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Burn your fat—a unique DIY board game about triacylglycerol breakdown

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Understanding metabolic pathways is challenging for students due to their complex nature and intricate interdependencies. To address this problem, gamification has emerged as a promising approach to make scientific concepts accessible and engaging. We present a DIY educational activity focusing on lipid and glucose metabolism to clarify the basic principles of biochemical transformations and provide practical educational resources for lecturers. The activity is designed to be accessible and requires minimal resources, using physical media such as printed boards and dice. It consists of two parts: an introductory session where students build a triacylglycerol molecule and a board game where teams compete to metabolically break down triacylglycerols and obtain ATP. The process in governed by rules based on metabolic transformations, with players taking on roles as walkers, counters, transformers, and strategists to encourage cooperation. The game aligns with the theories of cognitivism and constructivism and emphasizes knowledge acquisition, the formation of mental structures, and active learning through experience. It promotes a socio-cultural perspective and the development of interpersonal skills by encouraging teamwork, cooperation, and problem-solving. The thematic focus on obesity provides real-world context, and the DIY concept, 3D printing capability, and potential for creating extensions encourage student engagement and customization. The activity effectively teaches metabolic networks to high school students, is helpful for graduate students in visualizing experimental problems, increased engagement in the classroom and interest in the life sciences. A simplified version has also been used for the general public at science fairs, highlighting its versatility and accessibility.

KEYWORDS
games, lipids, carbohydrates, role-playing, metabolism, high school, biochemistry

1 Introduction

Understanding metabolic pathways can be a major challenge for chemistry students due to the complex network of biochemical reactions and complex interdependencies. These pathways represent the fundamental processes by which organisms transform molecules to produce energy and synthesize essential molecules for growth and maintenance. However, their dynamic nature, involving many enzymes, substrates, cofactors, and regulatory mechanisms, adds complexity to the learning process. Effective learning requires not only memorization of individual reactions but also a deep understanding of the fundamental principles governing metabolic regulation and the links to cellular physiology. Mastering metabolic pathways, therefore, requires critical thinking and an interdisciplinary approach involving the natural sciences.

Gamification can be utilized to portray complex scientific concepts and pathways in a more approachable and digestible manner. Science-themed digital and board games have been developed and published and have been used as an assistant tool in teaching to reinforce scientific concepts being taught in the course (O'Neill and Holmes, 2022). Most chemistry games are aimed at a select audience. Element Enterprise Tycoon was developed to help middle school students make connections between chemical elements and items in their everyday lives that contain them (Tsai et al., 2020). Simple chemistry games were used as a teaching aid for ionic bonding (Stojanovska and Velevska, 2018). The card-based game CHEMCompete helped undergraduate chemistry students with reactions of alcohols (Gogal et al., 2017; Camarca et al., 2019). A game-based application "Time Bomb Game" was used to teach high-school and undergraduate chemistry students the structural theory of organic compounds (da Silva Júnior et al., 2020). For analytical and organic chemistry students, several simple games were designed to illustrate and reinforce concepts learned during the course (Samide and Wilson, 2014). Triboni and Weber have not only briefly reviewed existing chemistry educational games but also developed the MOL (Mastering the Organic Chemistry Lab) board game, which emulates real organic chemistry lab conditions (Triboni and Weber, 2018).

Unfortunately, publications on biochemistry games are scarce. Television quiz shows were used as a format for two quizzes (AZ-Quiz and Jeopardy!) for high school students (Roštejnská and Klímová, 2011). The gluconeogenesis pathway was used as a basis for a board game, "Race to Glucose," for first-year pharmacy students (Rose, 2011). For medical students, a vitamin-themed board game based on answering quiz questions has been developed (Surapaneni, 2024).

With the exception of AZ-Quiz, Jeopardy, CARBGAME, and CHEMCompete, none of the game boards or applications mentioned were accessible at the current time, identifying a need for game resources that are easily accessible to scholars, students, and the general public. Furthermore, these games were used as an assistance tool in combination with taught courses, meaning that there is a lack of science-themed activities that could be accessible to those without education related to the game.

2 Pedagogical framework

The game has been designed according to (1) cognitivism theory to emphasize knowledge acquisition, mental structure construction, and information processing by individuals and to promote their active involvement and (2) constructivism theory to emphasize individuals' active construction of knowledge through their experience in a situated context (Ertmer and Newby, 2013). The players must understand the game's concept and rules and project their potential effects on the game (how much ATP to gain/lose via specific pathways, etc.). The game translates abstract biochemical processes into a tactile experience. The physical experience of moving the pawns (metabolites) and physically breaking them into smaller metabolites (acylcarnitines, acetyl-CoA, etc.) promotes the mental construction of the complex networks and helps the students to reflect on the textbook information from the lectures.

The activity also emphasizes socio-cultural perspectives and interpersonal skills development. It has been shown that an increase in in-person school, friends, and extracurricular activities is significantly correlated with an increase in social skills, which were negatively affected during the COVID-19 pandemic (Hernández and Jabbari, 2022). It promotes teamwork, cooperation, individual responsibilities in a group (roles in the game), and problem-solving skills and strategies when competing with the other team for the same resources. Competing against the other team also promotes horizontal thinking and creativity in providing alternative solutions to find a better / faster/ energetically cheaper pathway to gain ATPs or to avoid a metabolic crossroads blocked by the other team. This can be abstracted to more general problems of solving the distribution of electricity through the grid or logistic problems with cargo transport.

The theme of the game also aims to educate students in the fields of health and food sciences and to provide a real-life context. The worldwide problem of obesity and its metabolic complications are mechanistically explained. Students can experience for themselves how difficult it is to get rid of fat in case of excess sugar intake.

Student engagement is supported by the DIY concept, the option to 3D-print their own set of pawns and tokens, and also the option to create their own extension of the game. The suggested theme is amino acid metabolism, which would provide even more physiological context to the game. Teachers or instructors can pack the body of knowledge into a conveniently accessible game and integrate the knowledge with fun.

2.1 The underlying mechanisms and dynamics of the game

The turn-based strategy concept of moving physical tokens across the board and sequentially breaking them down into smaller building blocks best mimicked enzymatic processes and explained the concept of carbon-centered biochemistry. Students had to physically perform the reactions and experience the laws of mass balance and energy conversion. We abandoned the original token design using LEGO bricks due to the difficulty in obtaining the required type of monochrome bricks and the excessive rigidity and height of the "towers" built with the bricks. Disconnecting the LEGO bricks between reactions took an inordinate amount of time and the tall "molecules" had a tendency to fall down.

The element of randomness was introduced by rolling the dice so that the game could be unique each time it was played. Through test play, we selected a combination of six-sided dice as ideal for gaining a reasonable number of metabolic steps per round, and we added an element of randomness in the form of a roll of a twenty-sided die at the key crossroads.

The element of two game groups allowed for the competitive involvement of more students and introduced the dimension of competition of enzymatic reactions, when one group could limit the availability of the reaction for the other group. The assignment of game roles to individual students allowed to change the dynamics of the game, to create strategies and to promote cooperation within the group. Without this competition, students knew the final result of the game and the challenge was missing. Although the game can be played one-on-one, the educational dimension is best propagated when role-playing is done in groups.

3 Learning objectives

The goal of this work was to

- Design a game that increases student motivation and engagement with lipid metabolism concepts,
- Explain the basic principles governing biochemical transformations in living organisms,
- Provide educational resources tailored to educators to bridge the gap between scientific concepts and the practical utility of knowledge. The target audience is high school students, undergraduate students, and teachers.

4 Results, processes and tools

4.1 Game parts

The game is designed as a "Do it yourself" ("DIY") school project and no direct aid from professionals is needed. Game accessibility was taken into account during game development, as there are great differences between schools in terms of digital capacity and teachers' and students' skills in using information and communication technologies (Timotheou et al., 2023). Thus, the game was developed as a physical media requiring only a printer. The playing board should be printed in A0 format or similar. The game dice D6 and D20 (20-sided polyhedron) should be bought. The pawns, tokens, and building bricks can be 3D-printed using the provided models, or LEGO bricks can be used as replacements. All instructions are provided as Supplementary material.

4.2 Organization of the game

The game is divided into two parts, which correspond to two learning sessions (Figure 1). In the first part, students are introduced to the concept of the game and its rules. They review the theoretical knowledge about metabolic pathways and form two teams. The practical task in the first part is to assemble the game lipid pawn—the triacylglycerol molecule—using building blocks. In the second part of the game, the teams play a board game (Figure 2). Each team has to choose members for the roles of walker, counter, converter, and strategist. The teams compete for the resources available in the game to metabolically degrade triacylglycerols and gain 100 units of ATP. The board is divided into cellular compartments (lipid droplet, cytosol, mitochondria) and metabolic pathways relevant for triacylglycerol degradation (β-oxidation, Krebs cycle, lipogenesis, glycolysis, oxidative phosphorylation).

4.3 Game rules

The teams take turns and roll three dice, gaining a number of metabolic steps by which they can move their metabolites around the playing field. During the game, it is necessary to follow the rules of metabolic transformations and take care of the fate of individual 'carbons' and energy equivalents (NADH, FAD, GTP, etc.), which need to be converted into ATP. The first one to get 100 units of ATP wins. The game incorporates the element of chance by means of a roll of the twenty-sided D20 die and the strategic element of limiting the number of auxiliary metabolites, which allows the teams to create competitive strategies.

To reduce the complexity and to promote collaboration within the team, four roles in the game are defined: (1) 'walker' rolls the dice and moves the pawns (molecules) on the board; (2) 'counter' uses the step counter (abacus) to keep track of how many steps can be used; (3) 'converter' collects the cofactors, uses cofactor conversion table to generate ATPs, moves ATP token within ATP counter; (4) 'strategists' observe the board and define the best strategy to gain ATP.

More stringent rules for experts are available to increase the complexity when needed. The limitations include symmetry of molecules, reaction order, recycling of intermediates, and more random selection of pathways at metabolic crossroads. The game can be played with extension #1: 'The sugars strike back,' when glycolysis, glycogen, Kennedy pathway, and Cori cycle make the game more physiologically relevant. Students are encouraged to design their own extension, which would also consider amino acid metabolic pathways.

Board game-style rules and guidelines are included as Supplementary PDF file.

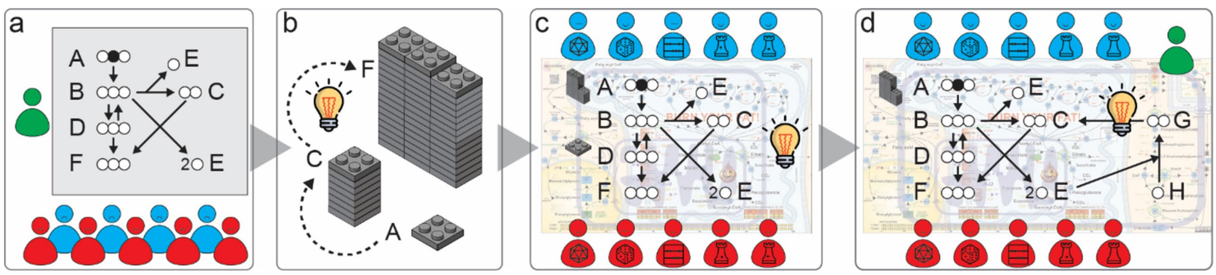

FIGURE 1
Organization of the game. (a) The principles of metabolic networks and the rules of the game are explained to the students in the first session. (b) Students should assemble a molecule of triacylglycerol (tripalmitoylglycerol) using building blocks representing single carbon units. Eventually, students can customize and 3D print all the game pieces. (c) In the second session, students form two teams, assign roles (walker, converter, counter, strategists) and play the game with the previously assembled molecules. (d) Students and teachers can create a customized extension of the game by adding more metabolites and pathways.

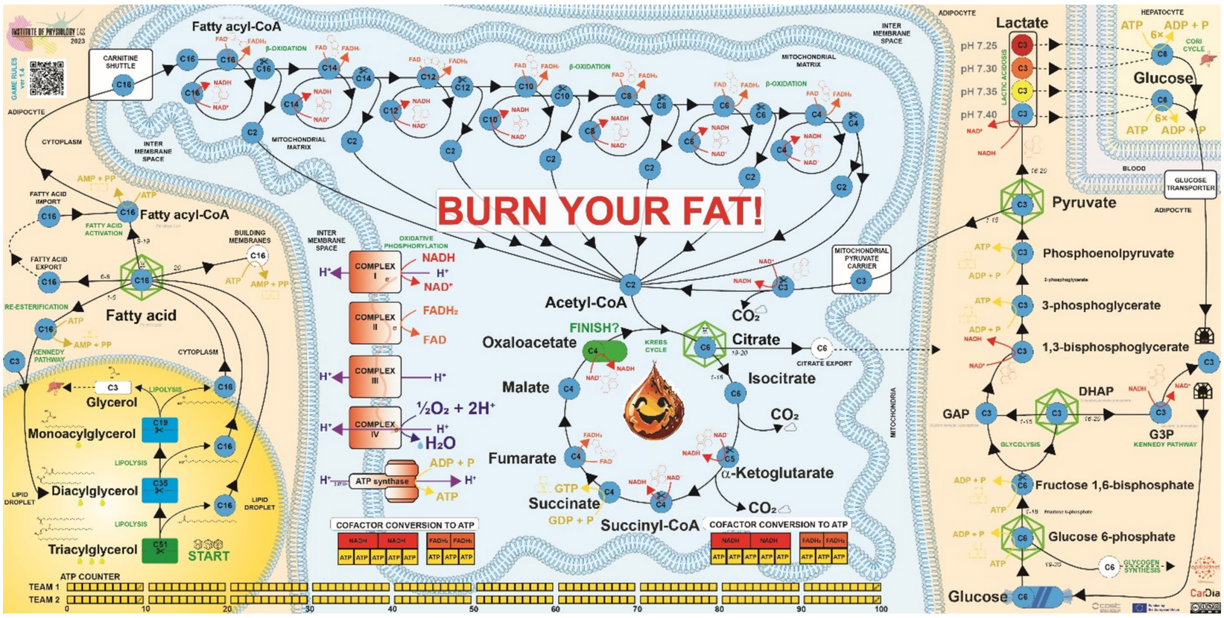

FIGURE 2
Overview of the game board. The game starts at the lipid droplet (green area) with the triacylglycerols. Players roll the dice, move the molecules forward, and follow the reaction steps through the cytosol to the mitochondria, collecting energetic intermediates such as NADH and FAD. The goal is to break down the triacylglycerol into CO_2 and collect 100 units of ATP by converting energy equivalents through oxidative phosphorylation. The expansion on the right adds the glucose pathways to the game plan. Complete game rules are available as Supplementary material.

4.4 Play modes—how to play

4.4.1 Elementary school students, science fairs, and general audience

Use only the game board and the assembled triacylglycerol molecule to explain the concept of carbon building blocks. Use the LEGO analogy to simulate the synthesis of a fat molecule and show how the fat molecule can be broken down by enzymatic reaction in the body by removing the building blocks sequentially across the game board. Students should play with the building blocks and associate the synthesis and degradation process with the carbon units. The general audience can be educated about the risks of obesity.

4.4.2 High school students

Teachers or instructors can prepare the game in a basic format at the moment when students have already acquired the necessary knowledge of chemistry or biology according to the curriculum. In this case, the primary aim of the game is to consolidate the principles of biochemical transformations in the form of a group game. The role of the teacher (game master) is to interactively explain to the students the current events on the game board and to place the game mechanisms in the context of the lesson being discussed. This is the main scenario for this educational tool.

4.4.3 High school students with specialization in biology or chemistry

A longer-term project approach can be planned for students in specialized classes or seminars. Students could be assigned specific roles (groups) in the project (3D printing the pawns, obtaining the dice, etc.) and the effort should be directed toward a group game organized by the students. This scenario promotes collaboration, problem solving and planning skills in addition to the biochemistry concept. The teacher's role is to supervise the project, balance the students' contributions, and keep the project within the curriculum.

4.4.4 University students

The game can be used to materialize the concepts of metabolic reactions and the students should challenge the rules, review the rules, and write their own modifications. It can be used as an open field to discuss the known and unknown regulations of metabolic pathways and design new experimental models.

5 Conclusion

The game was used to teach high school students (specialization in life sciences) and undergraduate students (biology, chemistry) the principles of metabolic networks. When the game was introduced to the students at science fair, the students chose the game format to be used in their curriculum. PhD students played the game at the expert level to visualize the experimental problems and to find an alternative solution or explanation for the results. Simplified versions of the same have been used at science fairs for the general public, similar to games like 'Sorry!' or 'Ludo'.

The game engages players in active learning by simulating metabolic networks. It promotes teamwork, problem-solving, and creativity while addressing real-world issues like obesity. It has proven effective for high school, undergraduate, and even PhD students and offers the potential for wider public engagement in science education.

Data availability statement

All material is available at GitHub https://github.com/IPHYS-Bioinformatics/Burn_your_fat.

Author contributions

DM: Resources, Validation, Writing – review & editing. OK: Conceptualization, Funding acquisition, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1485234/full#supplementary-material

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