



Review

Serious Games and the COVID-19 Pandemic in Dental Education: An Integrative Review of the Literature

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Abstract: The COVID-19 pandemic has forced faculties including dental schools into a ‘new normal’, where the adoption of remote or distance learning is required to minimise the risk of infection. Synchronous learning historically was favoured due to the perceived advantage of ‘real time’ interactions between instructors and learners; these interactions are not always possible in asynchronous settings. However, serious games can overcome this limitation of asynchronous learning. This integrative review explores the literature on serious games in dental education, to construct a conceptual framework of their strengths in this pandemic. Following consideration of inclusion and exclusion criteria, 15 articles on 11 serious games designed for dental education were included in this review. Our investigation points to an increase in the use of serious games since 2018. The findings of the review support the use of serious games in dental education during the recent crisis. Key strengths include positive educational outcomes, enhanced engagement and motivation, interactive asynchronous distance learning, a safe learning environment, and the advantage of stealth assessment. Consequently, the ‘new normal’ in education appears to support a very promising future for serious games, particularly in dental education. A conceptual framework is proposed to inform further research across all education settings and timeframes.

Keywords: asynchronous learning; COVID-19; dental education; distance learning; game analytics; game-based learning; integrative review; remote learning; serious games



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1. Introduction

The COVID-19 pandemic has been rapidly spreading around the world due to the SARS-CoV-2 virus. This outbreak has impacted on varied areas, including participation in the educational field at all levels. Students are not allowed to conduct learning activities on campus as they need to minimise the risk of COVID-19 infection. Technology-enhanced learning (TEL), especially in a remote or distanced setting, enables instructors and students to control time, location, and pace, which are weaknesses of traditional education [1,2]. Consequently, TEL can be helpful in this pandemic where distance learning is required.

‘Remote’ or ‘distance learning’ can be conducted in either synchronous or asynchronous formats [3]. The term distance learning will be used within this paper. Both synchronous and asynchronous formats have advantages and disadvantages. During the pandemic, synchronous learning employed videoconferencing and webinars to replace face-to-face teaching. It allowed instructors and students to have interactivity in real time [4]. Asynchronous learning has readily been implemented for a period to improve flexibility. It allows students to learn at any time, but there could be a problem with the absence of real-time interactivity between instructors and learners [4]. However, serious games are advanced technological tools that can be implemented to enhance interactivity in asynchronous learning.

Serious (rather than for entertainment purposes) games are those primarily designed for education and training [5]. They allow students to improve their competences using feedback provided by the game system until they complete a game task [6,7]. Students can be engaged while learning through the game components [8,9]. Safe learning environments can also be created within serious games for students in various fields including healthcare [10–13]. A rapid review of serious games in healthcare education found that they can offer a similar educational outcome to traditional strategies, but the learning approach used in games seems to be more engaging [11]. These arguments support the use of serious games in disciplines such as healthcare education.

In the current global context, where learning in face-to-face settings or in real situations is restricted, serious games should be considered as tools to enhance interactivity in healthcare education including dental education. In our recent review in 2018 we reported that serious games had been implemented in various fields in healthcare education, but very few had been developed to be used in dentistry [11]. As there had not been a review of the use of serious games in dental education since our rapid review, it was considered necessary to conduct this integrative review to explore developments in this fast-changing field and to evaluate their impact when used in extraordinary circumstances such as the COVID-19 pandemic. This would give us the opportunity to investigate whether there has been an increase in use of serious games in dental education since 2018.

2. Theoretical Background of the Review

Serious games have the advantage of combining game-based learning and TEL. The learning process within an educational game comprises the instructional content and the game characteristics, and these two components trigger a game cycle, where students are motivated to learn [14], the game cycle being an iterative learning process that engages user judgement, user behaviour and system feedback to lead to achievement of learning outcomes [14]. This model can be implemented to explain the concept of serious games [10]. The learning process in serious games can be further explained by the important role that failure plays [6]. Failure within the game allows users to improve their competence to complete a game task. Furthermore, entertaining components are required for serious games to engage users in the game cycle [5,14], otherwise users may stop playing before they can achieve the expected learning outcomes.

Performance assessment is another consideration when using a serious game. In the game engine, interaction between users and a game system (user-generated data) can be captured without interrupting the learning process, i.e., so called stealth assessment [7]. These serious game analytics will reveal how the competence of learners can be improved with formative feedback until game completion. Enhanced with TEL, serious games can provide immediate feedback, enabling students to recognise mistakes and reconsider strategies to complete the game [6]. The immediate feedback within a serious game can support users to learn from their experiences.

Since the outbreak of the COVID-19, social distancing has been recommended to minimise the infection risk, and therefore onsite learning in dental schools has been restricted. During this period, there has been more focus on remote online synchronous learning as a substitute for face-to-face settings, as instant feedback can be provided through real-time interactivity [15,16], with an argument that immediate response may not be possible in asynchronous learning [17,18]. However, immediate feedback is considered an important feature of serious games [19,20]. In addition, with TEL support, serious games may be used anytime and anywhere [2], and therefore they have the potential to create interactive learning environments for asynchronous settings in dental education. Consequently, serious games might overcome the limitations of other asynchronous learning approaches and help students to gain knowledge and skills with engagement and motivation during the COVID-19 pandemic. This integrative review aimed to analyse the literature concerning serious games in dental education, in order to construct a conceptual framework of their strengths in response to the COVID-19 pandemic.

3. Methods

An integrative review of the literature was selected as the most appropriate investigative tool to generate new concepts within the chosen context of serious games in dental education during the COVID-19 pandemic. The synthesis of literature addressing emerging topics is suitable for this type of review, with a view to constructing a new framework as an initial conceptualisation [21]. An integrative approach starts from (1) conceptually structuring the organisation of the review, (2) designing how to conduct it, and (3) writing up the outcome of the review through both critical analysis and synthesis of the literature [21]. The methodological search process was piloted and adjusted repetitively before performing the final search [22]. This rigorous method aimed to ensure the thoroughness of the review, in order to answer the following questions:

1. What is the trend in the current use of serious games in dental education?
2. What strengths of serious games make them suitable to be used during the COVID-19 pandemic?
3. How can a conceptual framework displaying the strengths of serious games emerge from this review?

3.1. Search Strategy

To assure that as much available evidence was identified as possible, the literature search was conducted across seven databases, covering areas of education, technology, and healthcare, including the Educational Resource Information Centre (ERIC), Web of Science, Scopus, Embase, Medline, ProQuest Dissertations & Theses Global, and Cochrane Central Register of Controlled Trials. In addition, Google Scholar and the reference lists of identified articles were explored to search for relevant papers. Grey literature was also screened to enable serious games used in dental education to be identified wherever possible. Search terms and Boolean combinations were implemented to identify relevant literature, which included 'Serious game', 'Computer-based game', 'Digital game', 'Video game' and 'Online game', together with 'Dental education', 'Dental student' and 'Dentistry'. The last search was conducted on 31 January 2021.

3.2. Inclusion and Exclusion Criteria

All types of empirical study of the use of serious games in dental education published between 2000 and 2021 were included in this review; however, they were excluded if they were not relevant to computer-based serious games and if they were not designed for educating and training dental learners. They were not included if they were not available in English or in full-text.

3.3. Literature Identified from the Search

The initial search across seven databases identified 120 articles. In addition, three further studies were identified through Google Scholar and the reference lists of identified articles. After removal of 18 duplicates, the titles and abstracts of 102 papers were reviewed. Eighty-two articles did not meet the inclusion criteria because they were not empirical studies and/or not relevant to serious games for dental students or professionals. Twenty full-text articles were accessed, of which a further five were excluded: one was not available in English; one was not relevant to dental education; and three were studies regarding non-serious games. Consequently, after consideration of inclusion and exclusion criteria, a total of 15 articles were included. This process is presented in Figure 1.

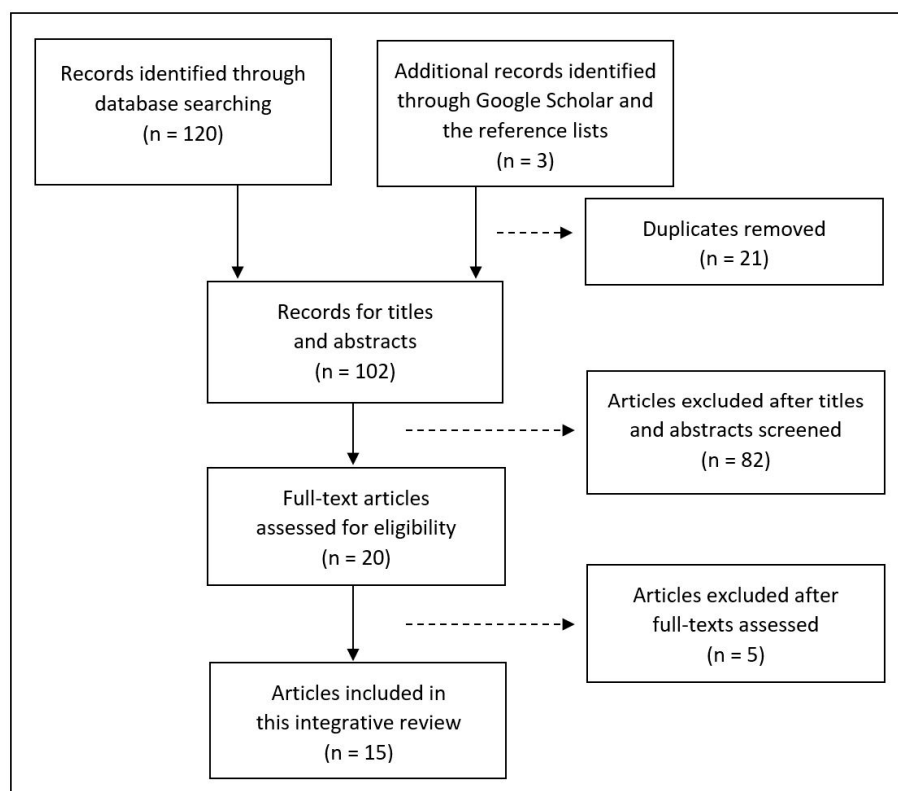


Figure 1. The articles selection process for the integrative review.

4. Results

4.1. Characteristics of Included Articles and Serious Games

The fifteen articles included in this review comprised seven journal articles [23–29], three conference papers [30–32], four book chapters [33–36], and one master’s thesis [37], including 11 serious games in dental education. Three serious games (reported in four articles) were designed for pre-clinical dentistry with a focus on tooth morphology in 2014 and 2017 [30,37], histology in 2019 [28], and skull anatomy in 2020 [36]. Eleven articles were relevant to clinical dentistry, including dentin bonding for operative dentistry in 2011 [23], alginate mixing in 2013 [24], diagnosis and treatment planning in virtual dental patients in 2013 [33], dental public health in 2013, 2016 and 2017 [25,26,34], biosafety in 2018 and 2019 [27,35], dental anesthesia in 2019 [31], diagnosis in virtual endodontic patients in 2019 [32], and clinical skill assessment in 2020 [29]. These serious games and their details are presented in Table 1.

Following synthesis of the relevant literature the following themes emerged: educational outcomes, engagement and motivation, asynchronous distance learning, safe learning environment, and assessment issues. These five themes were considered as the key attributes of serious game use during the COVID-19 pandemic in a remote or distance learning context. Table 2 presents frequencies of the themes as reported in the included articles.

Table 1. Table presenting the 11 serious games shortlisted for the review.

Topics and Names (When Provided) of Serious Games	Year	Aims of Serious Games	Learning Activities within Serious Games	Outcomes of Serious Games
1. Dentin bonding [23]	2011	To enhance knowledge in applying a three-step resin bonding system.	To perform the virtual procedure through the sequencing steps in applying dentin bonding.	The game could improve knowledge and skills with no difference to the control group. Students' satisfaction with the game.
2. Alginate mixing, <i>Skills-O-Mat</i> [24]	2013	To improve knowledge and skills in alginate mixing.	To improve skills in mixing alginate following a virtual instructor, with immediate feedback on a computer screen.	Student self-perceptions of their skills were increased after the game completion and achievement was higher than in the traditional approach.
3. Diagnosis and treatment plan [33]	2013	To enhance competence in diagnosis and treatment plan of dental patients.	To collect information on patients and then to make a decision on options of diagnosis and treatment plan.	No evaluation of serious game outcomes.
4. Dental public health, <i>GRAPHIC</i> [25,26,34]	2017	To enhance competence in how to design oral health promotion at a community-based level.	To select the best five options of health promotion programs to improve oral health of population in a virtual town.	The game could improve knowledge; the log system allowed instructors to assess students without interrupting the learning process.
5. Tooth morphology [30,37]	2014 2017	To enhance knowledge in tooth morphology.	To place virtual teeth in their correct positions in lower jaw, using autostereoscopy and Natural User Interfaces.	The game could improve student knowledge, and it was also perceived positively as entertaining.
6. Biosafety, <i>Biosafety in dentistry</i> [27,35]	2018 2019	To enhance knowledge about risk control and prevention in dental services.	To act as a chosen game character responding to provided questions, in a quiz-like game format.	No evaluation of serious game outcomes.
7. Histology [28]	2019	To enhance knowledge in medical and dental histology.	To interact with histology-related multiple-choice quizzes through Kahoot® (a web-based gamification platform).	Student satisfaction with the game in learning about histology.
8. Dental anaesthesia, <i>VIDA Odonto</i> [31]	2019	To guide students to conduct dental anaesthesia with an ideal trajectory.	To perform an anaesthesia technique in a virtual patient using VR haptic device.	No evaluation of serious game outcomes.
9. Diagnosis in endodontic patients, <i>RealTeeth</i> [32]	2019	To improve competence in diagnosis of endodontics.	To act as a new dental graduate who is required to diagnose ten endodontic patients in a job application.	The game was perceived as an interesting learning tool to bridge the gap between theory and practice, but gaming elements should be further developed to improve engagement and motivation.
10. Skull anatomy, <i>Visualisation Studio Sim</i> [36]	2020	To enhance knowledge in skull anatomy.	To interact with 3D models of skull anatomy with rotation and zoom functions and then decide whether the presented skull is correct or not.	No evaluation of serious game outcomes.
11. Clinical skill assessment, <i>OSCEGame</i> [29]	2020	To prepare students for an OSCE (Objective Structured Clinical Examinations).	To act as a student taking an OSCE in a virtual environment.	The game supported students in improving time management skills and reducing OSCE-related anxiety.

Table 2. A table presenting frequencies of themes as reported in the included articles.

Strengths of Serious Games	Number of Serious Games Reported to Support Each Outcome
Positive educational outcomes	7
Engagement and motivation	7
Interactive asynchronous remote/distance learning	7
Safe learning environment	4
Stealth assessment	1

4.2. Educational Outcomes of Serious Games

Educational outcomes were reported in seven out of eleven serious games [23,24,28–30,32,34]. All of them were found to have positive impact on knowledge improvement with only three of them (discussing dentine bonding, tooth morphology, and dental public health) were evaluated using pre- and post-tests to assess competence of students before and after the use of serious games [23,30,34]. One article compared the effectiveness of serious games to traditional approaches and found no statistical difference [24].

Six serious games were measured using user perceptions in either quantitative or qualitative format and were perceived positively as effective learning tools [23,24,28–30,32]. For instance, most students reported that the ‘OSCEGame’ (Objective Structured Clinical Examinations) could increase time management skills and reduce anxiety, which could prepare them well for further examinations [29]. Students also felt more confident after completing the games [23,28]. Therefore, serious games seemed to have a positive educational impact in dental education.

4.3. Engagement and Motivation

Engagement and motivation seem to be another key theme emerging when evaluating serious games. Seven serious games were surveyed to gather user perceptions towards entertaining components [23,24,28,30,32,34,36], which were positively perceived by dental students as engaging learning tools. The application of game rules within serious games can make learning activities more engaging. For instance, a challenge can motivate and engage users in completing a game task; however, there should be a balance between challenges and player skills. It might have been difficult for students to be engaged with learning content if they needed to repetitively perform a game task [36].

Entertainment features of video games could also be embedded for enhancement of learning engagement and motivation included having a colourful interface and using interactive music [24,26]. Technologies can also make serious games more engaging. For example, autostereoscopy and natural user interfaces can be implemented to enhance sensation and interactivity, enabling dental students to interact with three-dimensional objects using their gestures [30]. A high-quality graphic could also be used to enhance visualisation for engagement in a new generation of learners (Figure 2), in addition to pedagogical impact [36]. The enhancement of engagement and motivation can be considered as a key strength of serious games over traditional learning approaches.

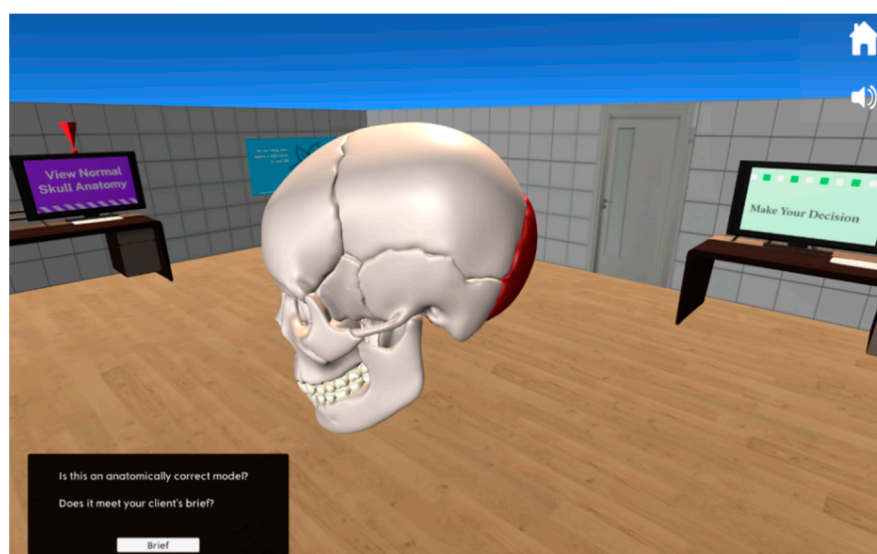


Figure 2. A screenshot from the skull anatomy game presenting an engaging graphic, reproduced with permission from Dall, R.

4.4. Serious Games as Interactive Asynchronous Distance Learning Environments

Seven of the eleven identified serious games in dental education enabled learning activities to be conducted online [23,25–29,32–36]. With these online serious games, asynchronous distance learning can be considered as an important strength in this COVID-19 pandemic. Distance learning allows dental students to learn to minimise the risk of COVID-19 infection. Together with asynchronous learning, students can learn in convenient time at a suitable pace [38]. Although the OSCEGame had set a limited time for students to complete each station, they could repetitively play the game until they felt confident about the examination [29]. Therefore, with serious games, each student can spend time differently in each section of the game and overall, based on their readiness.

There were three serious games requiring onsite settings to ensure learners had access to relevant materials [24,30,31,37]. Skills-O-Mat required a spoon attached to an accelerometer to capture how well students could mix alginate [24]. A serious game for dental anaesthesia implemented a haptic device for training students in conducting an anaesthetic procedure (Figure 3) [31]. Motion sensors seem to be important technologies for serious games in training psychomotor skills in dental education. According to a serious game for tooth morphology [30,37], although its learning outcomes were not psychomotor skills, auto-stereoscopy and natural user interfaces were implemented to enhance the interactivity of the game.

Instant feedback and immediate response appeared to be available in all included serious games in either formative or summative format [23,24,26–33,36]. The formative feedback allowed students to learn from their mistake [23,26], enabling them to improve their knowledge and skills. It appeared that informative feedback could be made more suitable, rather than being offered only in a numeric format [26]. The summative feedback would report how well students performed in a game task [24,32,36]; however, it could provide information on errors as a further improvement.



Figure 3. A user conducting a dental anaesthetic procedure using a haptic device [31], reproduced with permission from Nunes, F.L.S.

4.5. A Safe Learning Environment within Serious Games

Serious games can simulate a learning environment where students can experience dental practice safely. Dental students could be exposed to simulated patients in serious games, instead of ‘real’ clinical settings, to initially develop competences in oral diagnosis and treatment planning [32,33], as well as in local anaesthesia of the maxillofacial region [31]. This could minimise the risk of COVID-19 infection, whilst developing their skills in preparation for further training in clinical settings when possible.

In terms of community-based dentistry, serious games can simulate a learning situation where students can operate in a safe environment. GRAPHIC, (Games Research Applied to Public Health with Innovative Collaboration), a serious game for dental public health education, allowed students to gain disciplinary practice experience in a virtual town [26,34]. Within the game, students were firstly allowed to explore information on the virtual town provided by the system (Figure 4); they were then required to select the best five health promotion programmes, considering information about the town and research evidence, in order to improve the oral health of the population. This opportunity allows dental students to conduct community-based practice without being exposed to risk in a real community, and thus the risk of COVID-19 infection can be minimised.

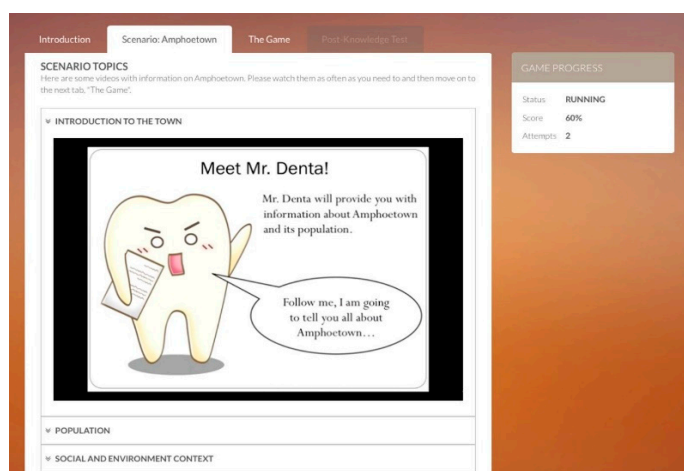


Figure 4. A screenshot of GRAPHIC (Games Research Applied to Public Health with Innovative Collaboration), where information on a virtual town is provided [34], reproduced with permission from Springer Nature.

4.6. Stealth Assessment in Serious Games

Stealth assessment, i.e., an approach to performance-based assessments that embeds assessments within digital games in order to measure how students are progressing toward targeted goals [7], can be considered as another strength when applied to serious games. The GRAPHIC system could record how students interacted with the game, and therefore dental instructors could assess logs of their performance and behaviours when performing the game task from the activity log data [26]. Designing stealth assessment in GRAPHIC also allowed students who did not progress to be identified, and therefore they could get additional support from academic staff for the achievement of their learning outcomes.

5. Discussion

5.1. Trends in Serious Game Use in Dental Education

This integrative review found an increasing use of serious games in dental education. There have been seven serious game papers published since 2018 [27–29,31,32,35,36], compared with eight between 2011 and 2017 [23–26,30,33,34,37]. This trend was similar to the use of serious games in general areas of education [39], including other healthcare education areas [11]. A rise in development of serious games may result from the increase of user demand, given that digitally-savvy generations are increasingly participants in all levels of education. In addition, game development software, together with increasingly advanced technologies, have become more affordable in recent years.

5.2. Potential in the Use of Serious Games in the COVID-19 Pandemic

Based on the articles reviewed, it appears that serious games should be supported for use as effective learning tools in dental education during the COVID-19 crisis, where distance learning is required to minimise the risk of COVID-19 infection. Given the time that it takes to complete research and move through publication, it may be that staff took the opportunity during the slowdown to ensure their findings were reported at that time, in support of their potential use. This development could be explained by the key strengths of serious games, which are (1) positive educational outcomes, (2) engagement and motivation, (3) asynchronous distance learning, (4) provision of a safe learning environment, and (5) assessment. These themes are discussed in this section to identify how they can support the use of serious games during the pandemic. The value of the development of a conceptual framework is that it allows further understanding of the key strengths of serious games, whether their effectiveness is evaluated during a pandemic or not.

5.2.1. Positive Educational Impact

Serious games can be considered as effective learning tools in terms of educational outcomes, as seen from the results of this review. Serious games have a positive impact on knowledge improvement amongst dental students, as there has been an increase of scores evaluated by pre- and post-assessments [23,30,34]. This outcome is broadly similar to serious games for other healthcare education areas [11,40]. In addition, most articles included in this review requested dental students to rate their perceptions of serious games [23,24,28–30,36]; the games were perceived by students as ‘helpful’ TEL tools in improving competence and preparing them for further studies.

In terms of learning design, serious games adapt a game concept to a learning process. According to the game cycle, introduced by Garriss et al. [14], there are three components: ‘user judgements’, ‘user behaviour’, and ‘system feedback’. In other words, when users preform an action in a game, the system should provide feedback for them to adapt their strategies to complete the game task, the so-called ‘role of failure’ [6]. Within serious games, a ‘failure’ is not a true ‘failure’, as it will enable learners to improve their knowledge and skills until they can complete a game task. Experiential learning can also be achieved while using serious games, allowing students to gain knowledge and skills through direct experience within games [41,42].

When comparing the effectiveness of serious games in terms of knowledge improvement, there seems to be no clear evidence in supporting them over other learning approaches. Only one article in this review compared the gaming approach with a passive format but found no statistical difference in terms of knowledge improvement [24]. The systematic review of serious games in healthcare education also reported similar findings, where the effectiveness of serious games over other learning approaches could not be sufficiently evident [40]. Consequently, it seems that serious games should be considered as a very helpful replacement of face-to-face learning formats during this pandemic, as they can provide positive educational outcomes at least as effectively as other learning approaches.

5.2.2. Engagement and Motivation

Engagement and motivation appear to be key strengths of serious games over other educational technology tools. Based on the results of this review, serious games were perceived positively as engaging learning strategies [23,24,28,30,34,36]. Although serious games are designed mainly for educational purposes, entertainment components are still required to engage and motivate learners. According to the game cycle [14], users need to perform a game task repetitively, failing and receiving feedback until they can complete the game. Therefore, if a serious game is not sufficiently engaging and motivating, students may cease the game, before achieving any learning outcomes.

The implementation of gaming technologies such as immersive graphics, gesture or motion control, voice recognition, and auto-stereoscopy appears to enhance serious games by making them more engaging. In the review, visual and audio aspects were reported to make the serious games more engaging. Both sounds and graphics can be considered as the entertainment components of serious games [43], and appear to play a fundamental role in engaging users [44]. Advanced technologies may also be used to enhance the entertainment value of serious games. Based on the included articles, interactivity can be designed using auto-stereoscopy and natural user interfaces to make the game more engaging [30]. This aspect can be considered as important, as this new generation of students in dental schools are familiar with video games, from an early age, and therefore serious games designed with very basic technologies might not be engaging for them.

Game rules and challenges can have an impact on the engagement with and motivation provided by serious games. One included article pointed out that a problem with engagement could occur if too many attempts were required for the same task [36]. This is an issue explained by the flow theory, where appropriate balance between competencies and challenges enhances flow of activities [45], which can be applied to game design [46–48]. In other words, if a game task is too simple, it could be boring. On the other hand, if it is too challenging, users may feel frustrated and stop playing the game. However, a serious game may be designed at different levels to allow learners to select a challenge that is suitable to their level of competence and knowledge.

5.2.3. Interactive Asynchronous Distance Learning

Of the eleven identified serious dental games, seven had already been using an online format [23,25–29,32–36]. Using an asynchronous format, these games allowed students to conduct their learning at a convenient time and suitable pace. Students with high knowledge and skills may progress through the game sooner than ones who require further improvement of competencies, in a personalised learning set up. Four of the serious games required students to conduct learning activities onsite [24,30,31,37], as they required specific equipment to capture the motions of students. However, they had the potential to be used in a distance learning setting, as these motion sensors appear to be affordable everyday equipment, such as smartphones, smartwatches, and game consoles.

Interactive asynchronous learning appears to take place in serious games, which can be considered as a unique strength for their use during the COVID-19 pandemic. As face-to-face sessions are constrained, online synchronous learning has gained more attention, and there is a real-time interactivity between instructors and students, where

instant feedback can be provided [15,16]. On the other hand, immediate response and instant feedback may not be provided in asynchronous learning [17,18]. However, this integrative review has shown that immediate feedback (formative or summative) could be provided within all the serious games we included in the review [23,24,26–33,36], and therefore an interactive learning environment can be embedded in distance educational settings. These arguments support the use of serious games as interactive asynchronous distance learning environments in the COVID-19 crisis.

5.2.4. Safe Learning Environment

As outlined above, serious games can simulate a learning situation, enabling dental students to gain experiences in a safe learning environment. This review identified serious games used for experiencing clinical practice in supporting cognitive [32,33] and psychomotor skills [31]. Not only is there no harm to patients, but any mistakes in the game may increase the awareness of each student in clinical practice. This strength of serious games has also been found in other healthcare areas including medical and nursing education [11]. A serious game for dental public health education allowed dental students to be exposed in a virtual town, where they could gain experience of community-based practice in a safe environment [26,34]. Such simulated environments ensure harm reduction when learning dental treatments as well as oral health prevention and promotion, and also remove the actual infection risk of COVID-19.

5.2.5. Stealth Assessment

Stealth assessment was discussed in one of the identified articles in the context of using log data analytics in a serious game to indirectly observe how students interact with the game [26]. Serious game analytics combining gaming and learning analytics seem to be an important feature for the improvement of a game [49]. Serious game analytics can capture user-generated data (by creating an activity log of interaction between users and a game system), which are valuable for game developers or educators to identify areas for improvement as well as to assess performance of learners. Stealth assessment can also determine how students are progressing toward targeted goals [7]. It was included in this review as it represents an important learning design element in capturing the performance and improvement of learners when progressing towards the expected learning outcomes of serious games.

With stealth assessment, the flow of serious games can be maintained, so students can be engaged in the learning activities without self-consciousness and time pressures [50]. Therefore, the actual behaviour of students can be evaluated through serious game analytics when capturing their activities in completing a game task. Stealth assessment is not beneficial specifically to the COVID-19 context, but it represents another unique trait of serious games.

5.3. A Conceptual Framework of Serious Games' Strengths in the COVID-19 Pandemic

Our review indicates that serious games have a positive educational impact in dental education, whereby learners can learn from their failure. Engagement and motivation can be considered as important as the learning activities themselves, since students need to be engaged with serious gaming activities to achieve learning outcomes. Immediate and interactive feedback within a serious game can also enhance an asynchronous distance learning environment, which is considered necessary in this COVID-19 pandemic. Log systems enable stealth assessment, where gaming activities of students can be recorded, allowing instructors to assess performance without interrupting the learning process. In addition, serious games can simulate learning in situations where face to face participation is not possible, for instance, allowing students to interact with virtual patients or communities to improve competencies in a safe environment. These key strengths of serious games work together in supporting dental students to achieve learning outcomes during the pandemic or in other situations when there are restrictions in engaging with face-to-face learning.

Figure 5 presents the key elements of the conceptual framework. It defines the relevant variables of our review and maps out how they relate to each other. In the Figure, strengths in boxes with a thicker border are the ones reported in most studies; positive educational impact, enhanced engagement and motivation, and interactive synchronous learning environment were considered in seven serious games, safe learning environment was discussed in four, whilst stealth assessment was reported in one serious game (Table 2). The strengths include traits that are specifically designed for educational purposes; however, entertainment features are still required to engage and motivate users to repetitively perform a game task [5,14]. The arrows represent properties of the strengths; solid arrows represent essential properties that support the learning process and dash arrows represent desirable aspects that can enhance learning design.

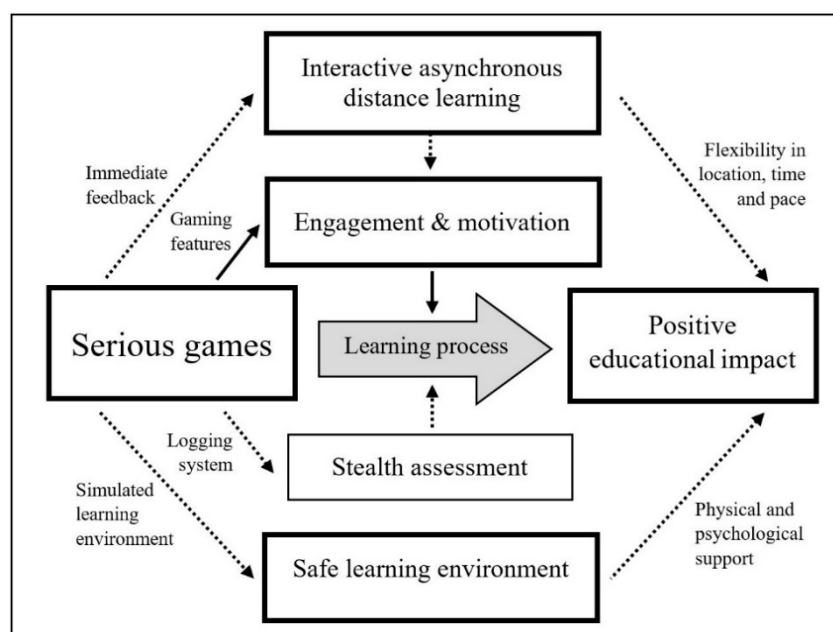


Figure 5. A conceptual framework of key strengths of serious games in the COVID-19 pandemic.

5.4. Limitations of this Review

There appears to be an increase in the use of serious games in dental education reported over the past two years since the last review we completed [11]; however, no research on serious dental games during the COVID-19 pandemic was identified. Consequently, it did not seem possible to evaluate the effectiveness of serious games for use in the pandemic crisis in dental education. In addition, although several serious dental games included in this review were designed as being available in an online format, none of the developers provided access to the games. Therefore, their descriptions were based only on the information provided in the included articles.

5.5. Implications for Future Research

This review has indicated the advantages of using serious games in dental education in extraordinary circumstances such as the COVID-19 pandemic. Further studies with robust methods, such as randomised control trials, are required to evaluate the effectiveness of serious games, compared with other learning approaches. In addition, future research should seek knowledge regarding the implementation of serious games in dental education both in normal and extraordinary circumstances such as in a pandemic crisis or a natural disaster. The conceptual framework presented in Figure 5 provides the basis of a useful tool to inform such research across all educational domains as innovations in TEL accelerate during and post-pandemic.

6. Conclusions

This integrative review revealed an increasing use of serious games since 2018. Our findings support the use of serious games in dental education during the COVID-19 pandemic and beyond, when and where the adoption of distance learning and teaching is necessary to minimise the infection risk. The conceptual framework derived from this integrative review combines the key supportive features of dental serious games i.e., (1) positive educational outcomes, (2) student engagement and enhanced learner motivation, the provision of (3) an interactive asynchronous distance learning, (4) safe learning environment, and (5) stealth assessment. The new normal for dental education forced by the COVID-19 crisis, consequently, appears to provide new opportunities for the use of serious games in dental education. However, future research should seek to employ robust methods to evaluate the effectiveness of serious games, in order to support learning strategies and their implementation in dental education.

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