To conduct this research, four recognized digital libraries and databases were consulted, and 536 articles were analyzed. Among such articles, 102 met the criteria for inclusion and exclusion defined in this article and only 80 contained relevant information to help answer the defined research questions: RQ1 identified the different features addressed during the use of SEGs; and RQ2 presented how LA can contribute to measure, evaluate and improve the usability of serious games in formal education.

The most important result of our study was the diversity of research works on positive outcomes and effects related to integrating SEGs into classrooms (Lamb

et al., 2018) (Yu et al., 2021). The multi-dimensional taxonomy proposed in this review has helped to provide a classification for categorizing and synthesizing the diverse outcomes of SEGs as well as other important dimensions such as success factors and game learning analytics. Based on our findings, it can be concluded that applying data science and learning analytics to game data play a crucial role for successful gameful learning experiences, and has the potential to enhance the deployment and usability of SEGs in educational systems. However, there are technical and ethical challenges needed to be considered in future works as described in the Discussion section. We expect our research can contribute towards an increase in research on LA in the context of SEGs and encourage researchers to investigate the challenges and research gaps for improving the usability of SEGs.

One limitation of this SLR was that the number of included papers was small ($n=80$) due to the search terms used and the databases included. The second limitation concerns the ability to generalize findings to different types of educational games covering different related fields. In fact, in this study, the majority of games were played digitally (from simply digital games to advanced simulations, virtual reality games and massively multiplayer online games). Moreover, we only focused on a specific topic that investigates the impact of exploiting SEGs in formal education as well as the role of LA in improving the usability of such environments. Hence, future research can explore other issues and research challenges not addressed by the studies included in this review like the design of interactive LA dashboards and recommender systems in education (Deschênes, 2020).

Authors' contributions I am the sole author and contributor of this article.

Data availability All relevant data and material are included in the manuscript.

Code availability (software application or custom code) Not applicable.

Declarations

Conflicts of interest The authors declare that there is no conflict of interest.

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