Good Practice Report

Marco Bortoli, Antonella Balasso, Giovanni Carta, Maristella Cestaro, Viviana Colla, Alessandra De Togni, Giulio Gallani, Cristina Giacometti, Laura Gianni, Lucia Giuffreda, Manuela Granella, Marina Iarabek, Enrico Lion, Giuseppe Mazzi, Caterina Migale, Stefano Milan, Paola Molesini, Mara Moretto, Roberta Predonzan, Ornella Priolisi, Rosella Romualdi, Cristina Rubini, Sandra Scarfì, Elena Tobaldini, Marco Dalla Tiezza, Enrico Nale, Massimo Bellanda, Gordon Kennedy, Gianpietro Sella, Alessandro Lanza and Laura Orian*

Chemical Quest: general knowledge and popular culture quizzes about the elements in a board game for the class

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Abstract: Chemical Quest is an innovative trivia game based on the 102 elements of the periodic table from H to No, developed collaboratively by upper secondary school and university teachers with the aim of increasing the interest of young students (age 14–18) in chemistry. As part of the project, a software version of the game was successfully played in 24 classes. 'Challenging, sometimes difficult, highly instructive, relaxing, captivating, ….' are some of the positive comments by students and teachers. In addition, Chemical Quest was conceived to be adaptable since the rules can be modified and the cards can be selected to match the educational objective.

Keywords: periodic table of elements; quizzes; chemical knowledge; popular culture; STEM; CLIL

***Corresponding author: Laura Orian**, Dipartimento di Scienze Chimiche, Università degli Studi di Padova, Via Marzolo 1, 35131 Padova, Italy, E-mail: laura.orian@unipd.it. https://orcid.org/0000-0002-1673-5111
Marco Bortoli, Department of Chemistry, Hylleraas Centre for Quantum Molecular Sciences, University of Oslo, P.O. Box 1033, Blindern, 0315 Oslo, Norway
Antonella Balasso, **Giovanni Carta and Ornella Priolisi,** ITIS 'Silvio De Pretto', Via XXIX Aprile 40, 36015 Schio, VI, Italy
Maristella Cestaro, IIS 'Veronese- Marconi' – Sede associata di Cavarzere, Via Tullio Serafin 15, 30014 Cavarzere, Ve, Italy
Viviana Colla, ITT 'Eugenio Barsanti', Via dei Carpani 19/B, 31033 Castelfranco Veneto, Tv, Italy
Alessandra De Togni, I.I.S. Ferraris-Fermi di Verona, Via del Pontiere 40, 37122 Verona, Italy
Giulio Gallani, Liceo Statale 'Ippolito Nievo'- Scientifico- Scienze applicate- Linguistico, Via G. Barbarico 38, 35141 Padova, Italy
Cristina Giacometti, Caterina Migale, Paola Molesini, Elena Tobaldini and Gordon Kennedy, ISS COPERNICO-PASOLI, Via Anti 5, 37132, Verona, Italy
Laura Gianni and Sandra Scarfì, Liceo Scientifico 'Ugo Morin', Via Asseggiano 39, 30174 Mestre, Ve, Italy
Lucia Giuffreda and Stefano Milan, IIS 'Levi Ponti', Via Matteotti 42, 30035 Mirano, Ve, Italy
Manuela Granella, IIS G. B. Ferrari, Via Stazie Bragadine 3, 35042 Este, Pd, Italy
Marina Iarabek, Liceo Statale "G. Renier" Economico sociale-Linguistico-Musicale-Scienze umane, Via Marchesi 71, 32100 Belluno, Italy
Enrico Lion, Istituto Cavanis, P.tta Pio x 3, 31054 Possagno, TV, Italy
Giuseppe Mazzi, Liceo E. Medi, Via Magenta 7A, 37069 Villafranca di Verona, VR, Italy
Mara Moretto, Istituto TecnicoTecnologico E. Fermi, indirizzo biotecnologie ambientali, Via S. Croce 14, 36061 Bassano del Grappa, Vi, Italy
Roberta Predonzan, Istituto d'Istruzione Superiore 'G. Veronese – M. Marconi', Via Togliatti 833, 30015 Chioggia, Ve, Italy
Rosella Romualdi, IIS 'Pacinotti' Chimica dei materiali articolazione Biotecnologie ambientali, Via Caneve 93, 30173 Mestre, Ve, Italy
Cristina Rubini, IIS Polo tecnico di Adria, Via Dante 17, 45011 Adria, Ro, Italy
Marco Dalla Tiezza, Enrico Nale, Massimo Bellanda and Gianpietro Sella, Dipartimento di Scienze Chimiche, Università degli Studi di Padova, Via Marzolo 1, 35131 Padova, Italy
Alessandro Lanza, Scuola di Scienze Università degli Studi di Padova, Via G. Jappelli 1, 35121 Padova, Italy

1 Introduction

The collaboration between upper secondary school teachers and university academics is an important source of innovation in the development of materials and methods for the education of young students. The Italian Ministry of Universities and Research (MIUR) periodically funds a specific project called Piano nazionale Lauree Scientifiche ("National Plan for Degrees in Sciences", PLS) to promote a series of Science Technology Engineering Mathematics (STEM) activities, most of which imply a strict cooperation between school and university ("Piano nazionale Lauree Scientifiche Chimica, Scuola di Scienze, Università degli Studi di Padova"). The main goal is to attract the interest of young students to the scientific disciplines and to orient them towards choosing a degree course in science. At the same time, upper secondary school teachers can be supported through advanced courses and labs and involved in the preparation of educational materials which can be used in the class to increase curiosity and stimulate discussion. These educational activities also aim to lower the dropout rate of students abandoning the university course after one year. In chemistry, this is often related to the wrong vocational choice at the outset. The outcomes of this actively promoted collaboration between university and high school teachers have not been limited to PLS and to the Italian chemistry scene but they gave rise to the publication of multiple contributions in international chemistry education journals (Bortoli & Orian, 2023; Carpentieri et al., 2023; Favero et al., 2019; Jurinovich & Domenici, 2022).

In the context of the PLS for chemistry, we organized a special unconventional laboratory for teachers with the aim of preparing and assembling a board game based on the periodic table of elements. This game is useful to introduce the chemistry of elements at school, but it also has the general goal of divulging scientific information about the chemical elements in popular culture ("History and Etymology of elements curated by the historian Peter van der Krogt"; "Periodic Table of Elements at LANL (Los Alamos National Laboratories)"; "The periodic table of videos (curated by Prof. Martyn Poliakoff at the University of Nottingham, UK)"; "The Royal Society of Chemistry's interactive periodic table", for URLs see References section).

The periodic table has a prominent role in teaching and learning chemistry and there is a vivid debate on the importance of putting atoms first in teaching general chemistry. Differently from standard approaches, the 'atoms first' approach (AA) (Esterling & Bartels, 2013) allows the teacher to start chemistry courses avoiding topics which are apparently disconnected from the discipline and are more related to physics. According to Scerri, the main limitation of this approach is that it neglects historical aspects (Scerri 2022). Nevertheless, the periodic table is a recognized cultural icon and is indeed an optimal starting point to learning chemistry due to the amount of information it contains, which can be easily employed to predict many properties of the chemical elements and their compounds. It is not surprising that the periodic table has inspired various educational games. Among them, many address mnemonic aspects connected to the association symbol-name of the chemical elements or to the position of the chemical elements in the table itself ("Periodic table of the elements with symbols – Science Quiz,"). Others aim at testing the level of understanding of the atomic number and mass number ("Periodic table challenge"). Most of them are individual games freely available in websites ("Learning the periodic table of elements with games"; "Periodic table challenge"; "Periodic table of elements – Games,"; "Periodic table of the elements with symbols – Science Quiz", see References sections for URLs), but also board games have been commercialized ("Periodic: A game of the elements Genius Games,") or published (Stanley Lourdes Benedict, 2023). Almost all these games aim at increasing the knowledge of the periodic table or of specific aspects of the chemistry of the elements. Conversely, the aim of our work is engaging students and boost their interest to chemistry. To pursue this goal, we stimulate their curiosity about the chemistry of elements, their names and history, their presence in daily life and in art, movies and music, their scientific and technological properties, exploiting the challenging potential of gamification. In addition, inclusion and students' cooperativity is promoted by organizing the class in teams.

In this paper, we present Chemical Quest, a trivia game with 510 questions (and answers) on the first 102 elements of the periodic table, patiently selected and validated against books on the topic (Aldersey-Williams, 2011; Kean, 2010; Levi, 1975, 1984). Then, we discuss the results obtained by the participating teachers who have played the game in their classes, using a software version of the board. Importantly, although the game was

initially prepared in Italian, it has been modified for use in English with the double scope of providing materials for lessons using the Content Language Integrated Learning (CLIL) methodology in Italian schools as well as to make it available to an international audience (Coyle et al., 2010). In some cases, a direct translation of the questions was not possible due to specific cultural references which would not make sense in translation. For example, the alphabetical order of the elements is different between the two languages and references to some parts of Italian pop-culture were too local requiring that some questions be reworked. The CLIL approach to bringing active engagement with a foreign language through the content of a non-linguistic subject is an important strategy being promoted by the Italian Ministry of Universities and Research to better prepare students whose focus is not languages for communicating in these subjects (Cenoz et al., 2013). Keeping this in mind, the availability of materials like Chemical Quest is potentially very useful because of the richness of the natural language which is used when playing a game like this. In order to distribute Chemical Quest to those teachers who want to play it in the class, a webpage has been created where after registration the whole electronic version of the game can be downloaded.

The paper is organized as follows: the idea and creation of the game is explained; then, the rules of Chemical Quest are presented in detail, followed by the instructions for the reader to get the complete version of the game; the experience of playing Chemical Quest in the class is reported highlighting the positive impact on students' engagement, their level of satisfaction and the encountered difficulties. The versatile use of the game prompted some of us to use it also out of the class. Thus, Chemical Quest was also tested on several occasions at divulgation events, which are nowadays popular to put the society in closer contact with science. This experience is also reported and commented in the last paragraph.

2 Results

Many difficulties are daily faced by chemistry teachers mainly because there is general mistrust against this subject. Chemistry is considered difficult and indeed effort is required in building models of molecular reality, an aspect which is intrinsic in approaching chemistry, but which is also related to individuals' capacity of gaining understanding. Since the 80s, chemistry teachers and educators apply the model of the Johnstone triangle at all stages of learning promoting the construction of correct knowledge of chemical concepts and laws (Reid, 2021). Engaging learners is another important aspect because stimulating the students' interest has certainly a positive impact on learning (Engaging Learners with Chemistry: Projects to Stimulate Interest and Participation, 2020). Thus, we decided to create a trivia game to stimulate the curiosity for the elements, but also to show that many unknown chemical elements are part of our daily life, including common and sophisticated technological objects we use, but are also mentioned in movies and songs. To ensure a homogeneous coverage of different aspects of all elements through the questions, we identified five categories, i.e., history, art music and cinema, food energy and life, science and technology, and miscellanea. They can be easily related to the chemical elements, and they include many aspects of modern life. At the same time, we were aware that formulating questions about less common elements is not easy, and thus we did not use too strict definitions for these categories; this was considered a good strategy by the teachers involved in the game creation.

2.1 Game creation

Gamification has been used in chemistry to motivate and engage students and improve their learning (Dichev & Dicheva, 2017; Nieto-Escamez & Roldán-Tapia, 2021). Although its efficacy is still under debate, many experiences showed positive outcomes (Chans & Portuguez Castro, 2021; da Silva Júnior et al., 2022; Tvarozek & Brza, 2014). With the aim of increasing the interest in chemistry of upper secondary school students through a captivating activity that can show the multiple ties of chemistry with everyday life, we chose to merge the periodic table, chemistry's most renown symbol and source of information (Scerri, 2019), with one of the most famous trivia games, Trivial Pursuit. The hardest part of creating trivia games is the preparation of the quizzes, because a whole

bunch of (often multiple-choice) questions must be provided. In the case of an educational game, writing the quizzes can be an intriguing challenge for the teachers, who can wisely and carefully select topics and tune the level of difficulty thanks to their experience in the class. For these reasons, the 510 quizzes of Chemical Quest were created in a one-day lab for upper secondary school teachers who participated on a voluntary basis. 10 groups of two-three people were created, and 8–10 elements were assigned to each group. Books on the periodic table and chemical elements were available and they could use network facilities to search in the Web. Inter-group collaboration and discussions were established especially when difficulties arose, i.e., the formulation of quizzes for less popular elements and more in general the search of good questions suitable for a general public. The formulation of the questions required accurate research on the assigned elements. The teachers used their experience with the young students to choose the questions, favoring the most interesting, unusual, or incredible, but also trying to tune the level of difficulty, because a too difficult game may generate frustration. Importantly, when the information was retrieved from the Web, the teachers checked carefully the reliability of the source, often looking for the same news elsewhere for confirmation. The Italian version of the game was initially prepared, but few months later the English version was also ready.

2.2 Gameplay

The goal of the game is to move around the board by correctly answering trivia questions. Questions are split into five categories, with each one having its own colour to readily identify itself; these are History (blue), Art, Music, Cinema & Literature (purple), Food, Energy & Life Sciences (yellow), Science & Technology (red), Miscellanea (green). The game includes a plastic (or virtual) board (Figure 1), plastic (or virtual) playing pieces marked with a different colour to distinguish the players/teams, question cards, small plastic (or virtual) beads (the colours of the beads are those of the categories) to fit into the playing pieces, and a die (a big soft one to play in the classroom). These elements are shown in Figure 2. Playing pieces used in Chemical Quest are either weighing bottles, in the board version, or glassware, in the electronic version. A small plastic bead can be placed into each of these pieces to mark each player's progress.

The game is played on a board which depicts a distillation apparatus. This track is divided into squares of different colors. It starts at the round-bottom flask and ends at the Erlenmeyer flask. At the bottom center of the board there is a three-neck flask. Before the game starts the deck containing the 102 element cards is shuffled and placed with the side of the cards containing the questions and answers facing down. On each of their turns, players roll a die and move their counter of a number of squares equal to the die roll in any direction following the

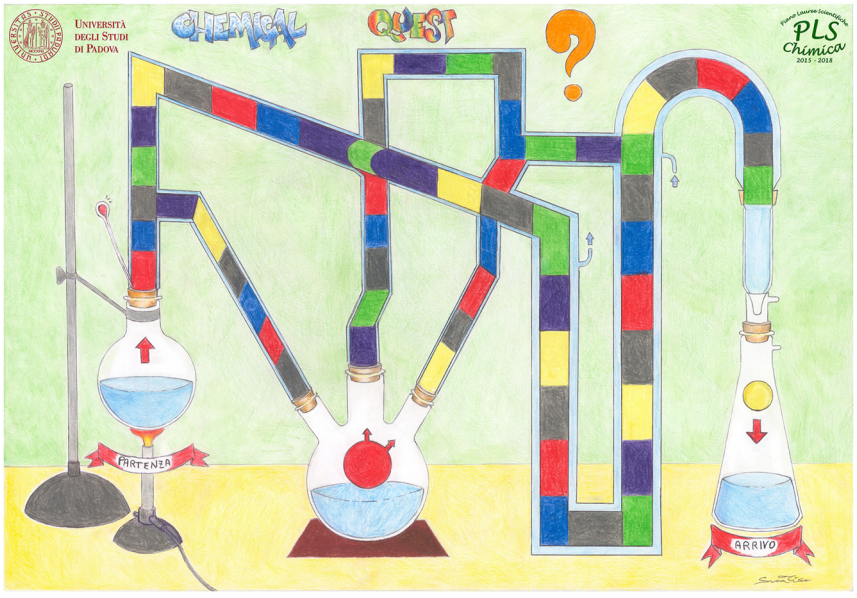


Figure 1: The board.

Figure 2: Die, playing pieces, plastic beads, cards with questions.

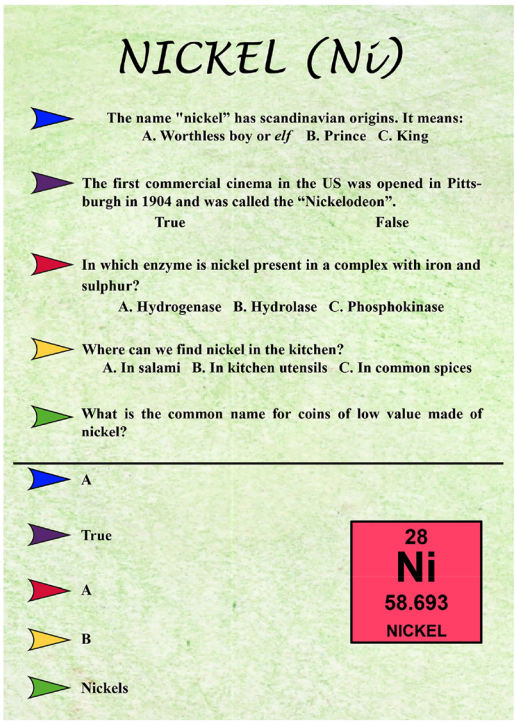
tubing. When a player's counter lands on a square, the first card is drawn, the player answers a question according to the color of the square, which corresponds to one of the five categories and the card is put on the bottom of the deck. If the player answers the question correctly, he collects a bead of the same colour which fits into the playing piece. Grey spaces ("roll again") give an extra roll of the die to the player. When a counter lands on the three-neck flask, the player must answer a question in a category selected by the other players. The player's turn ends on collecting a bead or after a wrong answer. When a player's counter lands on a space, but the team already has a bead of that colour, they can try to answer a question correctly to throw the die again, otherwise they can choose to simply stop. If a player chooses to answer the question, but the answer is wrong, the player's counter is moved back to the square it was in before the die roll. Any number of playing pieces may occupy the same space at the same time. Once a player has collected one bead of each colour and filled up the playing piece, they must reach the end of the distillation apparatus to win the game. The yellow ball in the flask containing the distillate is not a space of the game board and must not be counted.

There is no pre-determined order in which the beads must be collected, and Chemical Quest lets each team or player adopt the most convenient strategy to collect all five coloured beads and reach the end of the track.

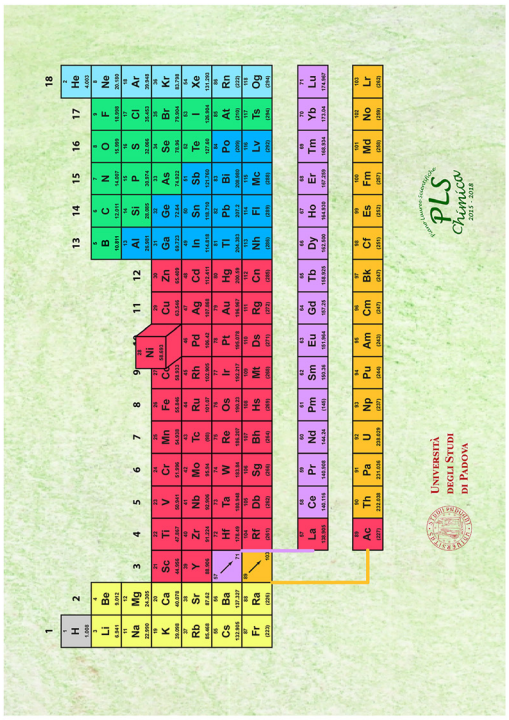
The core of the game is represented by the 102 cards, each one associated with a chemical element from hydrogen to nobelium. On each card there are five questions with the five corresponding answers. On the back of the card there is a periodic table with the position of the element highlighted. In Figure 3, the nickel card is shown as example. In this case, the History question deals with the origin of the name nickel and the Science & Technology one is about nickel-containing enzymes. They are both multiple-choice questions to give the most knowledgeable players better chance to answer correctly. Conversely, Food, Energy & Life Sciences and Miscellanea questions are open and deal with the use of nickel in everyday life as a component of kitchen tools and the name of 5 cent coins made of nickel, respectively. It is not impossible for students to answer correctly to both questions. In contrast, the Art, Music, Cinema & Literature question is a challenging one because it will be very rare to have students who know that the first commercial cinema in the US opened in Pittsburgh in 1904 was called 'Nickelodeon'. During the game, questions can be read out by the teacher or by the next player.

2.3 Playing in the classroom

The game was played in 24 different upper secondary schools (high schools (licei) and technical institutes), in a total of 44 classes involving students of the second, third or fourth year using the Italian language version. Relevant information such as the number of teams/components per team, the total time, the average number of beads gained, the most difficult/easiest subject, were collected by the teachers who were asked to compile a data sheet which is shown in Table 1.



(a)



(b)

Figure 3: Sample card: nickel, front (a) and back (b).

Table 1: Example of a form filled by the teachers to evaluate the level of success of the game in the class.

School					
Teacher					
Class					
Number of students					
Number of teams					
Game version					
Total time					
Were all cards used?					
	Number of beads at the end	**Winner**			
Team 1					
Team 2					
Team 3					
Team 4					
Team 5					
Team 6					
	Feedback				
Time	Too long	Long	Suitable	Short	Too short
Difficulty	Too difficult	Difficult	Suitable	Easy	Too easy
Most difficult category	Blue	Purple	Yellow	Red	Green
Enthusiasm	Very high	High	Normal	Low	Very low
Learning	Very high	High	Moderate	Low	Very low
Comments:					

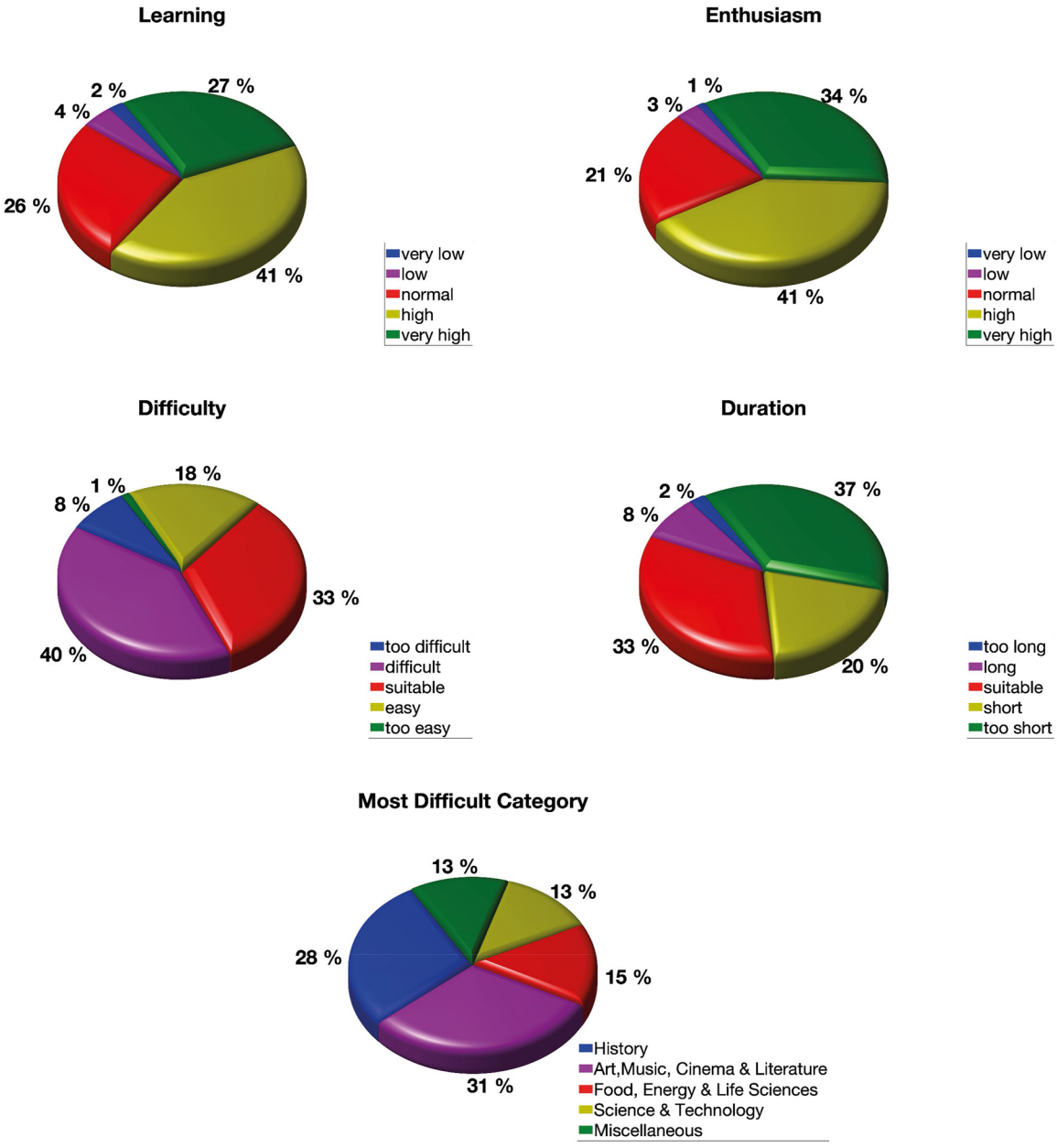


Figure 4: Feedback by the students who played Chemical Quest.

For convenience, teachers were recommended to set a time limit of 45 min and all matches ended within this time limit. On average, the teams gained at least three beads and no cases were reported of teams with 0 beads at the end of the game. All cards were used. The results collected from the feedback of 542 students are shown in Figure 4.

Most of the participants found the duration of the game suitable or too short, although we believe that the latter choice was provocative. Only 10 % thought that the game was long or too long, and this may be due to lack of interest, or this comment may arise from an excess of dead times during the game. Almost half of the students found the quizzes difficult, but a significant percentage found the level suitable. Indeed, in some cases it is extremely difficult to answer, especially to open questions, but we have intentionally inserted few 'impossible' questions to stimulate the competition. The most difficult categories are not directly related to science, but rather

to historical aspects and art, music, cinema, and literature. More than 70 % students have been highly enthusiastic/enthusiastic about the game, and more than 60 % have declared that they have learnt some chemistry of the elements. It is important to stress that the teachers have collected the feedback of the students in the class after playing Chemical Quest and have not organized any evaluation. Thus, the level of learning here reported merely reflects the perception of the students. On the other hand, our main goal was to boost the interest of young students in chemistry by making them aware that chemistry permeates our life. To facilitate the learning process, one should investigate what they have learnt playing Chemical Quest, or, even better, evaluate with specific tests the level of knowledge about the elements of the periodic table before and after playing Chemical Quest.

Finally, taking into account also the feedback received by the teachers, the following observations can be drawn: (1) the most difficult questions definitely belong to the blue and purple categories, which are not the 'scientific' categories; (2) on average each team gained at least three beads; on average teams of older students earned more beads; (3) the game is highly appreciated by the students and the teachers detected an efficient increase in interest in the subject; (4) the teachers recognize that Chemical Quest can be used to improve a general knowledge of the chemical elements, but also to relax the students from time to time during the school year; (5) in some cases, two or three students were able to manage the game and so the class became completely independent of the teacher when playing Chemical Quest; (6) questions with multiple answers are preferred over open questions which may be used to open a discussion at the end of the game or to stimulate a search to go into more depth on a particular topic; this would be useful to promote learning.

We also noticed that the rules of the game can be easily adapted by the teachers. For example, some elements can be excluded (lanthanides and actinides) especially when playing with younger students; alternatively, students can use Internet to find answers during the game since it is not straightforward to find all the information required.

2.4 Chemical Quest webpage

In order to make Chemical Quest available for teachers, we have created a web page from which the software version can be downloaded for free (https://pls.scienze.unipd.it/chimica/chemical-quest/). The homepage contains some general information about the PLS project and the game. Registration (name, surname, affiliation and e-mail address) gives access to a private area where the package containing the web version of the game can be downloaded. This contains three archives: the 102 cards in PDF format (English and Italian versions) and the compiled version of the main program. The software is written in Java and can be run both on Windows, macOS, and Linux machines with a working Java virtual machine installed via the respective launch scripts. A full description of the software and its configuration is reported in the Supplementary Information and contained in the archives in the respective README files.

2.5 Chemical Quest at scientific divulgation events

Due to the numerous quizzes of chemical culture, Chemical Quest can be proposed to the general public and thus be used at scientific divulgation events. The increasing importance of university 'third mission' activities, which are especially valuable to the establishment of a correct relationship between the society and scientific knowledge and progress, prompted us to organize Chemical Quest matches on several occasions. For example, we have played with adults (age 14–99) at Venetonight Eds 2017, 2018; 2019. Before the pandemic, this regional event was co-organized by three Italian universities, i.e., Padova, Venice and Verona, in conjunction with the European Researchers' Night in late September. In 2019, Chemical Quest was presented and played at the active poster session of Mendeleev150 in Saint Petersburg, the conference endorsed by IUPAC organized to celebrate the 150th anniversary of the periodic table (Cestaro et al., 2019).

3 Conclusions

We have presented a trivia game based on 102 elements of the periodic table from H to No. The game was prepared by upper secondary school and university teachers with the aim of increasing the interest of students in chemistry by showing how the elements are part of our daily life. The game was successfully tested in 24 upper secondary schools. The cards with the quizzes are amenable to different applications or can be used as a starting point to prepare further sets of questions at different levels of difficulty.

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Data availability: The raw data can be obtained on request from the corresponding author.

Supplementary Material

Five sample element cards and guide to the virtual version of the game. The complete game can be downloaded after registration and free of charge from https://pls.scienze.unipd.it/chimica/chemical-quest/ or is available upon request to the authors.

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