SOCIETY. INTEGRATION. EDUCATION
Proceedings of the International Scientific Conference. Volume I, May 26th, 2023. 338-348

CREATING A PROTOTYPE OF AN INTERACTIVE LEARNING GAME IN MOLECULAR AND CELL BIOLOGY

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Abstract. *At the beginning of medical studies at Rīga Stradiņš University (RSU), students' knowledge and skills differ widely. In the first semester, students must take a course, "Molecular and Cell Biology." In many cases, problems in students' abilities to absorb new information of this new, specific nature are evident. The reason for this is insufficient prior preparation. On average, 3-4 % of students failed this course each academic year. After focus group discussions and interviews with colleagues and leading specialists in information technologies, we concluded the need to create an interactive and pedagogically correct tool for improving students` competence in molecular and cell biology; one such tool could be an interactive learning game.*
This article describes the process of creating a learning game prototype in molecular and cellular biology. With the help of selected RSU students, a prototype was created. The involvement of students proved beneficial for them (improving understanding of the topics) and for us (clarifying students' preferences for the game's design).
The learning game was tested with a target group (1st-semester students from the Medicine and Dentistry faculties of RSU). Initial feedback from the students and teachers certifies that this example is an opportunity to provide a desired, low-stress self-paced learning resource.
Keywords: *Game-Based Learning, Interactive Learning Game, Molecular and Cell Biology.*

Introduction

Medical and dentistry studies include several specific subjects like medical genetics, DNA in vitro methods, horizontal gene transfer, and others, which require a basic understanding of the most important cellular processes, and cell

https://doi.org/10.17770/sie2023vol1.7147

structure. For this reason, in the first semester, students take a course "Molecular and Cell Biology." This course introduces students to concepts, terms, processes, problems and technologies which are new to many of them. The abundance of these new terms makes it hard for students to grasp the linkage between them and the application of the processes or methods described by these terms in problem-solving. Several of the terms are phonetically similar (for example, DNA *vs* RNA, transcription *vs* translation, genetic code *vs* genome, genetics *vs* epigenetics). Upon failure, some students stop studying, which means they have to repeat the course in the next semester, costing time. We are looking for solutions which would improve this situation. Some prior effort to familiarize themselves with these terms before the beginning of this course would reduce the probability of inadequate use or misunderstandings regarding these terms later and improve students' performance. It would also equalise the starting point of the students concerning the preparedness for this course, which, according to the experience of our colleagues, varies widely.

The article describes the experience gained in creating and testing a learning game prototype for the 1st-semester medicine and dentistry students for the study course "Molecular and Cell Biology."

In creating and testing a learning game prototype, we formulated three tasks and selected appropriate methods:

1. *Determine how many and why students drop out during the first year of study.*

To identify how many students dropped out during the first year of study, we started with document analysis from the Department of Biology and Microbiology. To determine the reason for dropping out, we had one interview with the Medicine faculty vice-provost, who holds interviews with students who fail courses.

2. *Find out typical pedagogical techniques we use to support students to improve their knowledge and skills in the study course Molecular and Cell Biology.*

One focus-group discussion with colleagues in our department was organised for this task. Eight teachers participated in the debate, and the conversation was audio-recorded and transcribed. The education specialist managed the focus-group discussion. After data transcription, we found out whether the current solutions were practical or not effective.

3. *Clarify technical and pedagogical specifications for developing a modern tool for learning Molecular and Cell Biology.*

Technical and pedagogical specifications for developing a modern tool for learning were set based on literature analysis about game-based learning (GBL). Engagement positively affects learning and motivation but relies on a pleasant design and appropriate game culture. Games, as part of 21st-century pedagogy, demonstrate the depth and breadth of scholarship on games (Jabbar & Felicia,

2015; Steinkuehler, Squire, & Barab, 2012). The authors emphasize the importance of enjoyment and motivation to sustain players' engagement. Barzilai & Blaun (2014) add that the central challenge of integrating GBL is helping learners connect the knowledge learned in the game and the knowledge learned in lectures, books, and practical classes.

Another meaningful aspect of implementing the GBL approach is the use of a smartphone interface, which is a big part of the everyday life of today's youth. Three interviews with universities' IT system administrators were conducted to make the learning game compatible with the technological interface of our universities' e-studies system (RSU). After the discussions and interviews with specialists, we concluded whether the current solutions are effective or not practical.

Secondly, students with good drawing skills and interest in the study subject were approached and asked to participate voluntarily in this project. Engaging volunteer students helped us to understand whether our ideas and designs were meaningful and exciting for the target group. Ten students participated in interviews. Six volunteered, and their motivation to participate in this project was recorded.

Interactive Learning Game

An analysis of the theoretical literature about valuable tools for improving students' learning outcomes and achievement indicated gamification as a promising solution. Gamification is the incentivization of learning, and one could think of game-based learning (GBL) as the fullest form of gamification.

Interactions with game-based learning environments hold significant promise for developing a deeper understanding of game-based learning, designing GBL environments to detect maladaptive behaviours, and informing adaptive scaffolding to support individualised learning (Emerson, Cloude, Azevedo, & Lester, 2020).

Educational game designer Kalmpourtzis shares some of the following characteristics, challenges, and difficulties for learning game-creating authors:

1. They are dedicated, interested, or simply curious to explore how games can be used and designed in learning contexts.
2. They constantly think of innovative and novel ways to design learning experiences in school, work, family, and daily life.
3. They impact the use and design of educational games.
4. They are creative minds interested in helping their field of work evolve and have a meaningful impact on their peers, friends, and society (Kalmpourtzis, 2018).

In the Handbook of Game-Based Learning (Plass, Mayer, & Homer, 2019) authors emphasise that learning games must comply with three options modes of competition and collaboration:

- self-directed learning,
- competition within a group of players,
- student interaction during the game to discuss the questions and answers.

According to pedagogical and theoretical literature analysis, GBL has a recommended concept structure. As noted by Boyle et.al. (Boyle, Connolly, Hainey, & Boyle, 2012), engagement in games is related to a wide range of elements inherent in the games (e.g., design), as well as to the attributes of players, and game-based education means a learning task is redesigned to make it more interesting, meaningful, and, ultimately, more effective for learning than a nongame or gamified reading. Many of the studies on this topic are limited to understanding the nature of engagement in games for entertainment purposes (and not those designed with learning in mind) and the outcomes; in such studies, learning outcomes are not assessed. Thus, we set a goal to make a game for learning molecular and cell biology. GBL can be explained as learning that is facilitated by the use of a game (Whitton, 2012), and players can engage on affective, behavioural, cognitive, and sociocultural levels (Fig. 1). The content of Molecular and Cell Biology studies is very complicated and demanding. Still, we can think about making the learning environment more motivating, transforming the learning exercise to make it more interesting, meaningful, and, finally, more effective for learning.

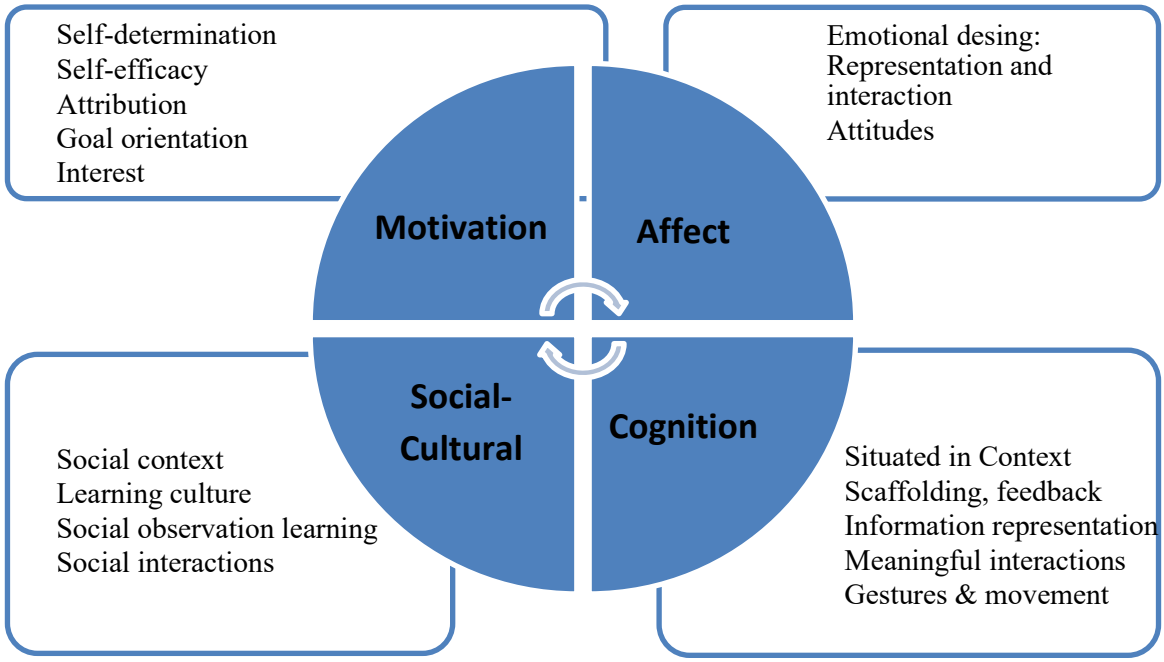

Figure 1 ***Game-based learning theoretical perspectives***
(Source: Plass, Mayer & Homer, 2019)

Before learning the game-creating process, we must define expected user motivation, such as self-determination and goal orientation, and consider different interests. We must consider it a game with competition or collaboration mode for a group of players. The social context is critical; we can respect and predict different learning cultures and social interactions. We can also see the entertaining aspect: knowledge-based competition with a little strategy, simultaneously including different learning cognition levels. And finally, we must remember the emotional aspect one gets during the game (Jabbar & Felicia, 2015). We strived to follow all the aforementioned suggestions to build a successful interactive learning game prototype. The learning game can be played individually as well, in which case the only benefits would be learning from high-quality material that includes questions and feedback with explanations.

Following an analysis of the theoretical literature, we see the essential principles relevant to creating a learning game (Fig. 2).

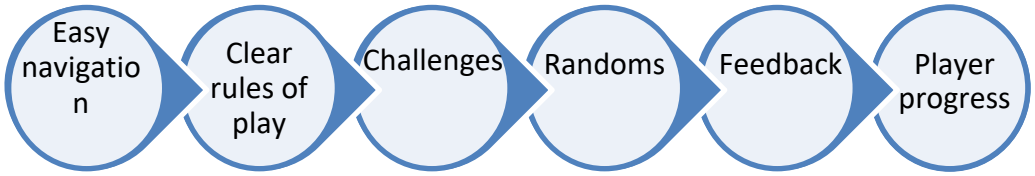

Figure 2 ***Relevant principles of play in an educational game*** *(Source: Foundations of Game-Based Learning, 2015)*

Parallel to the educational aspects, we thought about the interactivity of the game and the technical aspects because we wanted to create a combined game - a board game using a smartphone.

Last but not least, we studied game-based studying tools for molecular and cell biology available online or in print. Some of these are focused on a single subject (Gene of Fortune, Genetic Dice & Origami Organelles product line by Edvotec, Molecular Biology Vocabulary Review Game by Serendip studio, a range of video games and virtual labs by bioman.com, Central Dogma Game by centraldogmagame.com, Guardians of the Genome by AXS studio, Phylo by McGill University, EteRNA - a fascinating project developed by scientists from Carnegie Mellon University and Stanford University, and many more) thus don't provide a full overview of topics included in our course. The majority of the abovementioned games are not multiplayer. The game BioQuest (da Silva & da Costa Fuentes, 2020) covers several topics of applied molecular biology in a step-by-step fashion but it still is focused on methods and is single-player. Understanding that there are probably many more online and in-print tools

designed to help in teaching and learning molecular biology, the overall trend seems to be that these tools are too focused and are, with exception of in-print games by Edvotec, single-player. One exception, the game Discovering the Cell (Spiegel et al., 2008), which is multiplayer and addresses several topics, did come to our attention but the game is in Portuguese. Nevertheless, the scope of topics and concepts covered by this game is broad and the approach is intriguing. Still, what can be understood from the respective publication, the game is missing several topics important in the university-level course. Authors (Emerson, Cloude, Azevedo, & Lester, 2020) write that GBL environments integrate game content with learning activities (eg, exploring, navigating, investigating) to enhance domain-specific knowledge (e.g., microbiology) and skill acquisition (e.g., self-regulation), where activities typically involve problem-solving and challenge to foster students' perceived achievement (e.g., solve a mysterious illness outbreak).

We concluded that their content does not correspond to the content being studied at our university. Some of these games were too simple, and some covered only part of the content of our subject. These conclusions gave us the confidence to create a new and better-suited offer for our students – an interactive learning game in molecular and cell biology. Using such an approach, students can also improve teamwork in small groups and learn from each other.

Results

We analysed data obtained over the last seven academic years from 2015. /2016 academic year till 2021. /2022. Figure 3 shows a summary.

An average of 578 students per year take this course; on average, 23 (4%) fail it (regardless of whether it's the first time they fail it). The data set is too small to check for statistical reliability ($r=0.6904$, $p= 0.08$), but in this case, the human factor is crucial to us, and we had to find out the leading causes of students who dropped out of their studies.

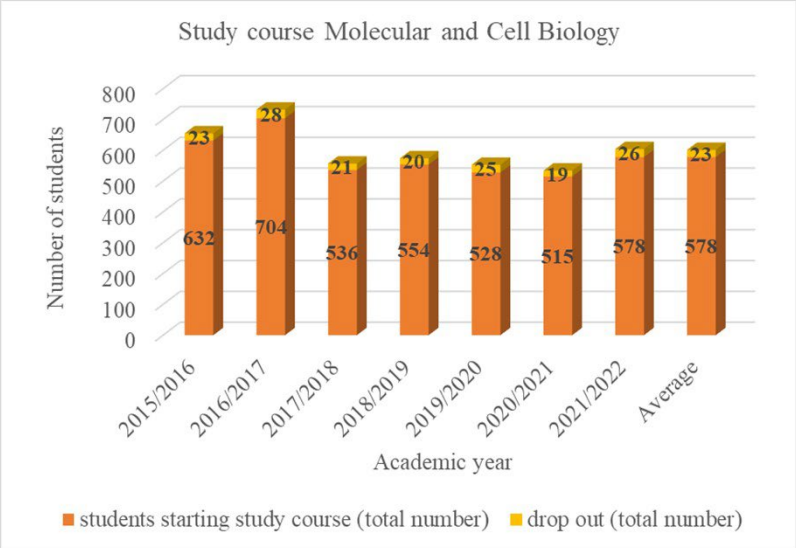

Figure 3 ***Changes in the number of students over seven years*** *(made by authors)*

In an interview with the Medicine faculty vice-provost, we learned that students need help with this course and are stopping their studies when they don't get it. Students admitted that they need more prerequisites in Biology from secondary school, and the new content in Molecular and Cell Biology is complex and voluminous. There needs to be more clarity between the latest topics. Some students also openly respond that university staff provides insufficient support, especially teachers. The traditional tutorial doesn't help. Therefore, we should see solutions for practical and genuine support for the students, which indicates the need for more support.

To accomplish the task, we organised a focus group discussion for all teachers who teach the Molecular and Cell Biology study course. All eight involved professors were interested in reducing the number of students failing this course.

After analysing the data obtained, we conclude that: teachers use only tutorials to support students. Also, as observed by the teacher, they don't ask questions in the lessons either.

The average experience of the teachers in teaching this course is 7.5 years. This experience is sufficient to make suggestions for improvements to the process. In addition, playing to a highly technological environment (daily use of smartphones and devices), the new tools must be modern, preferably smartphone-friendly, and interesting for a student to use.

Together with RSU information technology department specialists, we decided that the game has to be as simple as possible, for example, using a smartphone to scan a QR code that provides a random question after choosing a topic and difficulty level on the game board. Correct answers score points. Initially, the decision was to use the platform Moodle. The Moodle platform was

instantly available to test the concept and was familiar to teachers and students. Secondly, during development, it helps to protect copyright as authorization is required for access.

An important technical issue was "How to provide a random question?". This functionality is essential to make the game entertaining and, given the different difficulty levels, introduces a touch of strategy - the main gameplay challenge is to get a better score, yet the amount of questions is fixed.

After the discussions and interviews, we concluded that students nowadays study differently and use more information technologies. Some students use books and YouTube videos, and essential visual information, but verbal communication is more critical for others. This type of learning with mobile devices with wireless network connections, cameras, GPS, and other readers expands learning with games from the screen to learning in a mixed-reality environment using urban spaces as a game board (Huizenga, Admiraal, Dam, & Voogt, 2019). One of the first steps to a successful product is knowing your audience. "Have a better understanding of the needs, tools, materials, people, and procedures needed for implementing educational games so that you can handle issues, avoid pitfalls, and overcome obstacles that may arise throughout the process of creating your games." (Kalmpourtzis, 2018)

Our target audience is 1st-year university Medicine and Dentistry faculty students.

Therefore, a focus-group discussion was held with student volunteers with good drawing skills. The goals and target audience of this project were explained to the students. The volunteers supported this idea. Some interesting aspects of this cooperation between the students and we emerged – each of them draws in different styles and techniques and showed unique undertones in how they interpreted different steps or events in the biological processes included in the game. Occasionally participation of the students in this project clarified some unclear issues or misunderstandings regarding the topics themselves.

In subsequent work with students, we agreed on:

1. the learning game consists of six-game fields corresponding to six main themes: Cell structure and functions. Cell division: Mitosis. Cell division: Meiosis. DNA replication. Protein synthesis. Molecular transport.
2. Which playing field will each student draw?
3. Weekly meetings for progress monitoring, checking for mistakes, and editing.
4. Teachers (the authors of this article): agreed on the IT system used. Created the game's rules for online and printed versions and created a certain number (10-20) of questions/tasks in each topic and difficulty level and generated the corresponding colour-coded QR codes.

A total of six meetings were held with students, and every smallest nuance in the drawings of the six playing fields was analysed. 170 multiple-choice,

true/false questions, and 63 essay-type tasks were created on six molecular and cell biology topics. Three color-coded QR codes were included in each learning game field, providing a link with the RSU Moodle system, which served as the IT background of the game.

After creating the first versions, a group of students and colleagues were formed to validate the learning game "The Cell." Students received learning-game fields with QR codes and conducted a pilot test online (we worked remotely during this period).

Students and teachers had to play one of the on-playing fields and answer the questions:

1. What are the benefits of playing this game?
2. What were the disadvantages of the game?
3. What improvements can you suggest?

Initial feedback from the students was that this is an example of outside-the-box thinking and that they like it. Students take a long time looking for different learning materials, and this game provides a nice bundle. There was a loss of the stereotype that learning is hard work. It is one step towards a more positive vision and attitude for students. From students' answers: "*..this game is a great learning tool because it allows you to actively apply your knowledge and find out what needs to be repeated and what is not fully understood…"; "..in the game, I learned more new knowledge.."; ".. competitive spirit emerges that motivates to engage with full dedication..."; "…I usually have tension and anxiety in class that I don't know something, but there was no tension during the game...".*

One of the main recommendations was to change the Moodle platform of the learning game because when students open that platform, it generates memories related to tests, stress, and grades.

In the feedback from colleagues, the main conclusion was that the learning game prototype is interactive, and the playing fields are attractive. Several constructive suggestions were received:

1. The solution offered by the Moodle environment is clumsy. A more advanced game environment solution has to be sought.
2. In order to promote a better understanding of molecular processes in the cell, the questions should be arranged according to the principle of the processes.
3. Editorial review is recommended for questions.

As a result, all content issues were improved within a month, and several zoom meetings were organised with IT specialists of various publishers of educational materials in Latvia to identify the possibilities of the platform change. We concluded that none of the publishers could offer already established platforms perfectly fitting the intended final functionality of the game. It is necessary to perform additional programming on already existing platforms to eliminate various shortcomings, for example, the same question appearing several times (as it's assigned randomly), issues with keeping track of the score of each

player, issues with the addition of new tasks and playing fields, issues with specific feedback (for example video as feedback). We have contacted IT companies to clarify the cost of creating a new platform suited for learning games of other gameplay styles. We are now looking for funding opportunities to bring this game to the final design.

The next step to continue the research would be useful to have some data analysis regarding the efficiency of such a gamification approach, and we should approbating the game with all medical and dentistry students.

Conclusions

Necessity and motivation. As evidenced by the data obtained from historical records about student performance, interviews, and focus-group discussions, current pedagogical tools are ineffective for some students. New learning tools are needed to help students succeed in their studies.

Benefits for students. The students learn differently and improve cooperation and argumentation skills in small groups. They learn not only from the game but from each other as well. Self-directed learning is promoted due to the gamification of learning, assuming the design is welcoming and not frustrating (resembling colloquia or tests).

Competition within a group of players is more fun in any game. Yet, this game can be played individually as well, in which case the only benefits would be learning from high-quality material that includes questions and feedback with explanations.

Benefits at the institutional level. The interactive learning game "The Cell" has already been an example for other study course managers, teachers, designers, and students. It has encouraged colleagues to create analogy resources in the context of their courses.

Successfully designed and validated the interactive learning game "The Cell" can be used in various activities organized by the university for the society, for example, scientists' night event, open-door event, adaption week, and others, not to forget benefits in the marketing of the university brand.

The recommended concept for creating the prototype of an interactive learning game:

1) Learning objectives- clearly defined for creating tasks and improving knowledge and skills in the study course.

2) Entertaining aspect- knowledge-based competition with a little bit of strategy.

3) Player's role (main activity)- choose a topic, choose the difficulty level, and use a smartphone to scan a QR code that provides a random question. Answer correctly to score points and discuss your answers with other players.

4) IT platform – prioritize simplicity and design.

Acknowledgement

A prototype of the interactive learning game "The Cell" was created with financial support from the Boris and Ināra Teterev Foundation.

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