Change the Game with Vaccines: A “Play and Learn” Workshop for Science Education

Daniela Fioretti[1,3], Fabio Chiarello[2,3], Luisa Bracci Laudiero [1,3] and Sandra Iurescia[1,3]
[1]Institute of Translational Pharmacology (IFT), National Research Council (CNR), Rome, Italy
[2]Institute of Photonics and Nanotechnologies (IFN), National Research Council (CNR), Rome, Italy
[3]Rome Technopole

daniela.fioretti@ift.cnr.it
fabio.chiarello@cnr.it
luisa.braccilaudiero@cnr.it
sandra.iurescia@ift.cnr.it

Abstract: Due to the recent Covid-19 pandemic, the concept of genetic vaccination is not new. Genetic vaccines (DNA and RNA-based) are emerging as a new anticancer strategy, based on the same immunological mechanisms underlying vaccines against infectious disease. The development of RNA-based anticancer vaccines is a complex process that involves the use of messenger RNA (mRNA) to provide immune cells with the molecular instructions to produce harmless fragments of cancer-related proteins (antigens). These antigens alert the immune cells, helping them to identify and destroy cancer cells that express these proteins. To engage young students aged 12-18 in understanding the biology and the mechanisms of action of these vaccines, we created “*Vaccines: New Weapons Against Tumors*”, an educational game based on interactive activities. Presented at the Genoa Science Festival 2024, Italy's largest science communication event, it attracted over 1,000 participants. It consisted of an initial training phase that included images, videos, and explanations, followed by a playful activity, employing "interlocking" elements representing mRNA, transfer RNAs and amino acids, and plastic tiles (cards) representing antibodies and antigens. The goal of the workshop was to assemble the molecule that represents the mRNA vaccine, which is then translated into the corresponding protein, according to the rules of the genetic code. That protein serves as cancer antigen against which the immune cells are armed with antibodies to destroy cancer cells. Participants were divided into teams, each playing distinct role: the scientists who design the vaccine, the immune system cells and the cancer cells. The outcomes achieved through the self-report questionnaire indicated that the experience had a positive impact in terms of enjoyment and effectively increased participants' interest in the topics covered by the workshop. This experience highlights the potential of the game-based approach, tailored to STEM concepts, providing an immersive educational experience.

Keywords: Game-Based learning, Science communication, STEM, Genetic code, Transcription, Translation, Vaccines, Immune response, Cancer

1. Introduction

Game-based learning (GBL) has gained popularity in recent years due to its ability to increase student engagement, motivation, and retention of knowledge, as it is an interactive approach to teaching that uses games to provide students with hands-on experience (Vandercruysse et al., 2012; Nesti, 2017).

The use of playful elements aims to foster a powerful and active learning experience, which is beneficial for students as it increase their participation and engagement in the learning process (Pesare et al., 2016). Effective game design combined with the collaborative nature of gameplay can significantly enhance student engagement and skill development in science education (Kalogiannakis et al., 2021). In essence, playful content and gamification are effective tools for enhancing motivation, engagement, and knowledge acquisition across various disciplines including STEM (Sturges et al., 2009; Chiarello et al., 2023; May et al., 2023), highlighting the experiential value of game-based learning.

Bringing science closer to the public, commonly referred to as scientific dissemination, is a fundamental process that promotes scientific culture and encourages the citizens to take an active role in public life.

Science festivals in particular appeal to a variety of audiences by offering them the opportunity to explore numerous scientific topics and activities with just one visit (Durant, 2013).

The recent Covid-19 pandemic has renewed attention to vaccines. The rapid approval of genetic vaccines against Covid-19 (DNA and RNA-based vaccines) has raised many questions about their development, safety and effectiveness. Today, the internet is the primary source of health-related matters for many people, although, unfortunately, not always a reliable one. The infodemic during the pandemic made it hard to find accurate and trustworthy information.

The development of the genetic vaccines for fighting infectious diseases and cancer has actually been an active area of research for about 20 years (Fioretti et al., 2010; Sobhani et al., 2022).

Due to the rapid COVID-19 vaccines development, genetic vaccines, particularly mRNA vaccine, are emerging as a promising new strategy in cancer treatment. These vaccines are based on the same underlying principles as traditional vaccines used against infectious diseases. The development of RNA-based anticancer vaccines is a complex process that involves the use of messenger RNA (mRNA) to provide immune cells with the molecular instructions to produce harmless fragments of cancer-related proteins (antigens). Mutated antigens are displayed only by cancer cells, while most healthy cells show the normal ones. These mutated antigens activate immune cells by triggering them to produce antibodies to attack cancer cells expressing these proteins (Sobhani et al., 2022).

To intrigue young students aged 12-18 and engage them in understanding the mechanisms of action of anticancer mRNA vaccines and how the immune system works, we developed "Vaccines: New Weapons Against Tumors", an educational game based on interactive activities.

The workshop was presented at the Genoa Science Festival 2024, Italy's main science communication event with about 200,000 visitors attending, from October 24th to November 3rd, 2024. The theme of this latest Festival edition was "Challenges", a concept that inspired us to design the workshop on anticancer vaccines, which represent one of the current challenges of medical research. The interactive workshop, suitable for children aged 12-18, was also attended by elementary school pupils and general public (for example families on holidays and weekends), with a total of about 700 participants.

In this paper, we present the workshop and illustrate how we included our scientific educational contents within the game mechanics, allowing players to experience them directly during a fun and playful activity. We also summarize the feedback collected to evaluate scientific engagement, learning and enjoyment of the workshop.

This case study highlights the potential of the game-based approach, tailored to STEM concepts, providing an immersive educational experience.

2. "Vaccines: New Weapons Against Tumors": Description of the Workshop

"Vaccines: new weapons against tumors" is an educational workshop based on interactive activities, designed especially for middle and high schools' pupils but also suitable for adults. Our aim was to illustrate what a vaccine is, how it works, and how it can help in therapies against cancer through a playful and entertaining activity. We envisioned the workshop driven by this challenge.

The workshop lasts about 60 minutes for a maximum of 30 players. During the festival, two facilitators with university education in medicine manage all the activities.

The game simulates the assembly process of an mRNA vaccine molecule, which is then translated, according to the rules of the genetic code, into the corresponding protein. This protein serves as cancer antigen against which the immune cells produce antibodies that target cancer cells for destruction.

In the first phase of the workshop, participants undergo short training to capture audience attention and make scientific arguments more accessible (Figure 1 left and central). By means of images, drawings and video pupils take a journey inside the immune system, learning how healthy cells of our body can become cancerous and how the immune system can recognize and eliminate them. The topic of mRNA vaccines as a therapeutic tool in the fight against cancer is also discussed.

The genetic code language is then introduced, serving as the mission's rules to "build" the mRNA and the corresponding antigen protein. The genetic code uses four nucleotide bases - adenine (A), cytosine (C), guanine (G), and thymine (T) – in various ways to spell out three-letter nucleotide sequences called codons, each of which correspond to a specific amino acid within a protein. In mRNA, T is replaced with uracil (U). The decoding of instructions for making proteins occurs during the translation step, when the mRNA sequence is "read" according to complementary base-pairing rules: the adenine will always pair with uracil and cytosine will always pair with guanine. This process, called translation, results in the formation of a chain of amino acids that folds into a functional protein (Alberts et al., 2024). The translation process requires specialized RNAs called transfer RNAs (tRNAs), which act as "adaptor" molecules by carrying amino acids. One end of the tRNA molecule recognizes codons in the mRNA, while the other end is linked to a specific amino acid. Finally, two slides provide an overview of the phases of the game and present its rules (Figure 1 right).

Figure 1: Two moments of the first phase of the workshop: the training phase (left and central) and, on the right, one slide showing the game rules

2.1 Play the Game!

The workshop was held in an exhibition area by the National Museum of Italian Emigration (MEI). During the game setup, facilitators divide participants into two teams of "scientists" competing to compose the sequence of the mRNA vaccine molecule starting from the mutated DNA sequence belonging to cancer cell (Figure 2a). This mRNA vaccine lead to the synthesis of a protein, representing the mutated antigen peptide expressed by cancer cells. Each team uses the materials provided, including a set of mRNA triplets, and a set of corresponding tRNA triplets with associated amino acids. All these elements were made using Ethylene-vinyl acetate (EVA), a material typically used for yoga mats, and wood (Figure 2b).

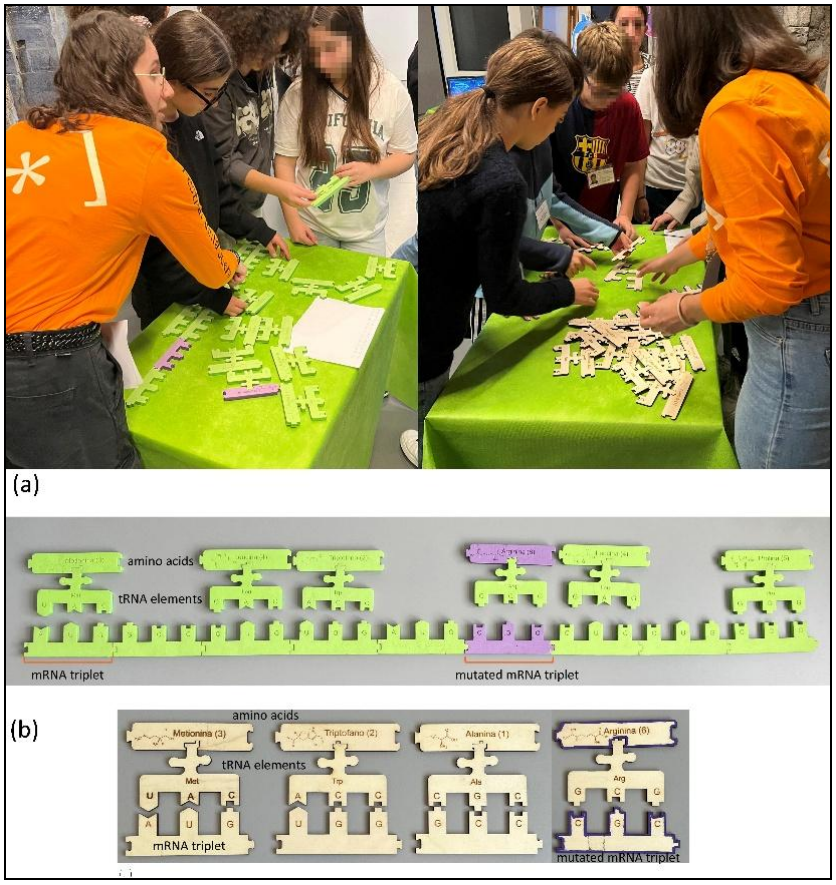

Figure 2: (a) facilitators and participants during the game; (b) the interlocking elements in ethylene-vinyl acetate (EVA) and wood materials

Both EVA and wood were cut using laser cutting-technology, to form RNA triplets with a series of “teeth” that terminate in interlockings, representing the four bases. RNA triplets can be joined together using puzzle-type interlockings to assemble the mRNA vaccine molecule. The tRNA triplets bringing the associated amino acids can be paired with complementary mRNA triplets. This process simulates protein synthesis, specifically the production of cancer antigen peptide. Each amino acid has a corresponding number, and the correct sequence of amino acids must be determined to obtain a numeric code to be used as the combination to open the locks that secure a wooden box (Figure 3).

Figure 3: The box storing the tiles showing the Y-shaped antibody figure, and the bibs showing the antigen shapes

The team that completes this mission first can unlock the box representing the immune system and retrieve the stored antibodies (tiles showing a Y-shaped antibody drawing) produced against the cancer antigen.

Facilitators ask the opposing team to wear small bibs with different shapes on them. These shapes represent protein antigens expressed on body cells surface. Most players show a normal antigen while a few players, representing the “cancer cells”, show a mutated antigen.

The next phase involves an engaging activity consisting of a game of tag. Pupils carrying the antibody tiles move around trying to recognize the “cancer cells” by finding shape that perfectly matches theirs, i.e., matching the antigen shape to the Y-shaped antibody profile.

At the end of the workshop, a short debriefing session is held to summarize the key concepts covered, address any questions, and gather feedback on the impact of the experience.

3. Evaluation of Engagement and Scientific Educational Contents

During the Festival workshops, a real assessment of learning could not take place due to the inability to thoroughly analyze participants' baseline knowledge and learning progress. To verify workshop efficiency as an educational tool and engagement, a written evaluation form, which included a brief anonymous survey, was distributed to the participants at the end of each workshop.

The questionnaire gathered basic information and self-evaluation answers. A total of 700 individuals responded, with an average age of 18.42 years, ranging from 8 to 79 years. Their age distribution is shown in Figure 4a.

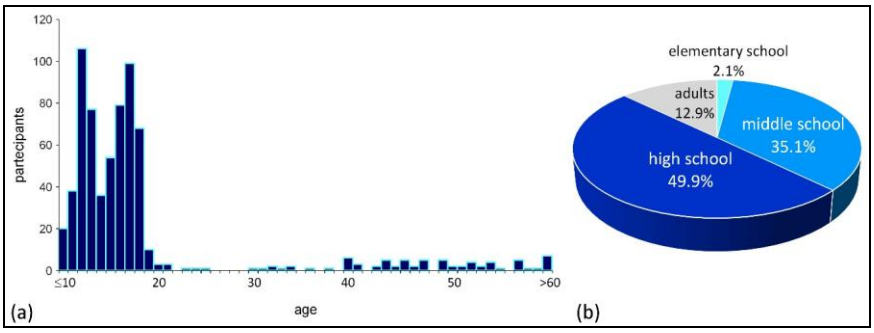

Figure 4: Participant's' age distribution (a) and frequency (b)

The age distribution indicated a considerable number of participants within the school-aged range (10-18 years), showing two notable peaks around ages 12 and 17, which correspond to middle and high school students, the anticipated attendees for the workshop. Nonetheless, the wide age range of participants demonstrated that the workshop had the potential to attract the interest of a broader audience. Figure 4b shows the frequency of participants divided according to their educational level, considering in the adults group a mix of college students, accompanying teachers and member general public.

To investigate how workshop participation affects the raising interest and learning, we asked participants to assign a score on a 4-point numeric scale, ranging from "not at all" to "very much", to the following questions: 1) "How interested were you in these topics before this workshop?; 2) "Has this workshop increased your interest in these topics?"; 3) "How much did you learn from this workshop?". Participants indicated their interest in the workshop topics both before and after the game experience (questions 1 and 2). The number of participants reporting low interest (rate 1 and 2) decreased after the experience (Figure 5b). At the same time, interest rated at level 3 increased significantly, indicating a rise in engagement. Rate 4 interest also saw a slight increase (Figure 5a-b). These results suggest that the workshop successfully boosted participants' interest in the topics covered. Figure 5c presents the perceived learning outcomes based on responses to question 3. Overall, the workshop was effective across all school types, with most participants rating their learning experience between 3 and 4, showing a strong educational impact of the workshop. Participants were also asked to evaluate their experience in terms of entertainment with the question 4) "How much did you enjoy the game?". Enjoyment scores were especially high for game-based activities (Figure 5d). In addition, observation of participants' actions provided a qualitative evaluation of the workshop. Facilitators reported a high level of participant engagement throughout the different phases of the workshop.

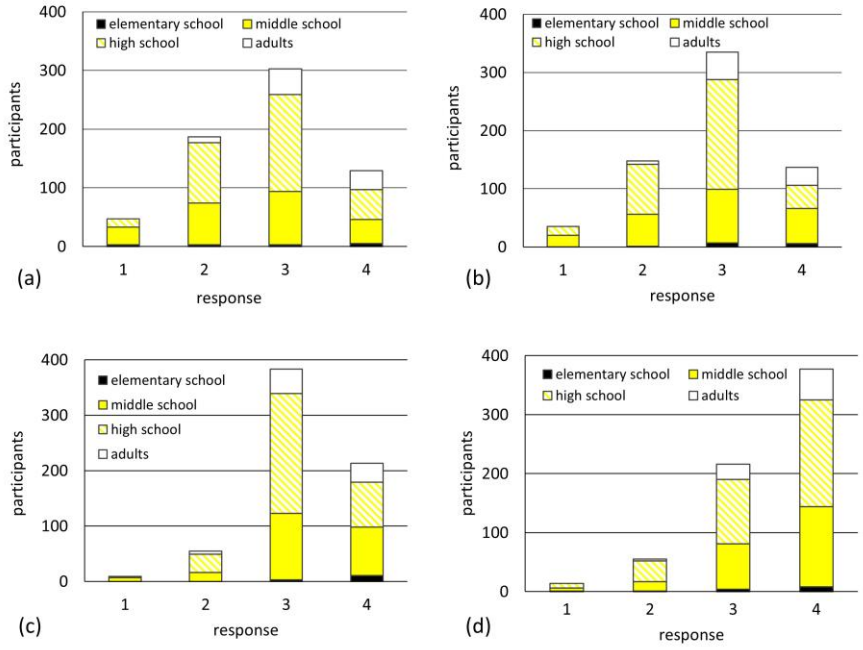

Figure 5: The histograms illustrate the scores obtained from the responses to the self-report test, categorized by different school levels and adult participants

(a) Interest before the workshop, question 1 "How interested were you in these topics before this workshop?"; (b) interest after the workshop, question 2 "Has this workshop increased your interest in these topics?"; (c) perceived learning outcomes, question 3 "How much did you learn from this workshop?"; (d) enjoyment, question 4 "How much did you enjoy the game?". (1 for "not at all", 2 for "not much", 3 for "a lot", 4 for "very much")

4. Conclusions and Discussion

The increasing presence of fake news in the media, especially on social media, poses considerable damage to our society. The web, today, is the place where most people try to orient themselves on health issues. The so-called infodemic has been unleashed during the recent coronavirus pandemic and made it hard to find accurate information. The most effective protection against fake news is continuous education and the development of critical thinking.

Playful content has proven to be an attractive way for science communication through this hands-on motivational approach, that is increasingly being exploited in various fields of application. Game-based learning leverages the interactive nature of games to communicate complex notions accessibly, promoting the dissemination of knowledge based on scientific evidence. It is therefore important that game tasks and mechanics reflect real specific topics to be effectively experienced and to promote active knowledge acquisition in participants.

During the Genoa Science Festival 2024, Italy's main science communication event, we presented "Vaccines: New Weapons Against Tumors", an educational workshop based on interactive activities. The workshop, suitable for teens aged 12 – 18, was also attended by elementary school pupils and adults, with a total of about 700 participants. We envisioned the workshop as a playful activity to engage young students to figure out how the immune system works and the mechanisms of action of vaccines, particularly anticancer mRNA vaccines. The main goal of the workshop was to let the scientific concepts be extrapolated autonomously and directly from the game itself.

For this reason, we investigated how players may perceive the scientific contents we embedded in the game mechanics. The data gathered through a questionnaire administered after each workshop suggested that the hands-on approach was well-received by participants and fostered understanding of scientific topics.

In addition, the data indicated that the experience had a positive impact on participants also in terms of interest and enjoyment. In particular, we want to underline the importance of having evaluated the workshop with targets of different ages and educational backgrounds.

The workshop combined scientific content with an engaging game structure, trying to offer participants an immersive learning experience. The hands-on activity fostered teamwork among participants by requiring them to collaborate on solving problems, while the tag game promoted active motor learning through physical engagement. All materials, including multimedia and jigsaw puzzle-like models, tiles and small bibs, helped to visualize difficult scientific concepts, thus significantly contributing to the appreciation of the game-based experience by the participants. This positive impact was also noted by the accompanying teachers. The comments in the survey also reported that facilitators were perceived as skilled and trustworthy. Overall, the features of the game-based activity likely have contributed to make the scientific notions linked to the game-based experience easier to remember.

Furthermore, the museum exhibition's open design encouraged interaction and collaboration. Indeed, a well-organized and visually appealing space facilitated visitors' experience and positively impacted visitors' focus.This case study thus highlights the potential of the game-based approach tailored to STEM concepts, with the wider objective to bring science closer to the citizen, especially to young people. However, to assess the workshop efficiency as an educational tool for game-based learning activities, we are planning to share the game feedback with the dissemination network of CNR researchers to develop an education project for middle and high school in Italy.

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AI Declaration: AI-based tools were used for language correction during the preparation of this manuscript.

References

Alberts, B. et al. (2024) Biologia molecolare della cellula, settima edizione.

Chiarello, F. et al. (2023) 'The Language of Life: A Game-Based Workshop for Introducing Protein Biosynthesis'. 17th European Conference on Game-based Learning, Enschede Netherlands: Academic Conferences International Limited Reading, UK, 102-107.

Durant, J. (2013) 'The role of science festivals', Proceedings of the National Academy of Sciences, 110(8), pp. 2681-2681.

Fioretti, D. et al. (2010) 'DNA vaccines: developing new strategies against cancer', J Biomed Biotechnol, 2010, pp. 174378.

Kalogiannakis, M. et al. (2021) 'Gamification in Science Education. A Systematic Review of the Literature', Education Sciences, 11(1), pp. 22.

May, J. E. et al. (2023) 'Gamification in Biomedical Science Education: The Successful Implementation of Resimion, a Scenario-Based Learning Tool', Br J Biomed Sci, 80, pp. 11756.

Nesti, R. (2017) Game-Based Learning: gioco e progettazione ludica in educazione.

Pesare, E. et al. (2016) 'Game-based learning and Gamification to promote engagement and motivation in medical learning contexts', Smart Learning Environments, 3(1), pp. 5.

Sobhani, N. et al. (2022) 'Therapeutic cancer vaccines: From biological mechanisms and engineering to ongoing clinical trials', Cancer Treat Rev, 109, pp. 102429.

Sturges, D. et al. (2009) 'Understanding protein synthesis: a role-play approach in large undergraduate human anatomy and physiology classes', Advances in Physiology Education, 33(2), pp. 103-110.

Vandercruysse, S. et al. (2012) 'Game-Based Learning: A Review on the Effectiveness of Educational Games', in Cruz-Cunha, M.M. (ed.) Handbook of Research on Serious Games as Educational, Business and Research Tools. Hershey, PA, USA: IGI Global, pp. 628-647.