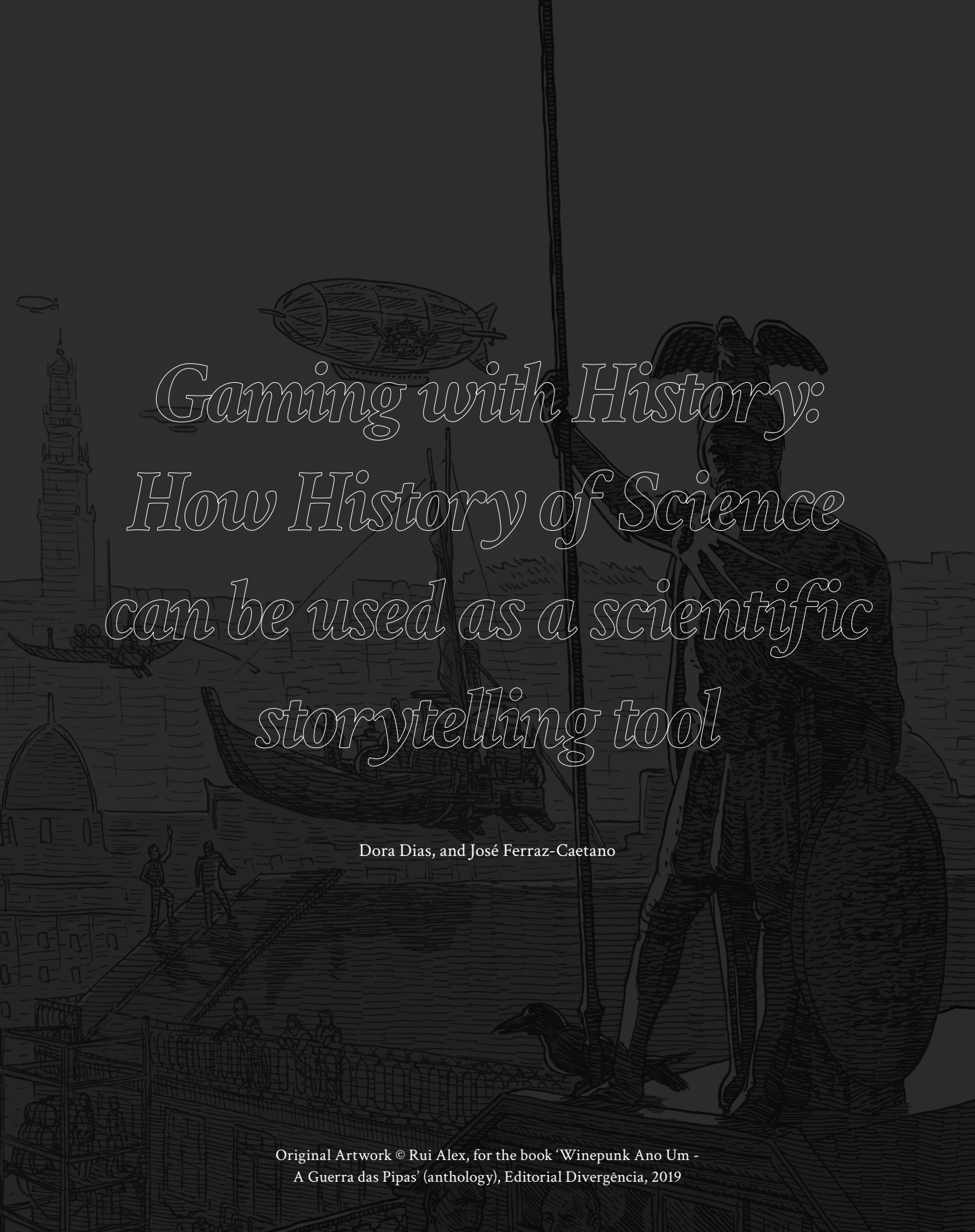

Gaming with History: How History of Science can be used as a scientific storytelling tool

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Abstract. Gamification can be a useful tool when engaging young students with science. When designing a new game, it is pivotal that a featured storytelling element can draw students' attention while providing an enjoyable experience. However, building such an insightful science dissemination narrative from scratch is often challenging. As real-life situations are frequently more appealing to students, adding alternative history elements can be helpful when designing such a game. In this paper, we present a novel educational framework to design an educational, science-based storytelling activity using the history of science and alternative hypothesis as ground tools for its inception. By analysing student's feedback when playing a science-based game with a historic episode outline, they report that their learning experience was fun and relatable, matching their scientific performance during the game.

Keywords: History of Science, Alternative History, Gamification, Storytelling, Chemistry, Ethics

1. Introduction

Introducing scientific topics to middle-school students is often challenging. Teachers and science communicators must design appealing educational vehicles, especially in the presence of many resources in multi-platform-based learning (revamped by the increasing use of digital media). In a classroom setting, there are several approaches to gather student's focus and engagement. For middle-schoolers, playing a competitive game is a very appealing activity [1]. And even more, if the game has real-life situations embedded in a storytelling scenery [2, 3]. But the design and adaptation of such activity require methodical research and time which, sometimes, overwhelmed teachers simply cannot invest. What we aim in this paper is to narrow this effort, conveying a fresh form of science communication framework, using the tools and insights of History and Alternative History.

As such, we present an educational framework that allows the adaptation of appealing History of Science (HoS) episodes, modelled by hypothetical history inputs into the design of a storytelling-based educational game. We will start by describing the background of the current use of HoS episodes in middle-school science teaching and why it is relevant for their academic syllabus. The emphasis will be on the advantages of storytelling when conveying difficult subjects of science dissemination. From there, it will be presented the proposed framework to adapt these HoS episodes into scientific storytelling games. We then move to a practical application of this model, in a pilot study of a science educational activity.

2. Background

2.1. History of Science for young educational storytelling

HoS is full of interesting episodes that reflect scientific discoveries, which could be used as the mainstay of educational activities for children [4, 5]. These episodes often portrait regular men and women whose purpose is to find answers to their questions [6]. These tales are more than just scientific stories, as they often can explain a scientific concept to a younger audience, more prompt to learn science when embedded with storytelling elements [7].

There are several educational advantages to scientific storytelling. Students often pay more attention to the plot, encouraging their imagination. It is reported that it helps students' long-term memory formation, helping them understand challenging topics entertainingly [8]. In some media, these types of activities are recalled as "edutainment" since they are both entertaining and educational [9, 10].

We often struggle to engage with a young audience with science topics. Therefore, science activities that include other effective learning techniques, such as hands-on activities or gamification, may be a good way to improve them. These techniques provide the benefit of adding another layer of entertainment to the activity. Hands-on activities provide a sensory and palpable interaction that attracts young students, while gamification (addition of game elements to a non-gaming context) [11] helps students to develop social skills such as teamwork, emotional and cognitive skills provided by the competitive factor of a game [12, 13].

The question that remains is how to choose a story that can draw the audience's attention. One way is to build suspense and have a mystery in the story, it arouses the curiosity of the audience. These types of "unsolved issues", "injustice", and "unanswered questions" are good plot foundations to capture the audience's attention. One type of plot that can have all these ingredients is a murder story. These types of stories provide

the necessary framework: they provide a problem (someone was murdered but why and who did it?), different scenarios, which can be can be provided to explain what happened, and in the best-case scenario provides a closure (the murderer is discovered and brought to justice). Previous studies focusing on forensic science have successfully promoted science and engage with participants [14-16], these include children's activities and crime laboratories [17, 18].

3. Framework for History of Science episodes adaptation

The fundamental steps towards a successful adaptation and expansion of HoS episodes into storytelling gamification applications are presented in this section. This approach was made using pivotal contributions from our pilot experience from a science dissemination activity, that we will develop in the next section. Broadly, we can summarize this framework within three major steps, highlighted in Figure 1.

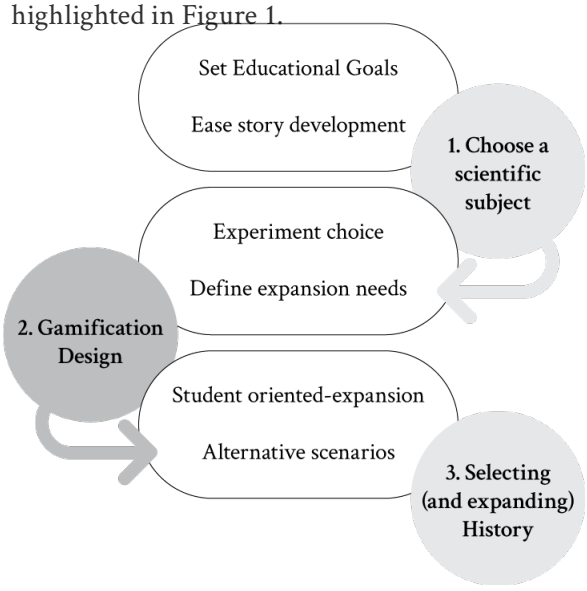

Figure 1. Schematic representation of the HoS-based gamification framework.

3.1. Choosing a scientific subject

The starting point should be the selection of the discipline (or school subject) that is the focus of the storytelling narrative. Although this seems rather trivial, this definition should come with several touchpoints that will ease subsequent framework steps.

On selecting a subject, one must identify what are the educational or communicational goals to be incorporated in the activity. If children are the intended audience, it is critical to devise a subject activity within the educational goals for their specific school cycle. For example, in chemistry, there are various ways to display the importance of redox reactions in our everyday lives, a topic included since the 8th grade program of Portuguese public schools [19]. But it is fundamentally different to address this issue towards middle or high schoolers. It is imperative to study the educational guidelines for this chemistry subject within the age range of the audience. Also, it is advised to extract from official educational guidelines (and/or teaching regulations) for the teaching of that discipline. Then, incorporate the chosen ones towards the story outline.

The primary advantages of doing this exercise are twofold [19]. Using official educational goals on the activity's touchpoints make their dissemination and subsequent implementation easier to justify. Not only to gain greater outreach but to address important specifications for application in school environments [19, 20]. The other major advantage is that it will help on the stage of adapting the HoS episode with alternative history elements [4]. As one can imagine, there are infinite ways to expand or continue a specific real-life tale. These goals will help us narrow this step. As we will discuss further, the main intent of the alternative component is to harbour and introduce pivotal storytelling elements to the actual story. If the intention is to expand the role

of certain experimental matters addressed in the educational goals, then an experimental element must be embedded in the story. The alternative scenario of a historical situation can help us blend the historical element in such a way, that its outcome depends on the new action introduced [21]. From a storytelling point of view, this makes our educational goal an intimate part of the history, as students cannot solve the gaming composed of the story without addressing these goals.

3.2. Gamification Design

This intermediate stage, besides setting the tone for the selection of the HoS episode, brings the most important dynamics into the activity. It defines what type of game should be built to be built and what science-based activities need to be introduced [13, 22]. Using the educational goals set previously, this step materializes their purpose in hands-on experimental activities. Since we are considering middle-school students, the experiments need to be adapted to their small laboratory proficiency, while addressing the highest security standards [23].

Each educational goal encompasses a possibility of a hands-on experiment. But, even for understanding how their learning experience is going, it is advised to congregate several goals in the fewest experiments as possible, as long as the goals share a common theme. For example, instead of designing two or three experiments to address redox reactions, one should devise a single activity where individual steps are made, to embed the remaining learning goals. Steps can be simple actions as "sample weighting", "add reagent to the sample", "compare results to a bibliographical key". However, it is important that these actions are intertwined, as the final result needs to be a consequence of the good application of educational goals. As for what types of experiments are to be done, it will depend on the practical scientific subject. Although there is not a comprehensive list to address specific school ages, we recommend that adaptations of school-sanctioned activities or minimal risk, but with enthusiastic visual effect to be chosen, such as colour changing experiments [24].

What also needs to be readily defined in this step, is the setting and context of the educational experiments so to better fit them into the storytelling. In our case, the experiments that we have chosen were not conducted (at least some) in the real episode. This could be done by questioning ourselves: "What if this event occurred differently?". Therefore, we must create an alternative scenario in our history plot to englobe the experiments. This needs to be done to ensure a proper design of the hypothetical historical scenario (defined as a conscious deviation from an historical fact) in the subsequent step. Characteristics like the location, actors, and circumstances need to be defined to intake these elements in the storytelling dynamic. From then on it will be easier to shift the story as we need it [25].

3.3. Expanding History of Science episodes with Alternative History

The HoS episodes can come across with different call-backs. We can consider as episodes any event that occurred in the past in which science (or scientists) were crucial in their outcome. Most of them can be readily categorized into several themes. Historical crime cases (in which science was important in their resolution), the discovery of hallmarks of science history (the story behind atomic and relativity theories), or events where science changed society (like introducing vaccines or other medical treatments) can portrait an effective number of cases to be explored.

The main criteria should always be an episode already described in the HoS literature. One fundamental deciding factor would be the asso-

ciation to the students' environment. So, the easiest and most effective way to succeed is to select an episode that took place in the student's home country. Better yet, if possible, should always be considered events that occurred in the same city as the activity is unfolding. This will facilitate students' acceptance and place a familiar setup when dwelling on the game [26].

We should be upfront that not all scientific sub-themes have dense and interesting HoS episodes that can be easily embedded within the framework of a storytelling-based activity. This is the distinctive feature of our activity. The way we can expand and design alternative scenarios for our episode marks an infinite way of interlacing topics, actors, and subjects.

However, it is the 'expansion' component that is central in our activity. As the episode itself cannot provide all the elements we need to build effective storytelling for our game, it is up to the promoters to devise alternative hypothesis and introduce the elements needed. The expansion is defined as the evolution of the original storyline, harmonized with the introduction of story elements.

As such, alternative history can be the promoting catalyst for this expansion. It requires notably three aspects: an outlined point of divergence from the written history; the practical change brought by the divergence; and the implications of such a change [25]. In our take, the 'expansion' component can be densified by these three aspects. The point of divergence can be our starting point for the expansion scenario. It identifies, with precision, when the promotor starts to diverge from written history, adding newfound elements to the storyline. Then, secondly, the main practical change is clarified. It sets to describe the alternative elements written in the story that takes the historical narrative to an alternative divergent reality. And finally, the 'expansion' is further explored, assessing the main implications and outcomes that make a perfect distinction between reality and alternative-based scenarios.

But what is the main tool that the design of alternative scenarios requires from alternative history? When addressing a divergent event from written history, we are introducing a chronological counterfactual event that devises a "what if" scenario towards the storytelling setting of history. This is important as this tool from alternative history is different form a simple "fictional element" introduced to design a story plot. It adds a deeper meaning to the purpose of the 'expansion', as it adds an historical research questions in the storytelling process. The questions posed by the "what if" scenario will address the various possibilities of increasing the allure of the story.

Let us discuss a practical example. Imagine we selected a "Real Life Crime" to be solved using scientific techniques. We can use this setting to introduce specific subject elements and goals that we have devised in Step 1. If we want to address 'redox reactions', we can introduce an experiment that exemplifies the use of this chemical knowledge. The outcome of the experiment by itself must be irrelevant to the disclosure of the episode, so the act of experimenting conducting it can be included in the storyline. For instance, one can design the experiments whose purpose is to identify the composition of samples. Substances like copper sulphate in combustion (a classic 'flame test'), give rise to a characteristic green flame (also occurring a redox reaction) can be used to identify such substance.

If the case needs several chemical tests to identify precise elements, we can introduce (or manipulate) practical experiments to be used as vehicles to address the devised educational goals. However, one must keep in mind that, for story purposes, the environment concerning the experiment must be coherent with the episode. Details as the laboratory and the scientist conducting it must be

in tune with the episode (ideally, making our actors execute the experiment).

But the expansion setup for alternative history topics can be used further than introducing elements or experiments. They can introduce themes that can dwell on other scientific topics. The ethics, values, and methodologies inherent to the scientific activity can be introduced coherently. Adding story elements that challenge the normal development of the scientific query can be an interesting bending of the storyline. This alternative storyline can help introduce 'conflicts of interest', 'professional ethics', or 'norms of conduct', by adding examples that emphasize their implications in the scientific endeavour.

By already having a laboratory setting, one can create quarrels between different investigators, where one judges the work of the other, not by its rigorous execution but by their personality. Including an alternative history insight is the creation of fake relationships between the real-life characters. By doing so, these characters gain new interests in the story plot, and could ultimately change their path in the story. If the characters are inserted into a crime-scene plot, a fake relationship between two characters could give them a motif to portrait the crime in question. This will open more story-ending possibilities that could enrich the plot of the story.

Nonetheless, the inclusion of these alternative history tools in a scientific activity will provide little results if the baseline story is unappealing for the audience. When choosing a story for a scientific activity with educational purposes one must select a story suitable to the audience, carefully thinking if it is age and culturally appropriate. It is helpful to incorporate a real story, an actual episode from the HoS, that can provide a better and deeper connection with the audience in question, since it can unite an idea from the story with emotion.

Other aspects should be taken into consideration when writing a scientific-based story for children. For instance, the story should provide a clear problem and an answer for it; several theories for its explanation; and a proper closure. But it should also captivate, unfold at the right pace (always according to the audience), have an interesting plot/characters, and leave a lasting impression. This can be achieved by enticing the audience's curiosity, leaving them in a quest to search for answers and to know more about the story. Finally, one must also consider that if the story is unknown to the audience, they will pay more attention to it, even if it is just to realize how it ends.

4. Perspectives on framework adaptation

We now introduce an educational activity where we tested our framework on adapting and expanding an alternative history segment for a storytelling-based board game. More specific details on the making of the activity and implementation of educational resources can be consulted in our previous work [26, 27]. This section is layered to accompany the framework stated above.

4.1. "Ethics against Chemistry" – A case study

Step 1. Choosing a scientific subject

The edutainment activity "Ethics against Chemistry" is an educational game created to disseminate chemistry [28]. It was presented at the Junior University in 2019 in the Faculty of Sciences of the University of Porto (Portugal) to students of 12–13 years old [29]. About 280 students took part, as this activity merges educational, storytelling-centred tools such as gamification and hands-on activities.

The official educational goals on the activity's touchpoints were identified based on official documentation provided for the chemistry sub-

ject, for middle-schoolers [30, 31]. The scientific themes selected to be addressed were precipitation reactions, exothermic reactions, non-Newtonian fluids, and redox reactions.

Step 2. Gamification Design

We elaborated on a science-based board game. The story of the game would have to feature at least five experiments to cope with the educational elements in Step 1. Hence, we attributed one experiment for each thematic group.

"Ethics against Chemistry" comes together in a board game format, inspired by a famous criminal game. Details of the construction of this activity were already published [26, 27].

Students formed teams of 3–4 elements (80 teams in total) and each team had to investigate a real-life based crime and find out who committed the crime and why. With hands-on experiments, students analyse samples provided as "evidence" that are submitted to laboratory tests to determine their composition. The results from the laboratory experiments are intimately connected to the storytelling. The investigation required the fulfilment of a digital game report and laboratory experiments to determine the murder weapon. The team that comes up with the right answer with a correct scientific-based explanation for it, wins the game. On the digital game report, ethical issues that the characters faced were addressed, also enabling us to track the teams' thinking process (by allowing them to change their answer as the game progresses).

Step 3. Selecting (and expanding) an History of Science episode

The authors chose a ninetieth century crime story, commonly known as "Crime of the Flores Street" (or the "Urbino de Freitas case"), that occurred in the Portuguese city of Porto. This was the HoS episode adapted to the making of this game. In 1890, Mário Sampaio, the grandson of a rich merchant family of Porto was poisoned to death, and his uncle, Vicente Urbino de Freitas, was accused of portraying such act. He was later convicted for this crime, whose resolution shaped the path of modern forensic chemistry in Portugal [32, 33]. It was a popular tale at the time, but it seems to be an unknown story for Portuguese middle-schoolers. This story was used as the main plot, though some alternative elements were added to raise the level of excitement, to match our educational goals, and to provide more scenarios to explain the murder. These elements do not taint in any way with the scientific results obtained by the hands-on laboratory experiments.

The major contribution of alternative history towards this activity was the restyling of the storyline, outlining the point of divergence from the classic historical narrative of the "Urbino de Freitas Case". The lure of the story, particularly in the densification of the backstory of the central characters and the added experimental steps in the game, was pivotal for adapting the story as an educational activity. The main change brought by these new elements was the questions raised by the added lure. For instance, the alternative backstory of the characters led to insightful questions on the role of ethics and conflicts of interest in science. Also, if the public understanding of science in the ninetieth century was more based on scientific arguments than the power of authority, would the outcome of the case have been different? How would Portuguese science have developed if its critical role on the conviction of Urbino de Freitas were downplayed in the courts? These and other questions, driven by the alternative elements added to the story, also helped to devise the experimental aspect of the activity.

By introducing fictional mandatory experiments on alternative crime-scene samples, the

story allowed students to engage with practical chemistry tasks, suited to their age and school insight. This divergence did not bring any implications on the outcome of the historical case but was pivotal to create the story setting that allowed the introduction of practical elements aimed at middle-school students. However, these changes implied the construction of a conceptual scenario with the students on the "what if" possibilities. If at the time of the case, science had some analytical tools that were not available at the time, maybe the outcome of the case and the public and scientific ramifications of the history of Portuguese science could be effectively different. More than conveying newfound knowledge to students at a young age, science communicators need to plant a conceptual vision of science, leading to a more critical and thoughtful materializing for children.

In the experiments, the students must figure out the composition of the samples available to them. For example, one of them was the copper sulphate mentioned previously. When we asked the teams, in an online interactive quiz what colour was the flame of the copper sulphate, 91,67% of teams (N=72) answered correctly (green).

After the activity, we asked our students to answer a small inquiry providing feedback on the game. This was a voluntary digital inquiry. We asked them to describe the activity "Ethics against Chemistry" in three words and we had 146 valid answers. The words were translated into the English language and arranged according to the frequency they were used, and that was most used to describe this activity was "fun" (90 times in 146 valid answers).

By analysing student's feedback when playing a science-based game with a historic episode outline, they report that their learning experience was fun and relatable, matching their scientific performance during the game [26, 27].

5. Conclusion

Storytelling has proven to be a good educational tool, particularly in the case of science. Although storytelling can be very engaging, the addition of other interactive features such as gamification and hands-on experiences can enhance children's learning experience while they enjoy themselves at the same time. HoS provides us with almost infinite choices that could easily explain the implications of scientific discovery in a more effective and captivating way.

Although real-life stories can impact middle-school students, the modification of the story plot through alternative history can ease the introduction of educational goals in a scientific activity. This incisive option led to the densification of the storyline, enriching with new topics and research questions, while also binding the whole activity together. The alternative history elements introduced enriched the plot by itself and the activity as a whole, as highlighted in the activity example "Ethics against Chemistry". By demonstrating the inception of a multi-layered activity that was able to address different and complex subjects (chemistry and ethics), integrating them into a story with the addition of alternative history elements, permitted the inception of an educational board game. It also allowed practical activities through hands-on laboratory experiments and discussion of results amongst the students. This allowed the participants to have an alternate learning experience, which was enjoyed as foretold by the reported results. It is educational activities like "Ethics against Chemistry" that remind us how important it is to have more multi-disciplinary activities and that history and science should work together more often.

6. Round Table Insight

The discussion of this work, during an Oral Presentation Round Table at the 2nd international Meeting of ' What if?...' World History, provided an important insight into storytelling, though used in different ways. Though the common feature is that the key point of storytelling is the human connection or emotion, and by achieving this, a scientific message or of any kind can reach the audience more effectively. Whether it is a story from the past or a story project in the future or merely a speculative story (that might have no impact on the future), we can learn from it. From the past, we learn from the evolution of knowledge and for the future, we learn how to plan and prepare ourselves for what is yet to come.

Stories often come will a moral lesson, a final message that arises from a moral or ethical dilemma on the story's plot. The inclusion of ethics, in some form, is always important, whether it is to explain one's conduct in a conflict-of-interest scenario or for scenario planning, speculating if the future consequences could touch an ethical conundrum of some sort.

It was brought to our attention the possibility of adapting this game to an online version, because of the Covid-19 pandemics and because online scenario planning became a reality in 2019. Although it has its advantages (such as lower cost, larger accessibility) it would lose the human connection that is so valuable in this case, through the screen.

Overall, it all resumes to the emotional connection that these types of activities provide, whether from storytelling or gamification methods. They are extremely important for education as they create a better learning experience, regardless of the inserted context.

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