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Glyphoscape: An Escape Room Game based on the Biochemical Principles of Herbicides using the Example of Glyphosate

Hilko Aljets[1], Niklas Momberg[2], Ingo Mey[3], Thomas Waitz[4]

[1] Institute of Inorganic Chemistry, Department of Chemistry Education, Georg-August University Göttingen, Germany
[2] Institute of Inorganic Chemistry, Department of Chemistry Education, Georg-August University Göttingen, Germany
[3] Institute of Organic and Biomolecular Chemistry, Georg-August University Göttingen, Germany
[4] Institute of Inorganic Chemistry, Department of Chemistry Education, Georg-August University Göttingen, Germany

Abstract

In the escape room Glyphoscape - The Forgotten Lab, students aged 16-18 explore an old, abandoned laboratory owned by a scientist who conducted private research on the herbicide glyphosate, while deepening their biochemical knowledge about pesticides and the inhibition of enzymes. To protect his research, the lab was sealed with various puzzles. These puzzles are presented in three sections: (1) the theoretical basis of pesticides and herbicides and their general mechanisms of action, (2) enzymes and their structure and (3) enzyme inhibition. After each section, the contents are secured by a gatekeeper puzzle and applied to glyphosate before the next section can be reached. The participants have to solve each puzzle to get out of the lab. After successful completion of the escape room game, students will be able to explain enzyme inhibition in general and the inhibition of 5-enolpyruvylshikimate-3-phosphate synthase by glyphosate in the shikimate pathway in particular. The presented escape room opens up various teaching possibilities and can be flexibly used.

Keywords: *escape room game, glyphosate, pesticides, herbicides, biochemistry, enzymes*

1. Escape room games in education

In an escape room game a team of players has to solve logic puzzles and tasks by using clues to finally reach a certain goal. Usually, this main goal consists of escaping from the room. Solving puzzles often leads to further clues or riddles that must be unraveled [1]. Meanwhile, the concept is not only used for entertainment, but has also been adapted for educational purposes by engaged teachers and educators [2].

Due to the challenging nature of the varying tasks, escape room games require logical and critical thinking, teamwork and creativity from the participants [1, 3], similar to common serious games [4]. Educational escape rooms are using this to offer a learning environment that promote these skills in addition to teaching and deepening knowledge [5]. By solving the escape room, learning objectives are achieved.

Research on the effects of escape room games on learning is still in its early stages [6]. Mainly only single case studies can be found, which evaluate self-created escape rooms and show positive effects on learning motivation and enjoyment [5, 6].

2. Framework of “Glyphoscape – The Forgotten Laboratory”

Participants of the escape room game *Glyphoscape - The Forgotten Laboratory* are told that they are young students exploring abandoned places and have accidentally come across an old laboratory. The goal is to explore the place before it is demolished in an hour. The secret lab was run by the fictional person Dr. Alba, who conducted research on the mechanism of action of the herbicide glyphosate. He saved his results on an old computer, but to secure these of unauthorized access he protected the data with various riddles. These riddles require knowledge of basic concepts of biochemistry, so only scientists can get access to the results. Luckily, the players can find old research notes from Dr. Alba containing information about glyphosate and enzymes as well as herbicides in general in the room.

2.1 Scientific principles

Glyphosate (*N*-(phosphonomethyl)glycine) (Fig. 1A) is one of the most used and most important herbicides. The development and use of glyphosate-resistant crops simplified the use of glyphosate in

agriculture [7]. Glyphosate was long considered non-toxic to mammals until 2015, when the International Agency for Research on Cancer classified glyphosate as possible carcinogenic, while the European Food Safety Authority came to a different conclusion [8]. This ongoing discussion is not content of the escape room game.

The herbicide inhibits the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS, Fig. 1B & 1C) of the penultimate step of the shikimate pathway, a metabolic pathway that occurs uniquely in higher plants and microorganisms and is responsible, among other things, for the synthesis of aromatic amino acids. EPSPS catalyzes the reaction between phosphoenolpyruvate (PEP) and shikimate-3-phosphate (S3P) to 5-enolpyruvylshikimate-3-phosphate (EPSP) and phosphate (Fig. 1D) [7]. Glyphosate and PEP share a similar ionic structure and exhibit the same ionic interactions with EPSPS. The increased length of the molecule can be compensated by slight rearrangements of amino acids [9].

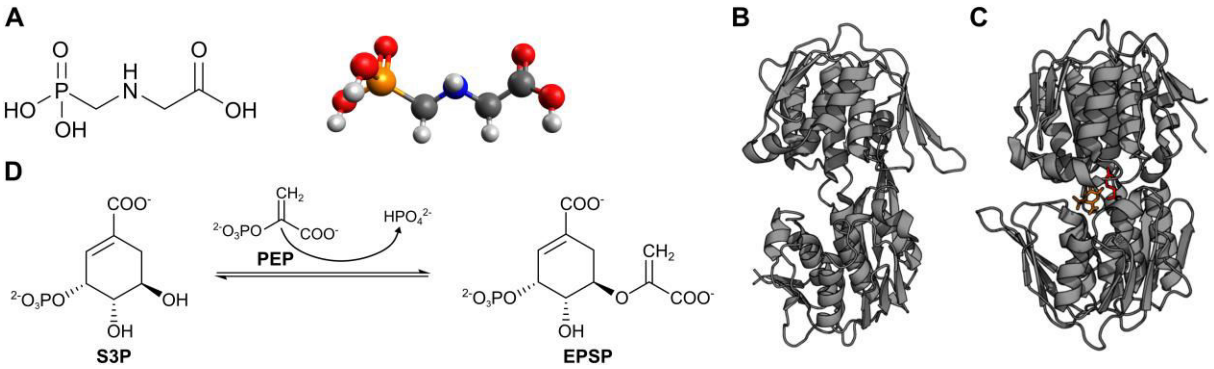

Fig1. (A) Structure of glyphosate. (B) Structure of the open EPSPS (image based on [10], PDB: 2GG4). (C) Inhibited EPSPS in grey with S3P (orange) and glyphosate (red) (image based on [10], PDB: 2GGA). (D) Reaction from S3P with PEP to EPSP. This reaction is catalyzed by the EPSPS.

2.2 Structure and content of the escape room

The game is divided into three sections with different subtopics. Each section consists of different puzzles in a linear sequence, so that only one puzzle can be solved at a time. This should prevent the division of the group into subgroups, which could solve tasks independently of each other. After completion of a section the players gain access to the riddles of the next section. Figure 2 shows the three sections of the games and their puzzles.

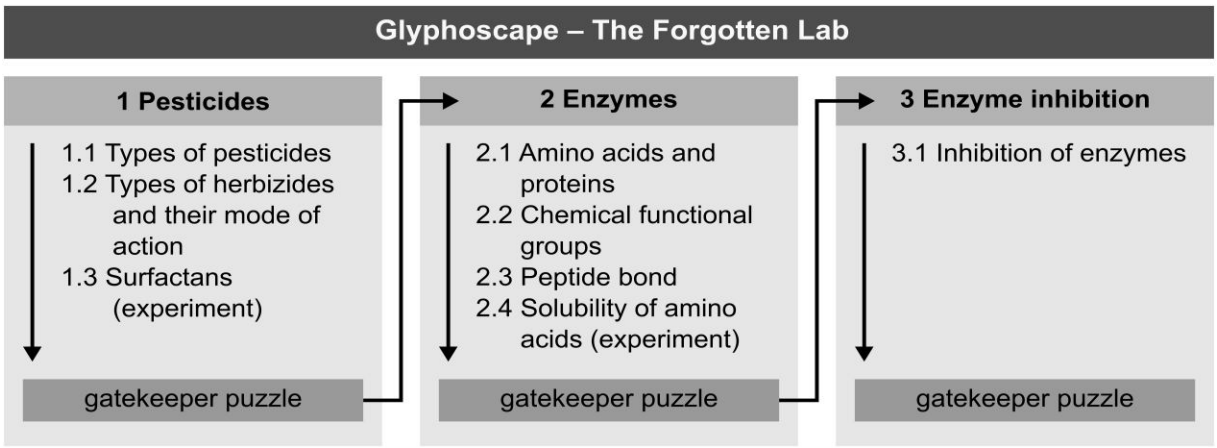

Fig. 2. Overview of the three sections of the escape room game *Glyphoscape – The Forgotten Lab* and their puzzles. Each section is linear in structure and ends with a gatekeeper puzzle on an old computer terminal. The successful completion of this last puzzle is required for the start of the next section.

In each section the students have to solve riddles and quizzes regarding the topic of the section. First, the students learn about the different types of pesticides and herbicides and their terminology. Since surfactants are often contained in pesticide or herbicide solutions as a wetting agent, an experiment on surfactants is conducted in the last puzzle of the first chapter. In the second section the players have to use their knowledge about basic (bio-)chemical principles to proceed to the next section. After they learn about the role of amino acids and proteins, they recapitulate some basic knowledge of organic chemistry. This will be important for the next riddles in which the students identify amino acids and peptide bonds in an image of a protein and investigate the solubility of amino acids. The last section provides only one riddle about the inhibition of enzymes. For the last riddle the players define and describe the competitive, uncompetitive and non-competitive inhibition by using a model.
The last puzzle of each section provides a password that can be used to unlock Dr. Albas computer. Before the next section can begin, a gatekeeper puzzles has to be solved on the terminal. The contents of the previous puzzles are applied in this puzzle. One question per puzzle is asked at the terminal which deepens the learning content or transfers what has been learned to glyphosate. For example, players have to evaluate what type of pesticide glyphosate is (section 1) or which type of inhibition applies to glyphosate (section 3). Correctly answering all the questions in the gatekeeper puzzle leads to the next section or –as in the last puzzle– out of the room. After solving each puzzle and riddle the computer terminal automatically prints a summary of Dr. Albas research, so the players can get a hand-out to take with them.

2.3 Possible use scenarios

The escape room game can be used in order to teach the role of the induced fit or the simplified lock and key model in the understanding of enzymes. It is also possible to use this game for an introduction to the scientific principles of glyphosate followed by a discussion about the carcinogenicity of glyphosate and also the way of classifying it. In a more social and sustainable approach this can be followed by discussions on the general use of pesticides in the environment and its consequences. For a more interdisciplinary teaching the game can be accompanied by discussions [11] or experiments [12] about genetic modifications of glyphosate-resistant crops. Furthermore, the escape room game can be used for interesting science outreach activities e. g. at open days or for project-based learning where students built this room at their school by themselves.
The escape room was designed to be very flexible and customizable. For half of the puzzles, alternatives were developed that require less effort or estimate lower costs. The difficulties of the puzzles can be adapted to the group of players through editing Dr. Alba's notes. The two proposed experiments are harmless and do not require a lot of laboratory equipment, but can still be replaced by simpler puzzles in which the results of the experimental procedures are discussed instead of conducting the experiment itself. Since immersion is an important factor for escape rooms [5], various optional interior items and furniture are suggested to decorate the room. Due to the great modifiability of the concept, the escape room game can be used variably under different institutional limitations.

3. Conclusion and outlook

The presented escape room allows an exciting and motivating approach to fundamental ideas of biochemistry, especially concerning the context of enzyme inhibition. As a result of the high flexibility, the game can be used in multiple use scenarios. The linear sequence of the puzzles secures that all players solve the puzzles together and transfer their knowledge to glyphosate in the gatekeeper puzzles. Due to the COVID-19 pandemic, we have not yet been able to examine the game for its learning and motivational effects. It is planned to make the concept freely available on the authors' homepage.

4. References

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