sustainability

MDPI

Article

Learning Theories in Games That Teach Responsible Antibiotic Use: A Literature Review

Andreea Molnar [1,*] and Ioana Molnar [2]

[1] Department of Computer Science and Software Engineering, School of Software and Electrical Engineering, Swinburne University of Technology, Melbourne, VIC 3122, Australia
[2] Vitreum, 430291 Baia Mare, Romania
* Correspondence: amolnar@swin.edu.au

Abstract: Sustainable use of antibiotics implies changes in the way they are currently used. Games have emerged as a creative medium that actively engages people with aspects of their health. One of the areas in which serious games have gained attention is teaching about appropriate antibiotic use. In this research, we identify games that aim to educate on responsible antibiotic use and prescription. The games addressed various segments of the population (students, healthcare workers, public in general), most of them focusing on students. Furthermore, the article explores the learning theories used in these games. The results show that most games do not explicitly identify the learning theories used as a foundation for designing the educational aspects of the games. The games that address this aspect include learning theories based on the constructivist approach.

Keywords: educational games; antibiotic resistance; constructivism; learning theories

check for updates

Citation: Molnar, A.; Molnar, I. Learning Theories in Games That Teach Responsible Antibiotic Use: A Literature Review. *Sustainability* **2023**, *15*, 4643. https://doi.org/10.3390/su15054643

Academic Editor: Antonio P. Gutierrez de Blume

Received: 31 December 2022
Revised: 20 January 2023
Accepted: 27 February 2023
Published: 6 March 2023

1. Introduction

Considered to be one of the most important challenges in medical systems [1], antibiotic resistance is considered less acute than COVID-19 but "not less crucial" [2]. Antibiotic resistance occurs when bacteria adapt in a way that antibiotics become ineffective in situations in which they used to be effective. The emergence of resistance is a natural phenomenon, which is accelerated also by the inappropriate use of antibiotics [3]. The discovery of new drugs helps as ineffective antibiotics can be replaced with effective ones. However for their impact to last, changes in how the antibiotics are used need to be achieved [4]. These changes are challenged by various misconceptions regarding antibiotic use [5–7]. Antibiotic resistance is also a concept difficult to understand, and the public continues to hold misconceptions that the person becomes resistant [6,8,9]. This belief is also held by students in pharmacy, dentistry and veterinary medicine [9,10].

Games could be used to simulate complex environments in which their users can engage and interact with the educational content [11,12]. They are emerging as an alternative to complement education and training on important healthcare issues [13–17]. One area of health in which the games are increasingly used is to educate students, clinicians and pharmacists, or the public in general about the importance of responsible antibiotic use and prescription [18–23]. World Health Organisation also highlights the increase of creative campaigns all around the world which make use of games to create awareness about antibiotic resistance [24]. In the context in which "traditional" healthcare campaigns show mixed results about their effectiveness [25], games could help alleviate some of the shortcomings of the existing campaigns by actively engaging their users [21]. They could allow players to better understand antibiotic resistance and address some of the common misconceptions. Through interactions with the game, players can explore the consequences of various actions in a risk-free environment. This can help alleviate the limitations of the more traditional methods of delivering knowledge (e.g., leaflets, advertisements) which involve passive methods of delivering the information. However, games have also limitations.

For example, spending too much time playing games is detrimental to other activities [26]; effectively using games in promotional activities is an area which still requires further research [21,27]; and games are not always seen as a professional tool by clinicians [28]. Furthermore, serious games are more expensive to create than other types of media and require expertise from different fields [29]. Both the advantages and the limitations of using games in promotional activities need to be considered.

As the research in this field is expanding, as could be seen by the previous review in the area [22,27], an overview of the field could identify trends and areas that require further attention. As opposed to the previous review that focused solely on games aimed at clinicians [27], in this review, we aim to provide an overview of all segments of the population. We do this to create a better overview of the areas where games are used and areas in which more research is needed. Learning theories, although important on games that aim to educate, are not covered either by previous literature reviews on games aiming to promote responsible antibiotic use [22,27] or on more general literature reviews focusing on interventions in this area [30]. Although there are various aspects that influence the efficiency and acceptability of the games, such as enjoyment covered by a previous review [22], we decided to focus on learning theories as all these games aim in the first instance to educate. Pedagogical methods can also make the games more acceptable especially in the educational community [31] and more effective in delivering educational messages [32].

With this in mind, this review aims to identify:

- What are the games used to teach responsible antibiotic use?
- What population groups are they targeting?
- What learning theories are used in these games?

2. Methodology

We conducted a critical narrative review [33]. This allows qualitative assessment of the studies and synthesis of the results. Although this kind of review does not have specific guidelines such as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [34], several researchers have provided recommendations on how this research is to be reported [35–37]. Following these recommendations, we discussed the terms used for searching, the search strategy and inclusion and exclusion criteria.

The articles were identified using the following query on Scopus, PubMed and Web of Science ((games OR game) AND ("antimicrobial resistance" OR "antibiotic resistance")). Scopus database is one of the largest for research in the education and social sciences field and has been previously used in reviews in the educational field [38–40]. As this review focuses on learning theories and games aimed to educate about health topics red, publications in this field are relevant to the research. PubMed focuses on the health and biomedicine fields and contains over 32 million citations [41]. As this research is interdisciplinary and the games address a health aspect it is possible that research in this area could have been published in the health field, hence, this database is also relevant. Web of Science indexes journals from social sciences, life sciences, biomedical sciences, engineering and arts [42] and could also contain articles published in this area. Other literature reviews [22,43,44] that have focused on health aspects and games have included also this database in their search criteria.

The search was restricted to title and abstract. Publications up to 15 January 2023 were included in the search criteria. In total 340 articles were identified. Among these 12 articles focused on electronic games that addressed antibiotic resistance. Further to these, we have added five other relevant studies which were identified through snowballing [45]: by looking at the articles that cited the selected articles and further work published by the authors. As some articles were indexed more than one database duplicates were removed. We also removed articles which focus on games that did not have an electronic version (e.g., articles focusing on board games). We include journals, conference proceedings and articles published as an abstract. The latter was included to have a better overview of the

games in the field, even if those do not provide extensive details about the games. Other types of articles (e.g., call for papers, reviews) were excluded. We also excluded articles published in a language other than English. Figure 1 describes the selection process.

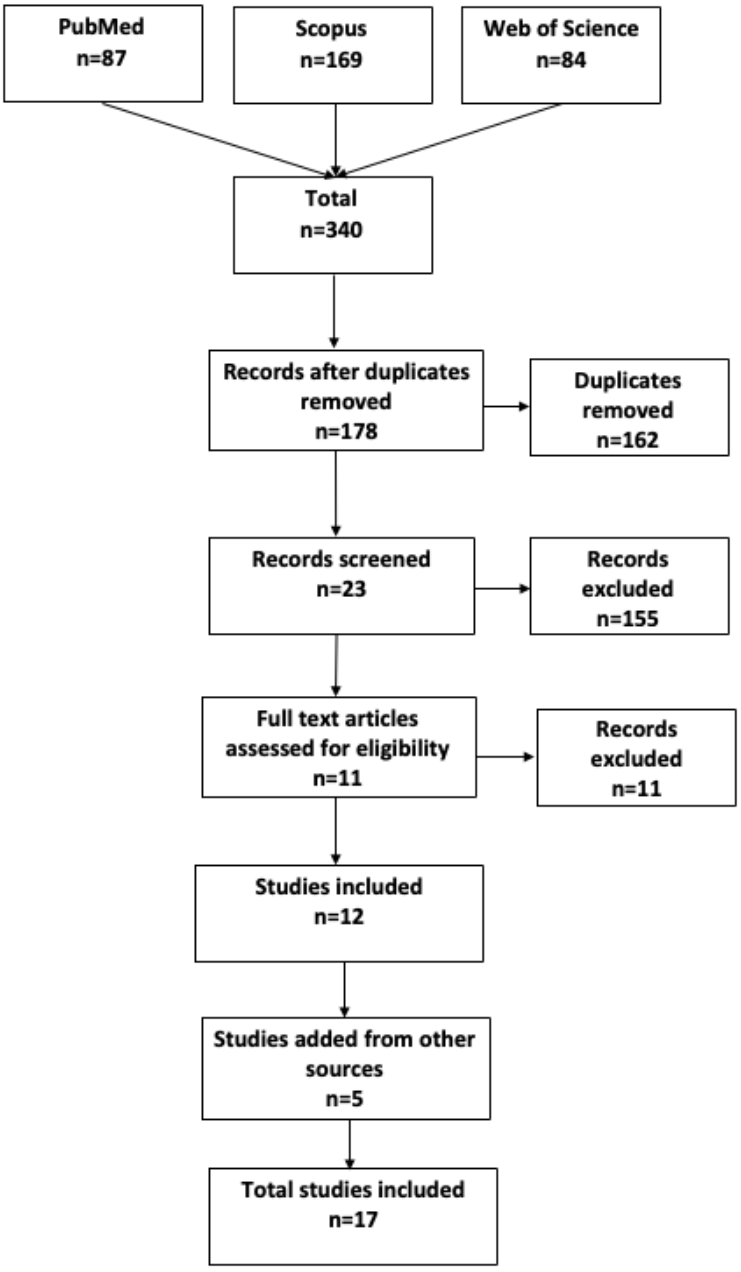

Figure 1. Search Process.

3. Results

3.1. Games and Population Targeted

The search identified 11 games briefly described below. The games were divided based on the demographic of the population that they covered: students, healthcare workers and the public in general. Table 1 presents a short overview of the games based on the above-covered demographics. Most of the games are aimed at teaching students (primary school, secondary school and medical students) various aspects of antibiotic resistance and responsible use and prescription.

Table 1. Games and Population Targeted.

Game Name	Brief Description
Students	
AntibioGame® [23]	Uses different case studies the primary medical students are taught knowledge of responsible antibiotic use.
Body Busters [18,20]	Focuses on how microbes interact with antibiotics. The game mechanics are similar to Pac-man.
Doctor Doctor [18]	Focuses on how antibiotics should be administered. It is a role-playing game. The players treat the patients with either antibiotics, water or bed rest depending on their condition.
edugames4all MicrobeQuest! [46]	The mobile version of Junior Game. Covers the same learning objectives as Junior Game and has similar game mechanics (e.g., the player—who is the size of a microorganism—collects white blood cells and "throws" them at the microbes (a similar approach for using treating with antibiotics. The player receives rewards for successfully performing an action).
Junior Game [19,47–51]	A digital platform game that can be played through the browser. It aims to teach microbe transmission, hand and food hygiene and antimicrobial resistance. It targets school children from 9 to 12 years old. The game's learning objectives were selected based on what is taught across several countries in Europe for this age group.
Senior Game [48–53]	A digital adventure game that can be played through the browser It is designed based on the European curriculum for 13 to 15 years old. The game is composed of three missions and teaches about microbe transmission, hand and food hygiene, and antimicrobial resistance.
Healthcare Workers	
AMS Game [54]	Focuses on the relevance of One Health [55] in antimicrobial stewardship. The game has a target audience of healthcare workers (e.g., doctors, clinicians, pharmacists, and students in the area). Tested across multiple countries.
GASDA [56]	Focuses on refreshing knowledge of antibiotic prescription guidelines and changing non-compliant prescribing practices. The game was piloted in Nigeria.
On call: antibiotics [57]	Focuses on antibiotic administration. The game has a target audience of doctors, clinicians and pharmacists.
General Public	
Aevol [58]	Simulates the Aevol model of bacterial evolution. Throughout the game, the player fights infections using different types of antibiotics.
Superbugs [59]	Educates about proper antibiotic use. Focuses on players accumulating knowledge on factors affecting antibiotic resistance. Can be played on mobile phones.

3.2. *Learning Theories*

Only three of the games presented in the section above explicitly mention instructional design paradigms. Table 2 column three presents them, and the subsections below expand on the work. Both methods are based on constructivism [60]. According to this learning theory the students learn by constructing their own knowledge rather than being passive recipients of the information. The games identified two instructional design paradigms: problem-based learning [61] and constructive alignment [62].

Table 2. Instructional Design Paradigms Mentioned in the Games Articles.

Game Name	Instructional Design Paradigms
Senior Game [52]	Problem based learning
edugames4all MicrobeQuest! [46]	Learning through game mechanics, constructive alignment
Junior Game [19,47]	Learning through game mechanics, constructive alignment

3.2.1. Problem based Learning

The Senior Game (Figure 2) follows a problem-based learning [19] approach. The player is presented with the problem before the learning occurs and learning is driven by problem-solving [63]. In this case, the player plays the role of a detective who is asked to solve a case (the problem). While looking for clues, the players learn about hygiene and responsible antibiotic use. The problem helps to contextualize learning [53]. The game comprises three missions each asking the player to solve a certain problem either on infection prevention or on responsible antibiotic use [64]. For example, the second mission of the Senior Game, Bugs Gone Wild focuses on antibiotic resistance. The player is presented with the problem: Across Europe, there are increasing reports of a disease powerful antibiotics could not cure. When a patient contracts this disease, the patient has to rely on his own body's self-defense mechanism. The player has to find out why there is this outbreak and what causes these bugs to be so powerful that antibiotics cannot cure them. In order to solve the problem, the player encounters a series of clues (i.e., the disease is found more often in areas where the doctors prescribe more antibiotics) and red herrings (e.g., the airport being in quarantine, suitcases and bins overflowing with tissues that once analyzed show some microbial activity but not enough to explain the outbreak). As the player advances through the game, they have to collect evidence and dismiss the red herrings. The mission ends when the player discovers the outbreak's cause: the overuse of antibiotics in certain countries has led to antibiotic resistance, which affects also other countries that have in place more stringent policies for prescribing.

Figure 2. Senior Game screenshot.

3.2.2. Game Mechanics and Constructive Alignment

Junior Game (Figure 3) follows a constructivism approach [47] and it is based on the work carried out by Koster [65] and Shaffer [66]. It focuses on game mechanics that encourage users to explore and, as a result, learn. The underlying learning covered by the game mechanics in the game is constructively aligned and hence compatible with the school curricula. Edugames4all MicrobeQuest! (Figure 4) follows the same approach as Junior Game, being an adapted version of the same game to be played on mobile devices [67].

For example, to learn that you have to take the whole prescribed course of antibiotics, the player throws antibiotics at the microorganism. If not all the antibiotics are delivered, the microorganism becomes stronger.

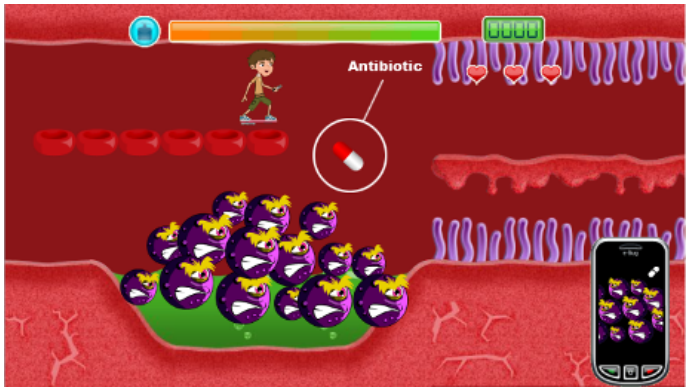

Figure 3. Junior Game screenshot: The player throws antibiotics to the bacteria and learns that antibiotics are efficient against bacteria.

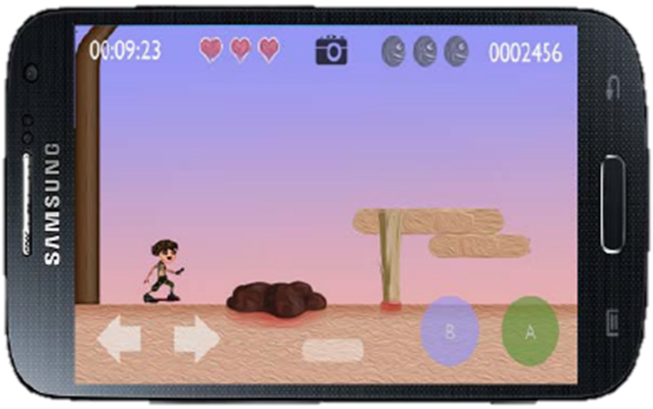

Figure 4. Edugames4all MicrobeQuest! screenshot [68]: Follows the same game mechanics as Junior Game but delivered via mobile device.

4. Discussion

In this article, we add to the existing literature reviews focusing on various aspects of games for health (see for example [15–17,22,27,69]). This research focused on games that aim to promote responsible antibiotic use across different segments of the population, and we identified the learning theories used in developing them. We identified 11 games that aim to teach various aspects of appropriate antibiotic use. The low number of games could be explained by the fact that this research is focused on a very specific field (i.e., antibiotic stewardship) and the fact that games are not uniformly developed across all health fields [15].

With two exceptions (GASDA [56,70] and AMS Game [54] all the games identified were designed by or tested with the developed world in mind. GASDA [56,70] focused on changing antibiotic prescription behavior and refreshing clinicians' knowledge of international guidelines for antibiotic prescriptions in the Nigerian context. AMS Game [54] was designed with the help of nurses from the UK and eight African countries.

The game covered three different segments of the population: students, healthcare workers and the public in general. The game for healthcare workers focused on refreshing knowledge of prescribing guidelines for antibiotics and changing non-compliant prescribing behavior. Games aimed at the general public and students focused on better-understanding antibiotic resistance and when antibiotics should be used. The games addressing the public, in general, did not focus on a certain age segment of the population.

This might not be the ideal approach, as some researchers argue that interventions need to be further personalized to adults of different age groups [8].

Most of the games are addressed to children. This might be because children are perceived as being more influenced by games [3] and sometimes seen as agents of change in their communities [71]. There is some evidence that when games are used in classroom settings, they increase classroom interaction [72,73]. Classroom interaction has been shown to improve learning in different contexts [74,75]. Research on games whose main purpose is entertainment has also shown that some children do more than just play the games [76,77]. They develop different other skills outside the game that help them master the games [76,77]. Except for formal learning, serious games can also be used by children in informal learning environments [52], however research from other fields suggests that an adaptive game might be best in this context since students who might find the content difficult tend to drop [78].

The lower number of games aimed at adults might be because, in other contexts, such as using games for clinicians, they are not accepted as a professional approach to training [28]. Exploring barriers to the adoption of games in healthcare settings and addressing them before deploying games in clinical settings is an area that needs to be explored before considering whether the games are the best solution for these settings.

In terms of content, most of the games focused on addressing issues with antimicrobial resistance which results from inappropriate use in humans. Usage of antibiotics in other settings (e.g., veterinary medicine, pollution) is not covered. Although inappropriate usage of antibiotics for human treatment is important, an effort to combat antibiotic resistance across different sectors is considered necessary [79]. The lower number of games in these settings could be explained by the relatively new shift in interest from addressing antibiotic stewardship in humans towards a One Health approach [55] which considers not only appropriate antibiotic stewardship in humans but also in other settings such as usage of antibiotics in agriculture, animals or pollution. The AMS Game covers the relevance of One Health [55] approach, which considers humans, animals and the environment when promoting responsible antibiotic use.

Concerning learning theories, few of the games explicitly reported them. The games that reported them used methods based on constructivism. Constructivism approaches focus on learners constructing the knowledge [80]. These approaches have the potential to help in learning about complex topics [81] such as antibiotic resistance.

The existence of a theoretical model in games could provide a better method to evaluate the effectiveness and would make it easier to reproduce and scale interventions to larger populations. The lack of a theoretical model makes it also difficult to determine what game mechanics or design elements are more effective in delivering the healthcare message or even to conclude that there is no "formula' that makes a game successful. Considering pedagogical dimensions when designing serious games could also make them more effective in their delivery of the educational message [32]. Furthermore, Becker [31] argues that connecting the games with learning theories could help alleviate the reticence of using them in education.

Although the games did not identify the theoretical models underpinning the development, it is possible that they have to use common sense pedagogical models. Furthermore, Backer [31] argues that well-designed games already use two learning theories: Gagné's Conditions for Learning [82] and Gardner's Theory of Multiple Intelligences [83]. Gagné's theory argues that there are different types of learning that are supported by different instructional methods. As the games used different approaches to engage players (e.g., text, verbal, intellectual skills) they could have invertedly implemented this learning theory.

The basis of Gardner's Theory of Multiple Intelligences is the idea of using different strategies for learning. These strategies are called intelligences [84] and they are: linguistic, musical, logical-mathematical, spatial, body-kinesthetic, intrapersonal, interpersonal and naturalistic. As most games will implement several of these strategies to engage players they could also be useful for learning.

The limited reporting on learning theories might also be due to the limited research on how existing learning theories could be applied to games, and pedagogical expertise not being easily translated in game design [85]. Other studies such as van Gaalen et al. [86] that have assessed gamification in health professions have also reported the lack of learning theories being mentioned. The appearance of a "lack of recent scholarship on learning theories" has been noticed also in the review carried out by Bodily et al. [38], a review that has focused on existing trends in instructional design and technology. Furthermore, the need for a theory-driven approach to serious games has been also advocated in Verschueren et al. [16] and Arnab et al. [87]. The latter proposes mapping game mechanics with learning mechanics and models such as the one proposed in this article could also help in evaluating the efficiency of the games and models such as the one proposed could also help in comparing and evaluating the efficiency of the games and make for easier comparison.

4.1. Implications for Theory and Research

The literature review adds to the state of the art by providing an overview of the existing games that aim to (also) educate about antibiotic resistance. It also groups the games based on the segment the population targeted. Furthermore, it provides an overview of which of these games have used learning theories and what learning theories are being used. The results showed that games are diverse, likely because they are targeting different segments of the population. This makes it difficult to compare them and further research should consider addressing this aspect.

There are few learning theories explicitly mentioned in the games publications. These theories are based on constructivist approaches suggesting that games might be particularly suitable for active learning. The limited mention of learning theories could suggest that there is still a need for research on how existing learning theories can be applied to educational games. Furthermore, in the context of this literature review, no new theories have been tested, that could be targeted specifically to games rather than re-using existing educational theories.

4.2. Implications for Practice

The results of this literature review could be useful for science educators, organizers of antibiotic resistance awareness campaigns and managers responsible for healthcare workers' continuous professional development. For science educators, the review presents an overview of the existing games aimed at students and distinguishes those based on learning theories. These could complement existing educational activities either in the classroom or as informal learning activities. Some of these games also offer methods to automatically track students' knowledge change through the games [46,88,89] and as a result offer teachers a method to determine whether the games are effective in their particular context without the need for a separate intervention. For organizers of antibiotic awareness campaigns, this research provides an overview of the existing games created by the research communities. These could be used as an alternative method to engage certain segments of the population and reach audiences that might otherwise not engage with traditional healthcare campaigns. Games aimed at healthcare workers could be used as part of their professional development and refreshing knowledge on antibiotic stewardship.

5. Limitations

As with all research, this study comes with several limitations. To maintain the scope of the review manageable we focused on three databases—one which is common for medicine and healthcare researchers to publish PubMed and Scopus and Web of Science which cover other disciplines. Although these are both databases that index most publications and we used a snowballing technique to identify other studies that we might have missed it is possible that there were articles that have been missed. Furthermore, we also did not include any grey literature and through this, we might have missed commercial games that would have addressed this topic but their use was not researched in the literature.

6. Conclusions

In this review, we identify games used to teach aspects related to antimicrobial resistance. We focused on identifying the populations they target and the learning theories underpinning their development. The games address students, the public in general, clinicians and pharmacists. Most of the games addressed the developed world with only one of them focusing on the developing world, highlighting the need to research the games in different contexts. The games also addressed only the use of antibiotics in humans, showing an untapped potential for the games in other areas where antibiotics are misused. Three out of 11 games explicitly mention learning theories and these follow a constructivist approach. Further research is needed on identifying why learning theories are not often reported in this kind of game.

Author Contributions: Conceptualization, A.M. and I.M.; methodology, A.M.; formal analysis, A.M. and I.M.; writing—original draft preparation, A.M.; writing—review and editing, A.M. and I.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Theuretzbacher, U. Global antibacterial resistance: The never-ending story. *J. Glob. Antimicrob. Resist.* **2013**, *1*, 63–69. [CrossRef] [PubMed]
2. Nieuwlaat, R.; Mbuagbaw, L.; Mertz, D.; Burrows, L.L.; Bowdish, D.M.; Moja, L.; Wright, G.D.; Schünemann, H.J. Coronavirus disease 2019 and antimicrobial resistance: Parallel and interacting health emergencies. *Clin. Infect. Dis.* **2021**, *72*, 1657–1659. [CrossRef]
3. Martin, C.; Murray, L. Digital games in the twenty-first century. *Learn. Media Technol.* **2006**, *31*, 323–327. [CrossRef]
4. Fahrenkamp-Uppenbrink, J. Countering Antibiotic Resistance. *Science* **2015**, *347*, 1109–1111. [CrossRef]
5. Carter, R.R.; Sun, J.; Jump, R.L. A Survey and Analysis of the American Public's Perceptions and Knowledge About Antibiotic Resistance. *Open Forum Infect. Dis.* **2016**, *30*, ofw112. [CrossRef] [PubMed]
6. Business, G. *Exploring the Consumer Perspective on Antimicrobial Resistance*; Wellcome Trust: London, UK, 2015.
7. Oh, J.M.; Ming, L.C.; Bakrin, F.S.; Goh, B.H.; Lee, L.H.; Khan, T.M. Social Aspects of Antibiotic use in the South and East Asian Students and General Population. *J. Young Pharm.* **2018**, *10*, 66. [CrossRef]
8. Guo, H.; Hildon, Z.J.L.; Lye, D.C.B.; Straughan, P.T.; Chow, A. The associations between poor antibiotic and antimicrobial resistance knowledge and inappropriate antibiotic use in the general population are modified by age. *Antibiotics* **2022**, *11*, 47. [CrossRef]
9. Jones, L.F.; Owens, R.; Sallis, A.; Ashiru-Oredope, D.; Thornley, T.; Francis, N.A.; Butler, C.; McNulty, C.A. Qualitative study using interviews and focus groups to explore the current and potential for antimicrobial stewardship in community pharmacy informed by the Theoretical Domains Framework. *BMJ Open* **2018**, *8*, e025101. [CrossRef]
10. Dyar, O.J.; Hills, H.; Seitz, L.T.; Perry, A.; Ashiru-Oredope, D. Assessing the Knowledge, Attitudes and Behaviors of Human and Animal Health Students towards Antibiotic Use and Resistance: A Pilot Cross-Sectional Study in the UK. *Antibiotics* **2018**, *7*, 10. [CrossRef]
11. Bilsen, A.v.; Bekebrede, G.; Mayer, I. Understanding complex adaptive systems by playing games. *Inform. Educ.* **2010**, *9*, 1–18. [CrossRef]
12. Souza, T.A.; Ramalho, G.L.; Queiroz, S.R. Resource Management in Complex Environments: Applying to Real Time Strategy Games. In Proceedings of the 2014 Brazilian Symposium on Computer Games and Digital Entertainment, Porto Alegre, Brazil, 12–14 November 2014; pp. 21–30.
13. Abd Majid, E.S.; Garcia, J.A.; Nordin, A.I.; Raffe, W.L. Staying Motivated During Difficult Times: A Snapshot of Serious Games for Paediatric Cancer Patients. *IEEE Trans. Games* **2020**, *12*, 367–375. [CrossRef]
14. Borda, A.; Molnar, A.; Kostkova, P. Serious games and participatory research in public health. In Proceedings of the 9th International Conference on Digital Public Health, Marseille, France, 20–23 November 2019; p. 133.
15. Ricciardi, F.; De Paolis, L.T. A comprehensive review of serious games in health professions. *Int. J. Comput. Games Technol.* **2014**, *2014*, 787968. [CrossRef]

16. Verschueren, S.; Buffel, C.; Vander Stichele, G. Developing theory-driven, evidence-based serious games for health: framework based on research community insights. *JMIR Serious Games* **2019**, *7*, e11565. [CrossRef] [PubMed]
17. Wang, R.; DeMaria, S., Jr.; Goldberg, A.; Katz, D. A systematic review of serious games in training health care professionals. *Simul. Healthc.* **2016**, *11*, 41–51. [CrossRef]
18. Eley, C.V.; Young, V.L.; Hayes, C.V.; Verlander, N.Q.; McNulty, C.A.M. Young people's knowledge of antibiotics and vaccinations and increasing this knowledge through gaming: Mixed-methods study using e-Bug. *JMIR Serious Games* **2019**, *7*, e10915. [CrossRef] [PubMed]
19. Farrell, D.; Kostkova, P.; Lecky, D.; McNulty, C. Teaching children hygiene using problem based learning: The story telling approach to games based learning. In Proceedings of the CEUR Workshop Proceedings, Thessaloniki, Greece, 23–25 April 2009; Volume 498.
20. Hale, A.R.; Young, V.L.; Grand, A.; McNulty, C.A.M. Can gaming increase antibiotic awareness in children? A mixed-methods approach. *JMIR Serious Games* **2017**, *5*, e6420. [CrossRef] [PubMed]
21. Molnar, A. Antimicrobial resistance awareness and games. *Trends Microbiol.* **2019**, *27*, 1–3. [CrossRef]
22. Molnar, A. Games that aim to promote antimicrobial stewardship: An overview of the entertainment potential. *First Monday* **2023**, *28*. [CrossRef]
23. Tsopra, R.; Courtine, M.; Sedki, K.; Eap, D.; Cabal, M.; Cohen, S.; Bouchaud, O.; Mechaï, F.; Lamy, J.B. AntibioGame®: A serious game for teaching medical students about antibiotic use. *Int. J. Med. Inform.* **2020**, *136*, 104074. [CrossRef]
24. Creative Campaigns Spread Awareness on Antibiotic Resistance. 2017. Available online: https://www.who.int/en/news-room/feature-stories/detail/creative-campaigns-spread-awareness-on-antibiotic-resistance (accessed on 18 January 2020).
25. Cox, J.A.; Vlieghe, E.; Mendelson, M.; Wertheim, H.; Ndegwa, L.; Villegas, M.V.; Gould, I.; Hara, G.L. Antibiotic stewardship in low-and middle-income countries: The same but different? *Clin. Microbiol. Infect.* **2017**, *23*, 812–818. [CrossRef]
26. Bavelier, D.; Green, C.S.; Han, D.H.; Renshaw, P.F.; Merzenich, M.M.; Gentile, D.A. Brains on video games. *Nat. Rev. Neurosci.* **2011**, *12*, 763–768. [CrossRef]
27. Castro-Sánchez, E.; Kyratsis, Y.; Iwami, M.; Rawson, T.M.; Holmes, A.H. Serious electronic games as behavioural change interventions in healthcare-associated infections and infection prevention and control: A scoping review of the literature and future directions. *Antimicrob. Resist. Infect. Control* **2016**, *5*, 34. [CrossRef] [PubMed]
28. Castro-Sánchez, E.; Sood, A.; Rawson, T.M.; Firth, J.; Holmes, A.H. Forecasting implementation, adoption, and evaluation challenges for an electronic game–based antimicrobial stewardship intervention: Co-design workshop with multidisciplinary stakeholders. *J. Med. Internet Res.* **2019**, *21*, e13365. [CrossRef] [PubMed]
29. Silva, F.G. Practical methodology for the design of educational serious games. *Information* **2019**, *11*, 14. [CrossRef]
30. Price, L.; Gozdzielewska, L.; Young, M.; Smith, F.; MacDonald, J.; McParland, J.; Williams, L.; Langdridge, D.; Davis, M.; Flowers, P. Effectiveness of interventions to improve the public's antimicrobial resistance awareness and behaviours associated with prudent use of antimicrobials: A systematic review. *J. Antimicrob. Chemother.* **2018**, *73*, 1464–1478. [CrossRef]
31. Becker, K. How Are Games Educational? Learning Theories Embodied in Games. 2005. Available online: http://www.digra.org/wp-content/uploads/digital-library/06278.23299.pdf (accessed on 22 May 2021).
32. Westera, W. Why and how serious games can become far more effective: Accommodating productive learning experiences, learner motivation and the monitoring of learning gains. *J. Educ. Technol. Soc.* **2019**, *22*, 59–69.
33. Grant, M.J.; Booth, A. A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Inf. Libr. J.* **2009**, *26*, 91–108. [CrossRef]
34. Yepes-Nuñez, J.; Urrutia, G.; Romero-Garcia, M.; Alonso-Fernandez, S. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Rev. Esp. Cardiol. (Engl. Ed.)* **2021**, *74*, 790–799.
35. Baethge, C.; Goldbeck-Wood, S.; Mertens, S. SANRA—A scale for the quality assessment of narrative review articles. *Res. Integr. Peer Rev.* **2019**, *4*, 1–7. [CrossRef] [PubMed]
36. Ferrari, R. Writing narrative style literature reviews. *Med. Writ.* **2015**, *24*, 230–235. [CrossRef]
37. Green, B.N.; Johnson, C.D.; Adams, A. Writing narrative literature reviews for peer-reviewed journals: Secrets of the trade. *J. Chiropr. Med.* **2006**, *5*, 101–117. [CrossRef] [PubMed]
38. Bodily, R.; Leary, H.; West, R.E. Research trends in instructional design and technology journals. *Br. J. Educ. Technol.* **2019**, *50*, 64–79. [CrossRef]
39. Molnar, A. Smart cities education: An insight into existing drawbacks. *Telemat. Inform.* **2021**, *57*, 101509. [CrossRef]
40. Pishtari, G.; Rodríguez-Triana, M.J.; Sarmiento-Márquez, E.M.; Pérez-Sanagustín, M.; Ruiz-Calleja, A.; Santos, P.; Prieto, L.P.; Serrano-Iglesias, S.; Väljataga, T. Learning design and learning analytics in mobile and ubiquitous learning: A systematic review. *Br. J. Educ. Technol.* **2020**, *51*, 1078–1100. [CrossRef]
41. PubMed Overview. 2017. Available online: https://pubmed.ncbi.nlm.nih.gov/about/ (accessed on 22 May 2021).
42. Web of Science Coverage Details. 2022. Available online: https://clarivate.libguides.com/librarianresources/coverage#:~:text=The%20Web%20of%20Science%20provides,research%20results%20and%20measure%20impact (accessed on 16 January 2023).
43. Dekker, M.R.; Williams, A.D. The use of user-centered participatory design in serious games for anxiety and depression. *Games Health J.* **2017**, *6*, 327–333. [CrossRef] [PubMed]
44. Raith, L.; Bignill, J.; Stavropoulos, V.; Millear, P.; Allen, A.; Stallman, H.M.; Mason, J.; De Regt, T.; Wood, A.; Kannis-Dymand, L. Massively multiplayer online games and well-being: A systematic literature review. *Front. Psychol.* **2021**, *12*, 2369. [CrossRef]

45. Wohlin, C. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, London, UK, 13–14 May 2014; pp. 1–10.
46. Molnar, A.; Kostkova, P. Learning about Hygiene and Antibiotic Resistance through Mobile Games: Evaluation of Learning Effectiveness. In Proceedings of the 6th International Conference on Digital Health Conference, Lyon, France, 23–26 April 2018; ACM: New York, NY, USA, 2018; pp. 95–99.
47. Farrell, D.; Moffat, D.C. Adapting cognitive walkthrough to support game based learning design. *Int. J. Game-Based Learn. (IJGBL)* **2014**, *4*, 23–34. [CrossRef]
48. Farrell, D.; Kostkova, P.; Weinberg, J.; Lecky, D.; McNulty, C. Online games teaching children hygiene and antibiotic resistance: Evaluation of the e-Bug games. *Int. J. Infect. Dis.* **2010**, *14*, e43. [CrossRef]
49. Farrell, D.; Kostkova, P.; Lazareck, L.; Weerasinghe, D.; Weinberg, J.; Lecky, D.M.; Adriaenssens, N.; Koprivová Herotová, T.; Holt, J.; Touboul, P.; et al. Developing e-Bug web games to teach microbiology. *J. Antimicrob. Chemother.* **2011**, *66*, v33–v38. [CrossRef]
50. Kostkova, P.; Farrell, D.; De Quincey, E.; Weinberg, J.; Lecky, D.; McNulty, C. eBug–teaching children hygiene principles using educational games. In *MEDINFO 2010*; IOS Press: Amsterdam, The Netherlands, 2010; pp. 600–604.
51. McNulty, C.A.; Lecky, D.M.; Farrell, D.; Kostkova, P.; Adriaenssens, N.; Koprivová Herotová, T.; Holt, J.; Touboul, P.; Merakou, K.; Koncan, R.; et al. Overview of e-Bug: An antibiotic and hygiene educational resource for schools. *J. Antimicrob. Chemother.* **2011**, *66*, v3–v12. [CrossRef]
52. Farrell, D.; Kostkova, P.; Weinberg, J.; Lazareck, L.; Weerasinghe, D.; Lecky, D.M.; McNulty, C.A. Computer games to teach hygiene: An evaluation of the e-Bug junior game. *J. Antimicrob. Chemother.* **2011**, *66*, v39–v44. [CrossRef]
53. Lazareck, L.J.; Farrell, D.; Kostkova, P.; Lecky, D.M.; McNulty, C.A.; Weerasinghe, D. Learning by gaming-evaluation of an online game for children. In Proceedings of the 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2010), Buenos Aires, Argentina, 31 August–4 September 2010; pp. 2951–2954.
54. Ashiru-Oredope, D.; Nabiryo, M.; Yeoman, A.; Bell, M.; Cavanagh, S.; D'Arcy, N.; Townsend, W.; Demenciukas, D.; Yadav, S.; Garraghan, F.; et al. Development of and User Feedback on a Board and Online Game to Educate on Antimicrobial Resistance and Stewardship. *Antibiotics* **2022**, *11*, 611. [CrossRef]
55. Kim, D.W.; Cha, C.J. Antibiotic resistome from the One-Health perspective: Understanding and controlling antimicrobial resistance transmission. *Exp. Mol. Med.* **2021**, *53*, 301–309. [CrossRef]
56. Birjovanu, G.; Wood, C.; Olufemi, O.; Ogunsola, F.; Okonji, P.; Kpokiri, E.; Luedtke, S.; Shallcross, L.; Soriano, D.; Lefevre, C.E.; et al. GADSA: Decision support app for antibiotics prescribing in Nigeria. In Proceedings of the 9th International Conference on Digital Public Health, Marseille, France, 20–23 November 2019; pp. 9–10.
57. Castro-Sánchez, E.; Charani, E.; Moore, L.; Gharbi, M.; Holmes, A.H. "On call: Antibiotics"-development and evaluation of a serious antimicrobial prescribing game for hospital care. In Proceedings of the GFHEU, Utrecht, The Netherlands, 27–28 October 2014; pp. 1–7.
58. Beslon, G.; Batut, B.; Parsons, D.; Schneider, D.; Knibbe, C. An alife game to teach evolution of antibiotic resistance. In Proceedings of the Artificial Life Conference Proceedings 13, Sicily, Italy, 2–6 September 2013; MIT Press: Cambridge, MA, USA, 2013; pp. 43–50.
59. Servitje, L. Gaming the apocalypse in the time of antibiotic resistance. *Osiris* **2019**, *34*, 316–337. [CrossRef]
60. Fosnot, C.T. *Constructivism: Theory, Perspectives, and Practice*; Teachers College Press: New York, NY, USA, 2013.
61. Wood, D.F. Problem based learning. *BMJ* **2003**, *326*, 328–330. [CrossRef]
62. Jervis, L.M.; Jervis, L. What is the constructivism in constructive alignment? *Biosci. Educ.* **2005**, *6*, 1–14. [CrossRef]
63. Barrows, H.S.; Tamblyn, R.M. *Problem-Based Learning: An Approach to Medical Education*; Springer Publishing Company: Berlin/Heidelberg, Germany, 1980.
64. Kostkova, P. Seamless evaluation of interactive digital storytelling games: Edugames4All. In *Proceedings of the International Conference on Electronic Healthcare*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 80–84.
65. Koster, R. *Theory of Fun for Game Design*; O'Reilly Media, Inc.: Sebastopol, CA, USA, 2013.
66. Shaffer, D.W. *How Computer Games Help Children Learn*; Macmillan: New York, NY, USA, 2006.
67. Molnar, A.; Kostkova, P. Teaching Hygiene and Responsible Antibiotic Use through a Mobile Game for Children. In *Mobile Apps Engineering: Design, Development, Security, and Testing*; CRC Press Taylor & Francis Group: Boca Raton, FL, USA, 2018; pp. 127–138.
68. Molnar, A.; Kostkova, P. Mind the gap: From desktop to app. In Proceedings of the 5th International Conference on Digital Health 2015, Florence, Italy, 18–20 May 2015; pp. 15–16.
69. Marvasi, M.; Casillas, L.; Vassallo, A.; Purchase, D. Educational activities for students and citizens supporting the One-Health approach on antimicrobial resistance. *Antibiotics* **2021**, *10*, 1519. [CrossRef] [PubMed]
70. Wood, C.E.; Luedtke, S.; Musah, A.; Bammeke, F.; Mutiu, B.; Ojewola, R.; Bankole, O.; Ademuyiwa, A.O.; Ekumankama, C.B.; Ogunsola, F.; et al. Exploring barriers to guideline implementation for prescription of surgical antibiotic prophylaxis in Nigeria. *JAC-Antimicrob. Resist.* **2022**, *4*, dlac044. [CrossRef] [PubMed]
71. Molnar, A. Children as agents of change in combatting antibiotic resistance. *J. Health Serv. Res. Policy* **2017**, *22*, 258–260. [CrossRef] [PubMed]
72. Molnar, A. The effect of interactive digital storytelling gamification on microbiology classroom interactions. In Proceedings of the 2018 IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA, 10 March 2018; pp. 243–246.

73. Vargas-Macías, Z.L.; Rodríguez-Hernandez, A.A.; Sánchez-Sáenz, C.L. Digital Games (Gamification) in Learning and Training: An Approach to Adaptation and Integration in the Classroom. *GIST Educ. Learn. Res. J.* **2020**, *20*, 171–188. [CrossRef]
74. Blasco-Arcas, L.; Buil, I.; Hernández-Ortega, B.; Sese, F.J. Using clickers in class. The role of interactivity, active collaborative learning and engagement in learning performance. *Comput. Educ.* **2013**, *62*, 102–110. [CrossRef]
75. Gan, C.L.; Balakrishnan, V. Enhancing classroom interaction via IMMAP—An interactive mobile messaging app. *Telemat. Inform.* **2017**, *34*, 230–243. [CrossRef]
76. Kahila, J.; Tedre, M.; Kahila, S.; Vartiainen, H.; Valtonen, T.; Mäkitalo, K. Children's gaming involves much more than the gaming itself: A study of the metagame among 12-to 15-year-old children. *Convergence* **2021**, *27*, 768–786. [CrossRef]
77. Strømman, E. Crossover literacies: A study of seventh graders' multimodal representations in texts about Pokémon Go. *Comput. Compos.* **2021**, *59*, 102629. [CrossRef]
78. MolnAr, A.; Virseda, J.; Frias-Martinez, V. Insights from EducaMovil: Involving teachers in creating educational content for mobile learning games. *J. Interact. Learn. Res.* **2015**, *26*, 209–221.
79. Léger, A.; Lambraki, I.; Graells, T.; Cousins, M.; Henriksson, P.J.; Harbarth, S.; Carson, C.; Majowicz, S.; Troell, M.; Parmley, E.J.; et al. AMR-Intervene: A social–ecological framework to capture the diversity of actions to tackle antimicrobial resistance from a One Health perspective. *J. Antimicrob. Chemother.* **2021**, *76*, 1–21. [CrossRef] [PubMed]
80. Gray, A.J. *Constructivist Teaching and Learning*; Saskatchewan School Trustees Association: Regina, SK, Canada, 1997.
81. Jacobson, M.J.; Wilensky, U. Complex systems in education: Scientific and educational importance and implications for the learning sciences. *J. Learn. Sci.* **2006**, *15*, 11–34. [CrossRef]
82. Glasser, R. Learning theory and instruction. In *International Perspectives On Psychological Science, II: The State of the Art*; Psychology Press: London, UK, 1994.
83. Gardner, H. The theory of multiple intelligences. *Early Prof. Dev. Teach.* **2012**, *133*, 133–141.
84. Armstrong, T. *Multiple Intelligences in the Classroom*; ASCD: Alexandria, VA, USA, 2009.
85. Theodosiou, S.; Karasavvidis, I. Serious games design: A mapping of the problems novice game designers experience in designing games. *J. e-Learn. Knowl. Soc.* **2015**, *11*. [CrossRef]
86. Van Gaalen, A.; Brouwer, J.; Schönrock-Adema, J.; Bouwkamp-Timmer, T.; Jaarsma, A.; Georgiadis, J. Gamification of health professions education: A systematic review. *Adv. Health Sci. Educ.* **2021**, *26*, 683–711. [CrossRef]
87. Arnab, S.; Lim, T.; Carvalho, M.B.; Bellotti, F.; De Freitas, S.; Louchart, S.; Suttie, N.; Berta, R.; De Gloria, A. Mapping learning and game mechanics for serious games analysis. *Br. J. Educ. Technol.* **2015**, *46*, 391–411. [CrossRef]
88. Molnar, A.; Kostkova, P. Seamless evaluation integration into IDS educational games. In Proceedings of the International Conference on the Foundations of Digital Games, Crete, Greece, 14–17 May 2013.
89. Kostkova, P.; Molnar, A. Educational games for creating awareness about health issues: The case of educational content evaluation integrated in the game. In *Proceedings of the Medicine 2.0 Conference*; JMIR Publications Inc., Toronto, ON, Canada, 2014.