Pharmacy Education (2023) 23(1) 762 - 768
https://doi.org/10.46542/pe.2023.231.762768

RESEARCH ARTICLE

Design and evaluation of a serious game for teaching nanotechnologies in pharmacy education

Amélie Meeus[1], Anne Sapin-Minet[1,2], Marianne Parent[1,2]

[1] Faculty of Pharmacy, Université de Lorraine, Nancy, France
[2] CITHEFOR, Université de Lorraine, Nancy, France

Keywords
Nanotechnology
Pharmaceutical education
Pharmaceutical technology
Serious game
Vectorisation

Correspondence
Marianne Parent
Faculté de Pharmacie
Université de Lorraine
France
marianne.parent@univ-lorraine.fr

Abstract

Introduction: A serious game was implemented and evaluated to consolidate the knowledge of third-year pharmacy students about drug vectorisation systems. **Methods:** After a lecture on nanotechnology in health, students were immersed in a magical world for the one-and-a-half-hour tutorial: to complete their mission, they had to pick the right cards and solve puzzles within a limited time. Then, in debriefing, all the key concepts were recalled and explained according to their metaphorical counterparts, i.e. the puzzles. Feedback from the beta-test in 2021 (n=112) helped to optimise the pitch, the game, the rules and the debriefing. A formative evaluation was performed in 2022 (n=140) investigating students' perception immediately after the session and immediate knowledge retention using a pre-test/post-test evaluation. The results of the final assessment were considered indirect indicators of student involvement. **Results:** Although the game itself did not immediately improve the students' knowledge retention, it really was a great tool to motivate and engage participants, which might explain a significant improvement in the final assessment. **Conclusion:** A serious game can be an interesting tool to teach pharmaceutical technology. To help colleagues wishing to revitalise their pharmacy interventions, a non-exhaustive list of ideas to consider before starting the game conception is provided.

Introduction

Game-based learning is a worldwide trend in the education of health professionals, including pharmacists (Oestreich & Guy, 2022). This educational strategy allows the enhance learning attitudes, soft skills and learning outcomes at various times in the curriculum (Aburahma & Mohamed, 2015; van Gaalen et al., 2021). The main forms of game-based learning are gamification, serious games and simulation (van Gaalen et al., 2021). Gamification is the use of game elements (e.g. points) in non-gaming contexts (Deterding et al., 2011), while serious games are full-fledged games in which the primary goal is education rather than fun (Michael & Chen, 2005). Simulations provide artificial conditions mimicking a realistic environment in order to experiment with something real in a safe environment: they do not necessarily use game elements (van Gaalen et al., 2021).

Pharmaceutical technology is mainly taught in the first grades (first, second and third years) in French pharmaceutical curriculum. Regarding the topic of nanotechnologies, three hours of traditional lecture and one-and-a-half hours of tutorial classes are delivered in the third year. Teachers acknowledged a certain passivity of students in tutorials and struggled to create interaction with and within the class, something that can be changed by a serious game. In the literature, only a few papers deal with game-based approaches to pharmaceutical technology (Garnier et al., 2021), and even less address undergraduate students (Gil-Alegre et al., 2020).

This educational brief focuses on the design of an innovative serious game for the tutorials to engage the students in a dynamic and positive attitude towards pharmaceutical technology learning. The design of the game has to fit with several practical constraints: 30 students playing simultaneously with a maximum of two supervisors; flexibility within different classrooms; 15 minutes to reset the game between two tutorials. A collaborative game would favour interactions between students and soft skills training. From a cognitive standpoint, the game was designed to reach the medium levels of Bloom's revised taxonomy of knowledge-based goals (i.e. apply and analyse) (Anderson & Krathwohl, 2001). This study aimed to address the following questions: 1) Is it feasible to create a serious game about nanotechnologies in health which fits into the various organisational constraints (duration, classroom, cost, accessibility to all students even those who haven't learned the corresponding lecture...)? 2) How is this initiative perceived by students? 3) Does this initiative have an impact on students' immediate knowledge retention and/or on results during the final assessment of this course? Through this example in pharmaceutical formulation, this study will improve the understanding of the impact of gamification on students' engagement, motivation and learning outcomes during pharmaceutical education.

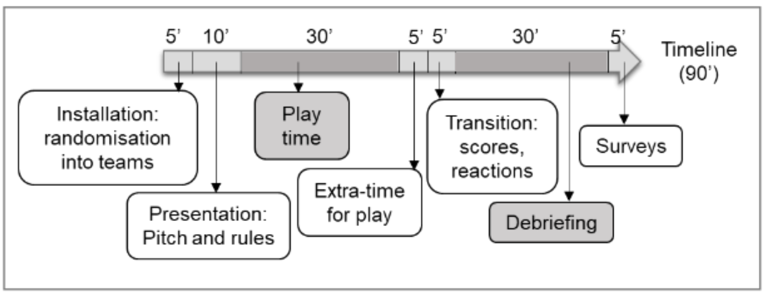
Methods

In accordance with French regulations in this case, no special procedures (*e.g.* ethics committee approval) were required for this project. However, the project was approved by the Faculty board.

Preparation and design

In Spring 2021, the authors asked by email students from previous promotions (n= 315) to evaluate the course and the relevance of an educational change. They were in their third, fourth or fifth year at this time, thus having followed the tutorial remotely in October 2020 (COVID restrictions) or in person in 2019 or 2018, respectively. The results led to the conception of a serious game: two pharmaceutical teachers and an instructional designer listed the main concepts that students need to remember and organised them into puzzles with a linear storyline for an escape game on the table. Students handle major nanotechnology concepts transposed into a magical universe through riddles mimicking decision taking in scientific research and the development of nanotechnologies (Figure 1). Teams have a limited amount of time to help the hero (the drug) find a way to enter a magic castle (route of administration/vector), find its mortal enemy (distribution/passive targeting) without being spotted (furtivity) and quickly defeat this enemy (kinetics of release) without causing damage to innocent bystanders (active targeting).

A



B

N°	Riddles	Gaming task	Educational notion related
1	Choose the best wand	Wheel puzzle	Kinetics of drug release
2	Choose a vehicle to reach the castle	Decision taking with a pros-and-cons list	Routes of administration
3	Open castle's doors	Look up/math riddle	Characteristics of the nanovector: composition, size, surface charge, …
4	Find the right potion to become invisible	Logical enigma	Furtivity
5	Find the enemy	Look up/ jigsaw	Distribution
6	Cast the correct spell	Coded message	Active targeting

(A: timeline, B: riddles and related notions)

Figure 1: Presentation of the ludo-tutorial

Students start the game with a pack of cards with numbered backs and the first clue: the number of the first card to draw is hidden in the text of a fictional newspaper. Following the instructions on cards, they progressively turn over more cards, providing a riddle or clues for future riddles and/or asking to discard previous cards. They sometimes draw a golden card, a signal to call the gamemaster to obtain additional material for the next enigma. Solving an enigma leads to the next card until they have reached the end card. At every choice, they have immediate feedback: if wrong, they receive a red card and penalty points. They can try again until they find the correct answer and then continue to play until the end. Students can ask for gamemasters' help for free at any time, and gamemasters can also spontaneously give help for a small penalty. The final score is calculated by adding points for each drawn card and subtracting penalty points. Extra points are added for the remaining time and completion of the online pre-test. The team with the highest final score was officially congratulated at the end of all tutorials (no real nor candy prize).

Development

The authors first tested the game with colleagues to assess the validity of the game concept and scientific content. In 2021, the beta-test was launched in real conditions with students for the first time. Third year pharmacy students (n=112) played the game under the supervision of one teacher and the instructional designer. A five item questionnaire was sent by email to students after the end of the tutorials. Following this session and feedback from students, all parts of the tutorial were modified or improved, allowing further development of the final version of the game.

Formative evaluation

In 2022 the authors performed a formative evaluation of the final version of this tutorial (n=140). Five sessions were animated by one teacher and the instructional designer. Each session was organised according to the same time schedule (Figure 1) and included up to 30 students divided into six teams.

Before the tutorial, students had a plenary lecture on the topic. At the end of the lecture, students were asked to answer a short knowledge test (three MCQ with five proposals each) and an anonymous survey about their perception of pharmaceutical technology. Filling out the knowledge test induced a message to the students indicating that they had unlocked a benefit for their future team (extra points for the game). At the end of the tutorials, the authors issued the same knowledge test and a new anonymous survey about the experience they had just lived. Students were free to answer or not to the questionnaires. Students' scores for the pre and post-knowledge tests were matched (paired samples) and compared with a non-parametric Wilcoxon test (p = 0.05).

At the end of the term, the final exam's results on the topic (score out of six points) were analysed. Assuming that populations and questions are similar (Persky *et al.*, 2007), scores were compared with the ones of 2021 and with the year 2018-2019 (before COVID) with a non-parametric Kruskall-Wallis test (and Dunn post-tests, p = 0.05).

Results

Preliminary survey to the game proposal

The authors received 79 answers (70%, 24% and 6% from third, fourth and fifth year students, respectively). Among respondents, 89% remembered the tutorial, 81% of these had appreciated it, and 56% considered that the pedagogical objectives were clear (16% disagreed, and the remaining 28% did not remember). When asked, they were indeed able to correctly list the main objectives. 25% found the tutorial difficult. In open-ended questions, students highlighted difficulties in following remotely (for the 2020 session), linking the course to the tutorial and integrating the many new concepts. These results confirmed that there was room for improvement. Thirty-nine respondents (49%) favourably reacted to the proposal of a serious game, but some worried about not being as well prepared for the final exam. One in three was interested in participating in game design and/or beta-tests.

Development

At the end of the 2021 beta-test, only 25 answers were received (22%). Among respondents, 88% were enthusiastic about the use of games in pedagogy. A majority considered the game helpful to understand/memorise the courses' concepts, 24% agreed but would have preferred traditional teaching, perceived as more useful, and 20% disagreed. As for the link between the game and the course, 8% detected it, 4% saw it during the debriefing, 52% detected it with difficulty, and 36% did not. The last two questions focused on the perception of help during the game and the grounds for asking for help. This feedback led us to correct small conception failures in the game, including the help system, and to propose an enhanced final version of the tutorial and game.

Formative evaluation

The perception questionnaires before and after the tutorial received 90 (64%) and 133 (95%) answers, respectively. Results are presented in Table I and show the positive perception of students.

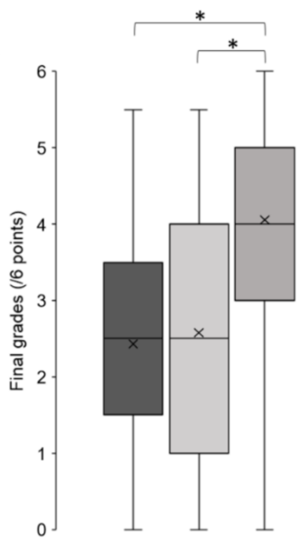
Table I: Student's perception pre- and post-test surveys

Before the tutorial (N=90 answers)					
	Pharmaceutical technology		Nanotechnologies in health		
Are both subjects interesting according to you? (%)					
Interesting	**91.1**		**82.2**		
Not interesting	8.9		17.8		
How would you qualify the learning and understanding of both subjects? (%)					
	Learn	Understand	Learn	Understand	
Easy	2.2	16.7	6.7	8.9	
Quite easy	32.2	**61.1**	27.8	**44.4**	
Quite difficult	**57.8**	18.9	**48.9**	34.4	
Difficult	7.8	3.3	16.7	12.2	
After the tutorial (N=133 answers)					
On a 5-point scale, how much do you agree to the following sentences? (%)					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The tutorial was interesting.	0.0	0.8	12.0	32.3	**54.9**
I enjoyed the serious game.	0.0	2.3	14.3	33.8	**49.6**
I appreciated the debriefing of the concepts after playing the game.	0.0	0.8	14.3	29.3	**55.6**
I understood the links between lesson's key concepts and game's enigmas.	2.3	11.3	24.8	**35.3**	26.3
I enjoyed working in a team.	0.8	0.8	9.8	33.1	**55.6**
I developed my knowledge on nanotechnologies in health thanks to the game.	2.3	9.0	33.8	**37.6**	17.3
The game helped me remember better the lesson's key concepts.	2.3	6.8	24.1	**42.1**	24.8
I improved myself in terms of team work.	1.5	3.8	**37.6**	30.8	26.3
Which statement(s) describe your experience? (Several choices possible) (%)					
I got bored during the game.				1.5	
I did not understand the rules to play.				6.0	
I had fun during the game.				67.7	
I lost track of time while playing.				56.4	
I strengthen my knowledge during the game and/or the debriefing.				58.6	
I wanted to win.				60.2	
I gave up.				0.8	
I did not understand the link between the game and the lesson.				12.8	
I enjoyed working in a team.				74.4	
I enjoyed playing within a magical universe.				53.4	
According to you, is the game suited to your level of knowledge? (%)					
No, it was too easy.				12.8	
Yes, it was well-suited.				**83.5**	
No, it was too difficult.				3.8	

Note here all your comments on the tutorial in general, the serious game and the debriefing.

NB: The class consisted of 143 students, 140 of whom attended the tutorial. Bold numbers correspond to majority responses

The authors received 115 (82%) complete answers to the knowledge tests (before and after the tutorial) and 25 uncomplete answers (five only pre-test and 20 only post-test). There was no significant difference between the results before and after the tutorial. Meanwhile, final grades (Figure 2 and details of statistics in Supp data) were not improved with the beta-test the first year but did increase significantly the second year (after optimisation of game, prebrief and debrief parts): this trend, if confirmed, is very encouraging.



Year (n)	2018 (122)	2021 (112)	2022 (143)
Game	No	Yes	Yes
Mean	2.43	2.58	4.06
Sd	1.40	1.51	1.48

Medians means (crosses), 1st and 3rd quartiles and ranges are shown, *$p < 0.001$. Between 2021 (beta-test) and 2022 (final version), improvements were made in the ludo-tutorial in presentation, game and debriefing

Figure 2: Box-plots of final grades for the nanotechnology topic

Discussion

For several years the authors observed a low oral participation of students (two or three "*leaders*" in every 30-student group) during the tutorials about nanotechnology. To change this, a serious game was developed aimed at modifying classroom dynamics and improving knowledge retention through medium levels of Bloom's taxonomy. This serious game has decisive traits of well-constructed games: goals, rules, feedback, and flow (McGonigal, 2011). Students were obliged to participate but adhered easily to the serious game: only one team of 30 did not want to play (four students out of 140). They enjoyed the game, lost track of time while playing and wanted to win. Winning was, however not essential, as only 40% of teams finished the game and only one in the first time-limit. Thanks to the linear conception of the game and the golden cards, the gamemasters were able to follow the progression of the six teams and to optimise help to ensure that all reach the last enigma during the playtime, thus avoiding too much frustration. In only 90 minutes, students learned the rules, collaborated to play, had fun, made mistakes, corrected them, won or not, and participated willingly in the debriefing. Time pressure was high: this was an element of the game itself and also a constraint they are likely to encounter in their future professional environment. However, an extra 30 minutes for the tutorial (10 for the game and 20 for the debriefing) would be ideal.

The authors developed a board game, for the pleasure of handling objects and to stimulate intra-team exchanges. Unlike a computer game, no specific competencies nor significant development were necessary, only a very low budget (paper, standard creative arts materials), time and creativity. They chose to randomise students into teams to get them out of their comfort zone and to cooperate with people they don't usually work with. They noticed that students had trouble accepting or asking for help. Moreover, although the game is theoretically a safe place for "*fun failure*" (Morris *et al.*, 2013), some teams were frozen when they struggled to find consensus for fear of drawing a red card (i.e. making an error) and getting a penalty.

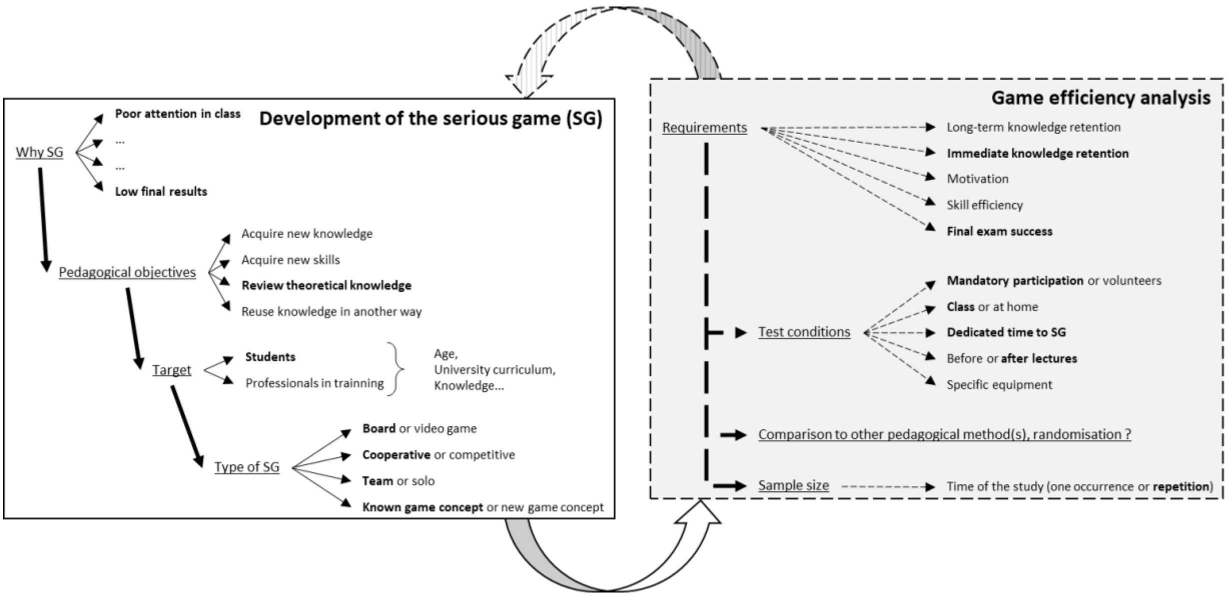
Special attention was paid to debriefing, a crucial time to reflect on the experience and foster long-term learning. The game itself could be played "*just for fun*" without previous knowledge. However, in debriefing, the key concepts of nanotechnology were directly related to the enigmas, with an intermediate to the high level of facilitation (Fanning & Gaba, 2007). This has been identified as a potential weakness from the early design stages and was also highlighted by the students in open remarks: they would like to manipulate the notions directly into the game. To meet this demand, the authors are thinking of the creation of a new complementary game that students could play independently and repeatedly, in which they should design a nanovector, soliciting Bloom's highest levels.

Opening the questionnaires directly at the end of the course or tutorial resulted in high response rates (which could also be a sign of students' raised interest, as responding was not compulsory). Feedback from the students has been very positive, proving, if necessary, that it was worth it. Performances (evaluated through a short test: three MCQs with five propositions each, five min) were not changed immediately after the tutorial.

Similarly to these findings, authors have reported that games improve learner's knowledge retention, but with a delayed effect rather than immediately after the lesson (Pierfy, 1997). However, further investigation will be needed to clarify if this lack of progress in immediate retention is real or due to study limitations (test too short, MCQs only and no open questions, pre-test done "*at home*" after the lesson, students informed of the pre/post-intervention assessments and of the aims of the pedagogical innovation…) (Aburahma & Mohamed, 2015). The majority of students (58.6%) felt that the game had helped them to integrate the concepts (that they had perhaps already correctly assimilated during the lecture). In this respect, it could have been interesting to test not only their answers to the tests but also their degree of certainty to see if the intervention can change this item (Garnier *et al*., 2023). Moreover, as the students do not directly manipulate the concepts in the game but rather metaphors, there may be a "*cognitive load*" phenomenon, which requires a little time to process. Interestingly, final results did rise significantly (after optimisation of the tutorial), suggesting that long-term retention and/or students' commitment to work towards the final exam are improved. In a previous study, Dabbous et al. (Dabbous *et al.,* 2022) demonstrated indeed that educational gamification is motivating for students and that there is a positive correlation between this motivation and the attainment of learning outcomes, which can result in improved student grades in the course. Finally, this experiment was started just after the COVID pandemic: it is possible that students were more receptive to any form of pedagogical interest after this particular period, and therefore especially good-responders to edutainment. Moreover, the study is restricted to a single French faculty and a relatively small sample size: further studies are needed to check if these findings are further confirmed in the next years. Other points could also be considered, in addition to the degree of certainty of the answers, such as, for example, retention at various times (immediately after the intervention, between the intervention and final exam, at the final exam, several months after the exam), or if the student motivation is changed only towards nanotechnologies or other topics of pharmaceutical technology as well.

Conclusion

Introducing gaming in pharmaceutical teaching is an opportunity to work on "*meta-skills*" and critical-thinking skills. This game clearly succeeded in increasing students' motivation for pharmaceutical technology. This did not translate into an improvement in immediate knowledge retention but may have had an impact in the medium term, as shown by the trend towards improving grades on final exams. This experience can help inspire others. With this in mind, the authors propose a roadmap of crucial points to consider when you want to develop a serious game (Figure 3). At a time when there is increasing talk of competency-based assessment, using serious games might be a really valuable tool in pharmacy education. Ideally, a global reflection on the use of edutainment in pharmacy studies in France would be really useful, as this is already the case in other countries (Cain *et al.,* 2014).



(the factors included in this study are highlighted in bold)

Figure 3: Roadmap of the critical points to consider before creating a serious game

Conflict of interest

The authors declare no conflict of interest.

Source of funding

The authors did not receive any funding.

References

Aburahma, M. H, & Mohamed, H. M. (2015). Educational games as a teaching tool in pharmacy curriculum. American *Journal of Pharmaceutical Education*, **79**(4), 59. https://doi.org/10.5688/ajpe79459

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: a revision of bloom's taxonomy of educational objectives*. Longman.

Cain, J., Conway, J. M., DiVall, M. V., Erstad, B. L., Lockman, P. R., Ressler, J. C., Schwartz, A. H., Stolte, S., & Nemire, R. E. (2014). Report of the 2013-2014 academic affairs committee. *American Journal of Pharmaceutical Education*, **78**(10), S23. https://doi.org/10.5688/ajpe7810s23

Dabbous, M., Kawtharani, A., Fahs, I., Hallal, Z., Shouman, D., Akel, M., Rahal, M., & Sakr, F. (2022). The role of game-based learning in experiential education: Tool validation, motivation assessment, and outcomes evaluation among a sample of pharmacy students. *Education Sciences*, **12**(7), 434. https://doi.org/10.3390/educsci12070434

Deterding, S., Khaled, R., Nacke, L., & Dixon, D. (2011). Gamification: Toward a definition. *CHI 2011 Gamification Workshop Proceedings*. https://www.semanticscholar.org/paper/Gamification-%3A-Toward-a-Definition-Deterding-Khaled/84fe3e41153d73dd0675ae14501a497c22b2a63f

Fanning, R. M., & Gaba, D. M. (2007). The role of debriefing in simulation-based learning. Simulation in Healthcare: *The journal of the society for simulation in Healthcare*, **2**(2), 115–125. https://doi.org/10.1097/sih.0b013e3180315539

Garnier, A., Vanherp, R., Bonnabry, P., & Bouchoud, L. (2021). Use of simulation for education in hospital pharmaceutical technologies: A systematic review. *European Journal of Hospital Pharmacy*, **30**(2), 70–76. https://doi.org/10.1136%2Fejhpharm-2021-003034

Garnier, A., Butaye, L., Bonnabry, P. & Bouchoud, L. (2023). A room of errors simulation to improve pharmacy operators' knowledge of cytotoxic drug production. *Journal of Oncology Pharmacy Practice*, 10781552231152145. https://doi.org/10.1177/10781552231152145

Gil-Alegre, M. E., Molina-Martinez, I. T., Veiga-Ochoa, M. D, del Rocio Herrero-Vanrell, M., Ruiz-Caro, R., Esteban-Pérez, S., Lopez-Cano, J. J., Garcia-Herranz, D., Bravo Osuna, I. & Andrés-Guerrero, V. (2020). Can we learn pharmaceutical technology playing? *INTED2020 Proceedings, 14th International technology, education and development conference*, 8952–8957. https://doi.org/10.21125/inted.2020.2448

McGonigal, J. (2011). *Reality is broken: Why games make us better and how they can change the world*. Penguin Press.

Michael, D. R, & Chen, S. L. (2005). *Serious games: Games that educate, train, and inform*. Muska & Lipman/Premier-Trade.

Morris, B., Croker, S., Zimmerman, C., Gill, D., & Romig, C. (2013). Gaming science: The "gamification" of scientific thinking. *Frontiers in Psychology*, **4**, 607. https://doi.org/10.3389/fpsyg.2013.00607

Oestreich, J. H., & Guy, J. W. (2022). Game-based learning in pharmacy education. *Pharmacy*, **10**(1), 11. https://doi.org/10.3390/pharmacy10010011

Persky, A. M., Stegall-Zanation, J., & Dupuis R. E. (2007). Students perceptions of the incorporation of games into classroom instruction for basic and clinical pharmacokinetics. *American Journal of Pharmaceutical Education*, **71**(2), 21. https://pubmed.ncbi.nlm.nih.gov/17533430/

Pierfy, D. A. (1997). Comparative simulation game research: Stumbling blocks and stepping. *Simulation and Games*, **8**(2), 255–268. https://doi.org/10.1177/003755007782006

van Gaalen, A. E. J, Brouwer, J., Schönrock-Adema, J., Bouwkamp-Timmer, T., Jaarsma, A. D. C, & Georgiadis, J. R. (2021). Gamification of health professions education: A systematic review. *Advances in Health Sciences Education*, **26**(2), 683–711. https://doi.org/10.1007/s10459-020-10000-3