



## Dancing with DNA: A Gamified Learning Approach for Enhanced Educational Experience

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### Abstract

*Among all the sciences, biology holds a unique place: it is the science of life itself, the key to understanding who we are and the ecosystems we depend on. Yet despite its relevance, biology is often perceived as difficult and abstract, confined to laboratories or textbooks. Making it accessible, engaging, and compelling is therefore one of the most pressing challenges of modern science communication. The ability to communicate science effectively while balancing accuracy and creativity has become increasingly essential. Several educational approaches can be used to spark students' interest in STEM disciplines. In particular, gamification can be a valuable learning tool to support pupils in studying biological sciences while having fun. In this work, we present the educational activity "Dancing with DNA" (original title "La Danza del DNA"), designed for primary and middle school pupils (8-12 years old), to introduce fundamental biological topics such as the cell cycle and DNA replication. The activity was tested in both formal educational settings (primary and middle schools) and informal educational environments (open-access events). This paper reports on the experience conducted during the Genoa Science Festival 2025, Italy's largest science communication event. The workshop consisted of an initial training phase including images, videos, and 2D and 3D models. Pupils were then engaged in a practical and playful activity aimed at illustrating the mechanisms of DNA duplication and cell division. Each participant acted as a nucleotide of the DNA molecule (adenine, thymine, cytosine, or guanine, A-T-G-C) or as one of the proteins involved in the biological process; working together, they simulated DNA replication by applying the rules of complementary base pairing (A::T, C::G). The feedback collected to evaluate scientific engagement, self-perceived learning, and enjoyment suggests that the activity supported perceived learning and was well appreciated by students, regardless of their initial familiarity with DNA. Teachers' evaluations were also highly positive, with the practical component emerging as the main driver of satisfaction. This case study strengthens the potential of a gamification-based approach and supports the integration of gamified learning into science education and communication strategies.*

**Keywords:** gamification; science communication; biology; DNA

### 1. Introduction

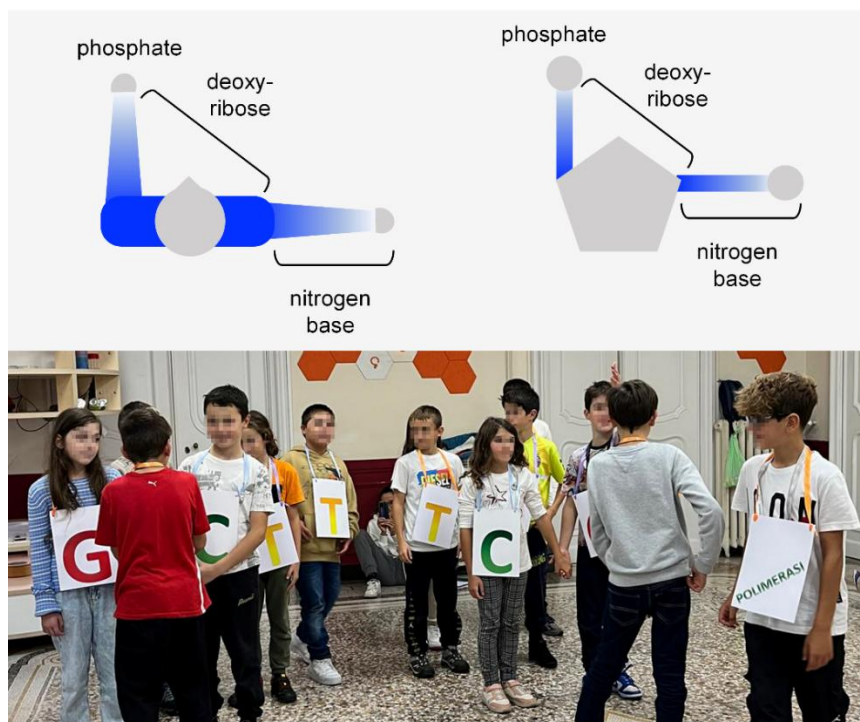
Gamification, defined as the integration of game-design elements in non-game contexts [1], is an emerging paradigm attracting significant attention for its innovative potential. In teaching and educational contexts, gamification leverages "game-based mechanisms, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems" [2]. At its heart, gamification operates on the principle that the motivational strength of game elements can be effectively transposed into educational settings. This method does more than make learning fun: it creates a safe environment for trial and error, encouraging students to experiment without fear of failure while transforming the learning process into an engaging and rewarding experience [3]. Indeed, gamification aims to boost intrinsic motivators, such as enjoyment and enthusiasm, to promote learning [4]. Therefore, gamification's role is to "affect psychological factors that mediate the learning outcomes" [5]. STEM education is a pivotal component of modern education, as it fosters active and responsible citizenship while highlighting the importance of science for young women and helping to bridge the gender gap. In this context, a primary objective of modern science communication is to ensure that biological knowledge remains accessible, intelligible, and engaging, a goal that increasingly requires balancing scientific accuracy with creative efficacy. The integration of gamification as a learning tool offers a valuable way to support young pupils in studying biological sciences through an enjoyable and interactive approach. By integrating game mechanics into science lessons, gamification can help overcome traditional educational barriers, boost students' motivation and enjoyment, and enhance



cognitive and metacognitive performance [6]. Although biology is the fundamental science of life, it is frequently perceived as complex and challenging; many students find it difficult to visualise and conceptualise core biological mechanisms, such as cell division and DNA replication. To address this challenge and facilitate a deeper understanding of their three-dimensional nature, we developed a kinaesthetic educational activity entitled "Dancing with DNA". The workshop was tested in both formal educational settings (primary and lower secondary schools) and informal educational environments (open-access events). This paper reports on the experience conducted during the Genoa Science Festival 2025, Italy's largest science communication event, which attracted more than 200,000 visitors from October 23rd to November 2nd, 2025. Inspired by "Weaves" (original title in Italian: "Intrecci"), the theme of this Festival edition, we presented our workshop "Dancing with DNA" [7]. Assessments of scientific engagement, self-perceived learning, and overall enjoyment suggest that the activity fostered perceived learning. Furthermore, the experience was met with great enthusiasm by students across both primary and lower secondary school levels. Teachers' evaluations were also highly positive, with the practical component emerging as the main driver of satisfaction. This case study underscores the potential of gamified approaches and contributes to the growing body of evidence supporting active and engaging learning strategies, thereby advocating for the integration of gamified learning into science education and communication strategies.

## 2. Dancing with DNA: Inside the Mechanics of the Gamified Learning Format

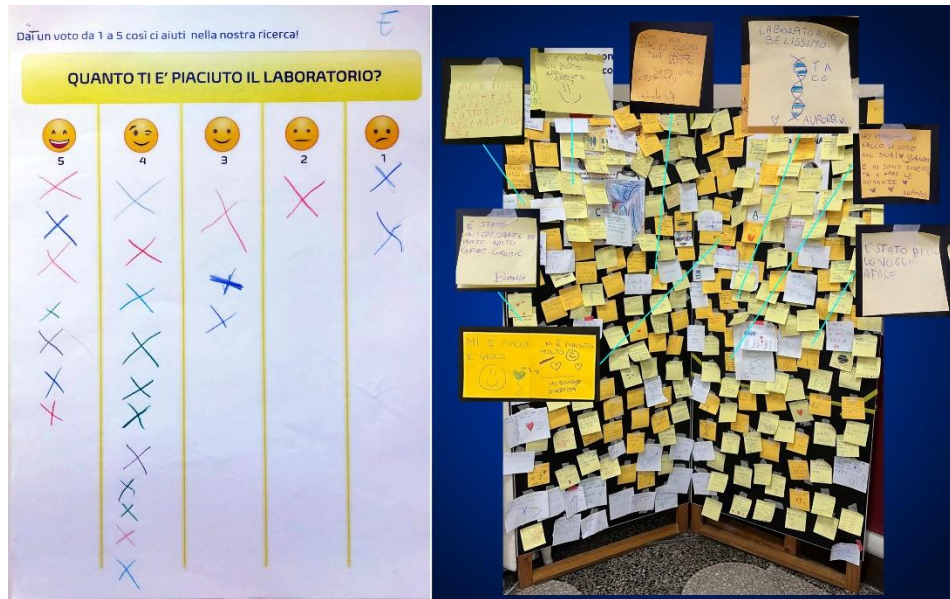
The DNA molecule - the foundation of life as we know it and the blueprint of every living being - engages in a true dance every time it replicates, as two strands intertwine in space to weave a new double helix [8]. "Dancing with DNA" is an active learning exercise that focuses on DNA replication and cell division and is designed especially for primary and middle school pupils (8-12 years old). Our aim was to allow participants themselves to become the DNA molecule, physically moving their bodies through the core stages of cellular life. This kinaesthetic role-playing format can be used to visualise how nucleotides link up, how base pairs form, and how the replication process gives rise to two new DNA molecules belonging to the two daughter cells. The workshop lasts about 45 minutes and can involve up to 60 participants. It was held in a large hall within the School of Robotics building in Genoa, which provided an appropriate setting for the game dynamics. During the Science Festival, two facilitators with university-level training in biology managed all activities for each scheduled session. Before the Festival began, we met with the facilitators to share the key workshop information and suggestions for adapting the playful component to different classroom contexts. The workshop starts with a training session designed to capture the audience's attention and make the scientific content accessible to everyone. Using visual storytelling - including drawings, videos, and real-world examples - participants journey inside the cell to explore how cells divide, why duplication is necessary, and how DNA duplicates itself to produce two identical molecules ready for the newly formed cells. Once the training session is completed, each participant receives a colour-coded tile representing one of the four nucleotides, transforming complex molecules into tangible building blocks and the four chemical bases into a physical game of DNA assembly. Half of the participants are asked to align themselves as a small region of a DNA molecule, simulating its ladder-like shape. They are told to form two parallel lines, using one hand to simulate the bond between the nitrogenous bases (base pairing) and the other to simulate the 3' hydroxyl bond. In this way, each participant places one hand on the shoulder of the child in front of them and joins the other hand to the child next to them in the parallel line (Fig. 1 upper panel). In addition to nucleotides, some volunteers play special roles as part of the molecular machinery (the enzymes) that coordinates the process: helicase ("the unzipper"), which separates the parental double-stranded molecule by breaking the hydrogen bonds between nucleotides; polymerase ("the builder"), which brings free nucleotides to their correct partners to form the complementary DNA strands; and ligase ("the gluer"), which forms the new bonds between nucleotides. The experience then evolves into a living DNA model, with each participant playing the role of a specific nucleotide or protein (Fig. 1 lower panel). By stepping into the role of the molecule itself, pupils can visualise how nucleotides link up and how base pairs form. The crucial task is to keep the base-pairing rules in mind: A always pairs with T, and C always pairs with G. To keep the simulation realistic, participants also have to respect a vital balance between speed and accuracy. Just like the enzymes in our cells, they have to work quickly while maintaining focus, because a single pairing error can lead to a DNA mutation. To set the beat for this hands-on phase, we chose Queen's "We Will Rock You", using its iconic rhythm to turn the simulation of DNA replication into an engaging, choreographed dance. Once the mission is accomplished, participants are invited to look around: the original DNA molecule has successfully replicated, resulting in two identical DNA helices ready for the next generation of cells.



**Fig. 1.** Upper panel: in this representation, the body/head corresponds to the deoxyribose sugar; the arm extended horizontally to the right (in this case) is the nitrogenous base, which pairs with that of a complementary "nucleotide student" within the complete double helix; the arm extended forwards corresponds to the phosphate backbone. Lower panel: representative image of students participating in the workshop.

### 3. Assessment of the Impact of the Workshop

Approximately 1,000 individuals attended the workshop during the festival. Due to the large number of participants and the rapid succession of sessions, conducting a robust assessment of impact, objective learning outcomes, and long-term follow-up proved challenging. After each session, both students and teachers were invited to provide feedback on their overall experience with the educational activity through anonymous questionnaires. Students' learning outcomes should be interpreted as indicative and self-reported, due to self-selection bias and the inability to establish participants' baseline knowledge before the workshop. To ensure accessibility and ease of understanding for young primary and middle school pupils, a five-point Likert scale (1 to 5) accompanied by facial-expression icons was used to represent varying degrees of understanding and satisfaction (Fig. 2 left panel). This visual support facilitated engagement and interpretation, ensuring that the questionnaire was age-appropriate and effective for data collection. The questionnaire included three items: Q1, "Before this workshop, how much did you know about DNA?" (prior DNA knowledge); Q2, "How much do you think you learned from this workshop?" (perceived learning from the workshop); and Q3, "How much did you enjoy the workshop?" (workshop enjoyment). These items helped differentiate baseline familiarity from perceived learning gain and emotional involvement. Students were invited to tick the column featuring the emoji that best represented their level of knowledge, learning, and enjoyment; these responses were collected cumulatively across three large-format sheets, each dedicated to one of the three categories. As an interactive and engaging way to gather feedback on the hands-on activity, young participants were also invited to leave a comment or drawing using post-its and coloured pencils, sticking them onto a designated panel (Fig. 2 right panel). In addition, facilitators conducted a qualitative assessment by observing participants' behaviour and noting high levels of engagement throughout the workshops.

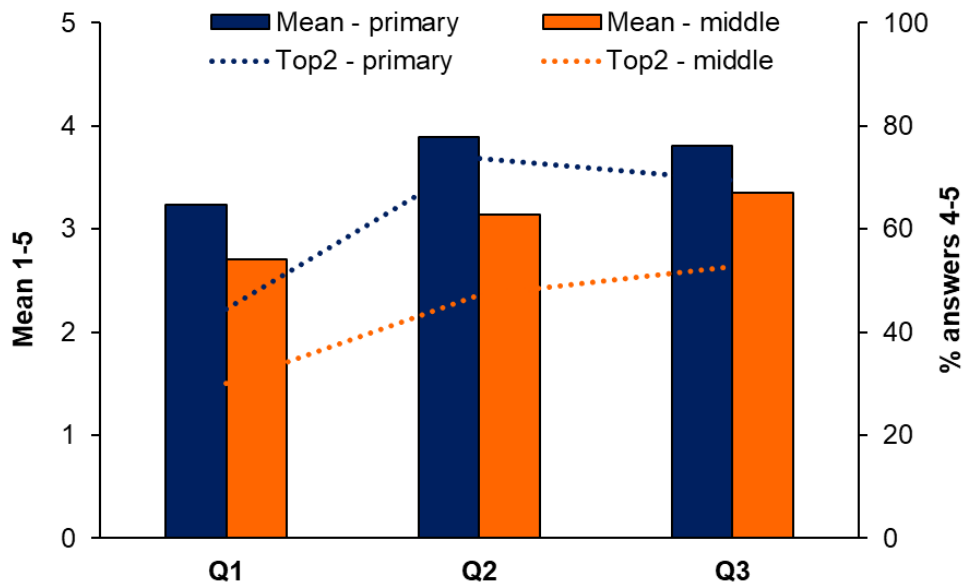


**Fig. 2.** On the left: example of a children's questionnaire using emojis. On the right: display board showing sticky notes with feedback or drawings created by the children.

In the primary school cohort, Q1 yielded a mean score of 3.23/5 (Table 1 and Fig. 3). High ratings (4-5) accounted for 44.44% of responses, while low ratings (1-2) represented 31.17%. For perceived learning (Q2), the primary school cohort recorded a mean score of 3.89/5. The share of high ratings reached 73.61%, indicating a strong perception of learning after the activity. Workshop appreciation was also high: Q3 yielded a mean score of 3.81/5, with 69.35% of responses in the top two categories. In the middle school cohort (Table 1 and Fig. 3), baseline knowledge (Q1) was lower overall, with a mean score of 2.70/5. Only 30.06% of responses fell in the 4-5 range, while 50.92% were in the 1-2 range. Perceived learning (Q2) nevertheless remained positive: high ratings represented 47.21% of responses, suggesting that the workshop was considered educationally valuable even among older students. Appreciation of the workshop was likewise favourable, as Q3 yielded 52.68% of high ratings.

Question	Primary school				Middle school				Mean Difference
	N	Mean +/- SD	4-5%	1-2%	N	Mean +/- SD	4-5%	1-2%	
Q1. Prior topic knowledge	369	3.23 +/- 1.37	44.4	31.2	489	2.70 +/- 1.45	30.1	50.9	0.53
Q2. Perceived learning	288	3.89 +/- 1.27	73.6	14.6	430	3.14 +/- 1.53	47.2	35.6	0.75
Q3. Enjoyment of the workshop	447	3.81 +/- 1.37	69.4	20.1	429	3.35 +/- 1.51	52.7	30.1	0.47

**Table 1.** Summary comparison of questionnaire responses between primary and middle school students. N = total number of student respondents. Values in the mean columns are reported as mean +/- SD.

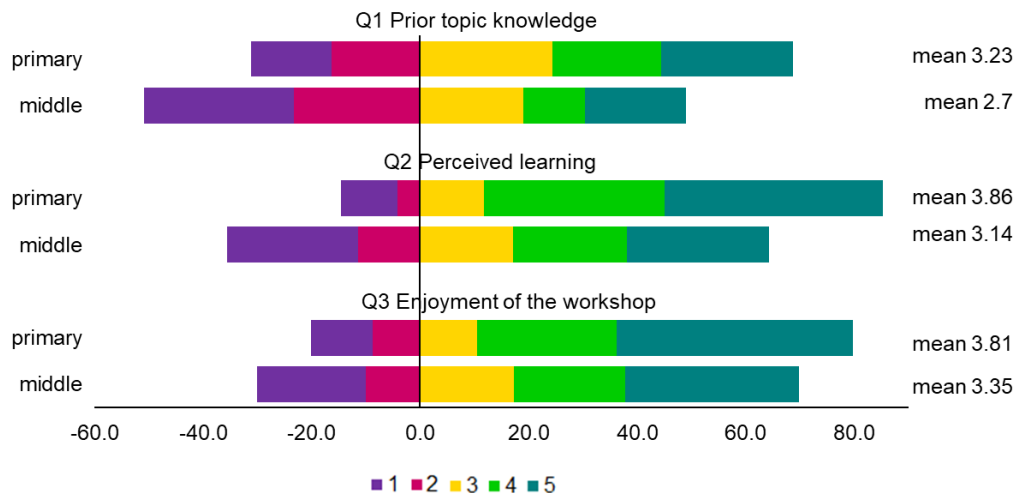


**Fig. 3.** Comparative overview of primary and middle school responses: mean scores and percentage of high ratings (4-5). Q1 = "Before this workshop, how much did you know about DNA?"; Q2 = "How much do you think you learned from this workshop?"; Q3 = "How much did you enjoy the workshop?".

Primary school pupils' scores were higher than middle school students' scores in all areas (Table 2 and Fig. 4). All differences were statistically significant ( $p < 0.001$ ). The largest gap was observed for perceived learning (Hedges'  $g = 0.53$ ), followed by initial knowledge and enjoyment. Comparing the mean values of Q1 and Q2 showed an average perceived gain of +0.66 points for primary school pupils and +0.44 points for middle school pupils. Thus, the workshop appeared to encourage perceived learning in both groups; however, it was perceived as more effective among primary school pupils, considering the greater variability observed among older participants.

Question	Chi-square p	Cramer's V	Top-2 p	Hedges' g
Q1. Prior topic knowledge	<0.001	0.207	<0.001	0.37
Q2. Perceived learning	<0.001	0.27	<0.001	0.525
Q3. Enjoyment of the workshop	<0.001	0.179	<0.001	0.324

**Table 2.** Statistical evidence for the comparison between school levels. Chi-square p and Top-2 p refer to between-group comparisons. Cramer's V quantifies the strength of distributional differences; Hedges' g quantifies the standardized mean difference.





**Fig. 4.** Diverging stacked bar charts comparing the distribution of questionnaire responses between primary and middle school pupils for the three items: prior topic knowledge (Q1), perceived learning (Q2), and enjoyment of the workshop (Q3). Mean scores are reported for each group.

It is worth noting that participants' baseline knowledge levels differed (Table 1; Q1). Primary school pupils showed greater familiarity with the workshop topic, whereas middle school students generally rated their knowledge as lower. This may indicate a more rigorous self-assessment among older participants. Despite this, in both cohorts Q1 produced lower means than Q2 and Q3, suggesting that the workshop focused on a subject with which many participants were initially less familiar. Nonetheless, they still reported substantial perceived learning and enjoyment after the experience (Fig. 4).

Each teacher filled out an individual questionnaire to assess the game from an instructional standpoint (N = 66 primary school teachers; N = 87 middle school teachers). Feedback was also obtained via a 5-point Likert scale, enabling structured and systematic collection of expert evaluations. The questionnaire included four core questions assessing teachers' evaluation of the workshop in terms of overall satisfaction, contribution to the development of interest in science, and support for understanding the scientific topics proposed to young participants. Teachers were additionally invited to indicate what worked in the workshop in terms of content, methodologies, and communication methods, and to respond to an open-ended question about other relevant aspects from their perspective. This design facilitated the collection of both quantitative and qualitative data, thereby supporting a more comprehensive evaluation of the programme's feasibility and of the influence of the game on the development of essential competencies.

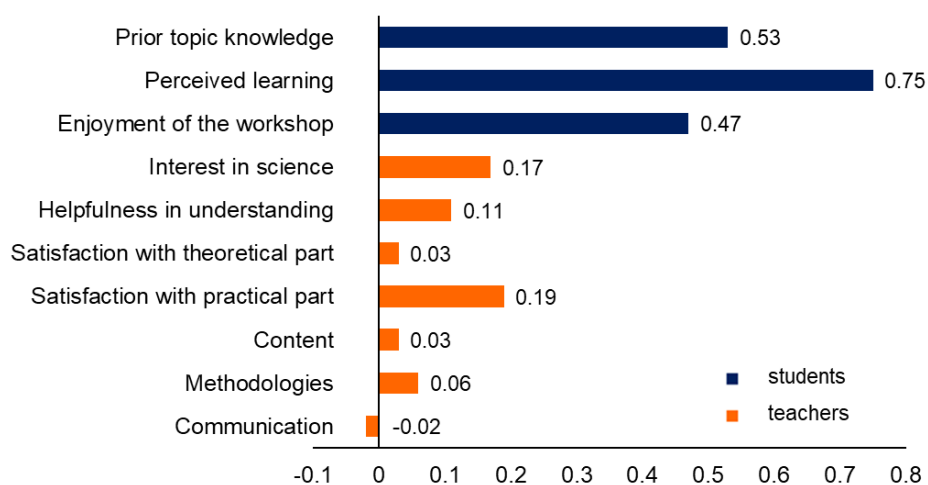
The teachers' questionnaire data (Table 3) indicate an overall positive evaluation of the workshop across both school levels. The most favourable ratings concerned the perceived educational value of the workshop for understanding the DNA replication process, together with the practical component, indicating that the hands-on format was the most appreciated element. Primary school teachers gave a mean score of 4.05 for interest in science, 4.11 for perceived support in understanding DNA, and 4.18 for satisfaction with the practical part. Among middle school teachers, the corresponding means were 3.87 for interest in science, 4.00 for support in understanding DNA, and 3.99 for the practical part. Between-group differences between primary and middle school teachers were assessed using Welch's t-tests, with Hedges' g reported as a measure of standardized mean difference (Table 3). Overall, differences between the two teacher cohorts were small, suggesting that the workshop was perceived positively and broadly consistently across both educational levels.

Indicator	Primary school		Middle school		Mean Difference	Hedges' g	Welch's p
	Mean±SD	% 4-5	Mean±SD	% 4-5			
Interest in science	4.05±0.90	74.2%	3.87±0.71	70.1%	0.17	0.21	0.204
Helpfulness in understanding	4.11±0.83	80.3%	4.00±0.72	74.7%	0.11	0.14	0.406
Satisfaction with theoretical part	3.76±0.86	57.6%	3.72±0.82	60.9%	0.03	0.04	0.808
Satisfaction with practical part	4.18±0.88	75.8%	3.99±0.86	77.0%	0.19	0.22	0.174
What worked: content	3.85±0.81	65.2%	3.82±0.76	70.1%	0.03	0.04	0.801
What worked: methodologies	4.00±0.93	72.7%	3.94±0.87	72.4%	0.06	0.06	n.a.
What worked: communication style	3.97±0.93	68.2%	3.99±0.75	75.9%	-0.02	-0.02	0.893

**Table 3.** Teachers' evaluation of the workshop by school level. Values are reported as mean +/- SD, percentage of ratings 4-5, percentage of maximum ratings, mean difference, Hedges' g, and Welch's p-value. Welch's p-values refer to between-group comparisons between primary and middle school teachers. n.a. = not available



Within each teacher cohort, ratings for the practical component were significantly higher than ratings for the theoretical component (Wilcoxon signed-rank test: primary schools,  $p < 0.001$ ; middle schools,  $p = 0.005$ ). This supports the interpretation that the workshop was judged most effective when scientific explanation was embedded in an interactive, hands-on activity. The items referring to what worked in the workshop also showed favourable ratings, particularly for methodology and communication style, which were close to 4 in both groups. Qualitative feedback from the open-ended questions highlighted play, hands-on engagement, and physical movement as the most valued elements of the workshop. Teachers emphasised the importance of active involvement and experiential learning, suggesting that these components enhanced both comprehension and retention of the scientific concepts presented. In conclusion, the positive feedback collected suggests that participants reported high satisfaction with the learning experience. The format appears particularly well calibrated for primary school pupils, who showed higher levels of engagement, appreciation, and perceived learning (Fig. 5). At the same time, teachers' evaluations were highly positive and broadly consistent across primary and middle school levels.



**Fig. 5.** Differences between primary and middle school ratings across questionnaire domains, expressed as the mean score in primary school minus the mean score in lower secondary school. Blue bars represent pupils' responses and orange bars represent teachers' evaluations.

## Conclusions

During the 2025 edition of the Genoa Science Festival, we proposed the "Dancing with DNA" workshop. As the festival attracts a diverse audience with varying socio-economic and cultural backgrounds, the findings offer a degree of generalisability to broader educational contexts. Therefore, a primary strength of this educational case study lies in the breadth and heterogeneity of the sample. The workshop relies on a kinaesthetic learning approach and combines storytelling with visual elements and cooperative gaming. This methodology was designed to spark curiosity and interest in science among young people while simultaneously promoting soft skills through an engaging and enjoyable hands-on experience. This was supported by the facilitators' qualitative observations and by the feedback collected through interactive posters and questionnaires, which highlighted high levels of engagement and interest in the topics covered. The active modelling of DNA replication was successful in introducing DNA-related concepts and the spatial organisation of the cell to learners with heterogeneous prior knowledge, as well as in encouraging active participation and integration into group dynamics. The results suggest that this workshop may be suitable for supporting the development of basic scientific understanding of DNA and cell replication, integrating educational aims with an enjoyable play-based activity. While the findings resonated with both young participants and teachers, the data suggest that the format is currently best calibrated for primary school pupils, who reported higher levels of appreciation and perceived learning. Feedback from middle school students suggests that the format may require further refinement for this age group. This discrepancy likely stems from their more advanced cognitive baseline and different expectations regarding interactive learning.

Overall, this case study suggests that a gamification-based approach is feasible and promising as an educational tool for science communication and school-based science education. Further studies using pre-post designs and objective learning measures would be needed to quantify learning gains more robustly.



The proposed approach uses appropriate yet simple materials, making the educational activity well suited for inclusion within school curricula. We successfully proposed the workshop in standard classroom settings. Indeed, the activity is featured in the "Mappa della Citta Educante" of the Municipality of Rome, a catalogue that offers a variety of free educational activities to schools of all levels across the city.

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