# The Language of Life: A Game-Based Workshop for Introducing Protein Biosynthesis

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**Abstract:** Protein biosynthesis is a complex process that involves the transcription of DNA into mRNA and the subsequent translation of mRNA into proteins according to the genetic code. To introduce this fundamental process to a broad audience, we developed "The Language of Life", a game-based workshop that was presented at the Genoa Science Festival 2022, the largest science communication event in Italy. The game-based workshop employed jigsaw puzzle-like elements to represent DNA, mRNA, and aminoacyl transfer RNAs, enabling participants to pair them through codon combinations. The game-based workshop lasted for an hour and the framing was a "special mission" inside a cell. It consisted of an initial training phase that incorporated videos, models, and explanations, followed by practical "missions'' in which participants reproduce transcription and translation mechanisms by moving inside the cell and using the provided materials. The workshop was attended by 1,505 participants, primarily students aged 6-18, and received positive feedback. In this paper, we present our experience conducting this workshop and discuss its impact and potential for future use.

**Keywords:** Game-based learning, Genetic code, DNA, mRNA, protein, Transcription, Translation, Protein biosynthesis

## 1. Introduction

Motivation and participation are crucial elements of the learning process (Nesti 2017). Motivation refers to the drive or desire to engage in a particular activity or behavior, while participation involves actively contributing to the learning process, such as asking questions, participating in discussions, and engaging in hands-on activities. When students are motivated and actively participate in the learning process, they are more likely to achieve their learning goals.

Games can be a powerful tool for promoting motivation and engagement in learning activities (Nesti 2017, Yoon 2014, Whitton 2012, Annetta 2009). Games can provide a more collaborative and engaging classroom experience, especially for students struggling to stay focused. By incorporating gaming activities into education, instructors can mitigate learning anxiety while promoting student motivation to learn (Dorfner 2021).

Game-based learning has proven effective in STEM education. A few meta-analyses have been conducted, showing that digital games are a promising pedagogical method in STEM education (Wang 2022, Vu 2017). These studies have found that game-based learning has positive effects on cognition, motivation, and behavior (Arztmann 2023). However, further research is necessary to better understand when game-based learning is an appropriate approach and when it is not (Gao 2020).

While digital games hold promises and are increasingly popular tools, physical games have been shown to be effective in game-based educational programs (Bilancini 2023, Di Paolo 2023). We believe that more practical and playful activities can have a positive impact as well on STEM education (Sturges 2009, Chiarello 2016). Therefore, we conducted a survey during a workshop where game-based activities with jigsaw puzzle-like models were proposed to students with the purpose to engage students, fostering their interest, and imparting essential knowledge about DNA coding and protein biosynthesis.

The workshop was developed for the Genoa Science Festival 2022 (from October 20th to November 1st), which is the main Italian science communication festival, attracting about 200,000 visitors. The theme of this latest edition, “Languages”, inspired the title of this workshop, “The language of life”, and its main objective: to explain the protein biosynthesis process and the specific “language” involved, the genetic code, with a game-based learning approach. The workshop was designed to engage people of different ages, particularly primary, middle, and high school students, but also to accommodate the participation of older adults and parents with children.

## 2. "The Language of Life: Introducing Protein Biosynthesis"

DNA, or deoxyribonucleic acid, is a long molecule that, like a recipe book, contains the instructions (the *genetic code*) for making a specific protein in a cell. 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 corresponds to a specific amino acid within a protein.

The protein biosynthesis process is how the cell converts genetic information contained in the DNA sequence (genes) into proteins. This multilayered process consists of two major steps. First, the genetic information is transferred to a *messenger RNA* (mRNA) through a process called *transcription*, where the DNA serves as a template for complementary base-pairing to generate a single-stranded copy of the gene. Then, the decoding of instructions for making proteins occurs during the *translation* step. The mRNA sequence is "read" according to the genetic code to assemble the chain of amino acids that form a protein (Alberts 2002). This process requires specialized RNAs called transport RNAs (tRNAs), which act as adaptor molecules between the mRNA and the protein. They have one end that can "read" the triplet code in the mRNA through complementary base-pairing and another that brings a specific amino acid.

## 3. "The Language of Life" Workshop

The workshop lasts one hour and is primarily designed for a single class (20-30 participants). However, it can also be adapted for a smaller number of players. The workshop is presented as a "mission" with the goal of helping a cell produce a protein, which in turn unlocks a series of locks. Various materials are used to support the activity, including four sets of genetic code elements: two complementary DNA long strips (coding and template DNAs), a series of messenger-RNA triplets (mRNA), and a series of similar triplets of transfer-RNA (tRNA) with associated amino acids (fig.1).

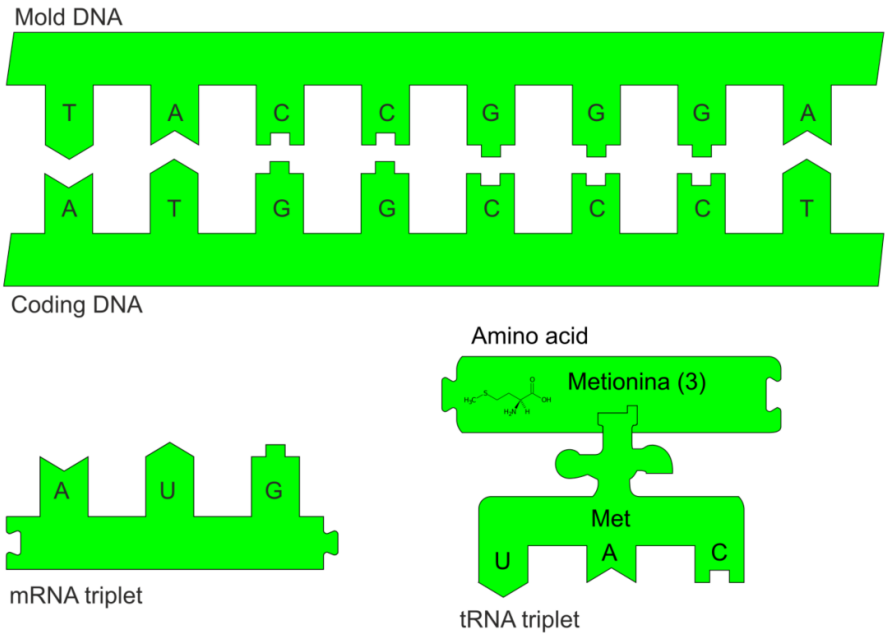


**Figure 1: Scheme of the DNA and RNA elements: Template and Coding DNA strips (top), the mRNA triplet (left-bottom), and the tRNA triplet with its associated amino acid (right-bottom)**

All these genetic code elements are created using Ethylene-vinyl acetate (EVA), which is a typical material for yoga mats. The EVA is cut into one-centimeter sheets using laser cutting technology, forming "backbones" with a series of "teeth" that terminate in interlockings, representing the four bases that can be coupled with complementary elements. Specifically, C is paired with G and A is paired with T or U (fig.1). The DNA consists of two long strips, while RNA triplets are separated and can be joined together using puzzle-type interlockings. Additionally, there are also four small wooden boxes that are closed by combination locks. The correct sequence of amino acids forming the protein must be determined to unlock the boxes (fig.2).

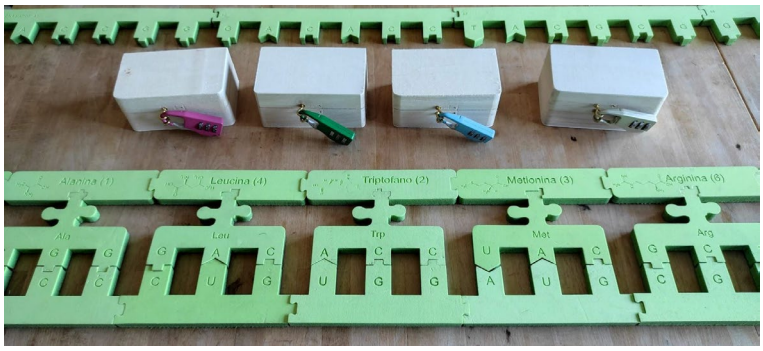


**Figure 2: Photograph of DNA strips (top), boxes with locks (middle), and mRNA and tRNA triplets with their corresponding amino acids joined together (bottom)**

In the first phase of the workshop, players are given training for their mission through a presentation and a series of videos (fig.3). Next, the first group is tasked with the "transcription" phase. They enter a designated "nucleus" zone in the room, separate the two DNA strips, and couple the complementary triplets of mRNA with the template DNA strip, thereby composing a copy of the DNA coding sequence. The composed strip of mRNA is then taken out of the nucleus zone and given to the second group of participants for the "translation" phase. The triplets of tRNA are paired with the complementary mRNA elements, and through this process, the single amino acids associated with the tRNA triplets are joined together to form the protein. Each amino acid has a corresponding number, and the correct order of these numbers is used as the combination required to open the locks, ultimately leading to the completion of the mission.

**Figure 3: A moment of the workshop, during the training phase**

After completing the workshop, there is a short debriefing session to summarize and reinforce the learned concepts, answer questions, and gather feedback on the impact of the experience. Two facilitators with university education in biology manage all of these activities.

During the Festival, there were approximately 70 workshops, and a total of 1,505 participants attended. Due to the fast-paced nature of the event and the large number of participants, it was challenging to conduct a comprehensive evaluation of the impact of the workshop in terms of raising awareness and promoting learning. Collecting accurate feedback data, conducting an analysis of the initial conditions, or ensuring long-term follow-up with participants proved to be practically impossible. Therefore, we conducted a short anonymous survey that only required basic information and a few self-evaluation questions. 1,045 responded to the survey. The gender distribution was 52.6% female, 43.0% male, and 4.4% not indicated. The main age was 16.8. Their age distribution is shown in fig.4.

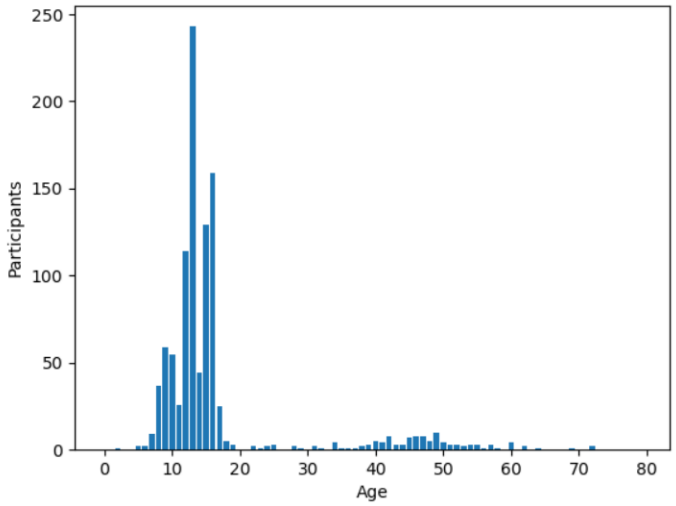


**Figure 4: Age distribution of participants**

The age distribution shows a significant peak in the range of school-aged children (6-18 years), which is likely related to the large number of visiting schools. There is also a smaller peak around 45 years, likely due to accompanying teachers. The main peak has three smaller sub-peaks around 9, 13 and 16 years, which may be linked to the time when students are studying genetics and related topics in their school curriculum. To evaluate the impact of the workshop, participants were asked to rate their experience on a 1-4 linear numeric scale (1 for "not at all", 2 for "not much", 3 for "a lot", 4 for "very much") on three main questions concerning interest raising ("Do you think your interest in these topics has grown thanks to this workshop?"), learning ("How much do you think you learned from this workshop?"), and appreciation ("Did you like this workshop?"). The summarized answers to these three questions are shown in fig.5, with a breakdown into four age groups: (A: 5-10 years, B: 11-13 years, C: 14-20 years, D: >20 years).

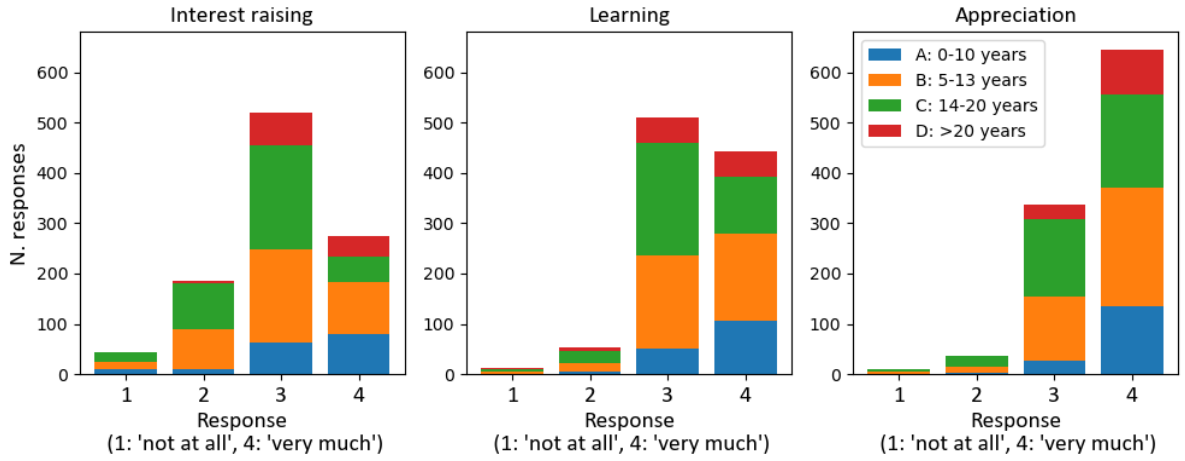


**Figure 5: Histograms of the responses (disaggregated for age group) to the self-evaluation questions: "Do you think your interest in these topics has grown thanks to this workshop?" (left), "How much do you think you learned from this workshop?" (center), "Did you like this workshop?" (right)**

In Table 1, we provide the mean values of the responses to the three questions, classified by distinct age groups. The results demonstrate a relatively balanced distribution for all three questions. Specifically, group B shows responses close to the overall average, while group C exhibits slightly lower scores, and groups A and D display slightly higher scores compared to the average.

**Table 1: Mean values of the response to the self-evaluation questions for different age groups**

| | Interest raising | Learning | Appreciation |
|---|---|---|---|
| A: 5-10 years | 3.31 | 3.60 | 3.78 |
| B: 11-13 years | 2.98 | 3.38 | 3.57 |
| C: 14-20 years | 2.78 | 3.21 | 3.42 |
| D: >20 years | 3.32 | 3.36 | 3.73 |
| Overall | 3.00 | 3.36 | 3.57 |

The results appear highly promising and suggest the effectiveness of this approach. However, further comprehensive studies are needed.

## 4. Conclusions

Game-based workshops can be a highly effective form of game-based learning, particularly suitable for younger students. Using games to teach and reinforce key concepts and skills can create a more engaging and memorable learning experience. Games can also provide a safe and low-risk environment for participants to experiment, try new things, and make mistakes without fear of failure. Moreover, games can be tailored to individual participants' abilities and preferences, providing a more personalized and effective learning experience. Ultimately, the use of game-based workshops can lead to improved knowledge retention, better collaboration and communication among participants, and improved performance outcomes. Therefore, organizations looking to enhance their training and development efforts may benefit from incorporating game-based workshops into their learning programs.

During the Genoa Science Festival 2022, we conducted a game-based workshop where 1,505 participants, primarily students aged 6-18, practically experienced DNA coding by combining jigsaw puzzle-like models. The data collected through questionnaires administered at the end of the workshop indicates that the experience had a positive impact on the participants, in terms of increased interest, understanding, and appreciation. However, further studies with an experimental design in a more controlled setting are needed to confirm the efficacy of game-based workshops as a useful tool for STEM education.

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