Storytelling and hands-on activities boosting young children's awareness and understanding of chemistry

Abstract This article sums up three case studies carried out at a Portuguese science center, an elementary school, and a preschool, where storytelling and hands-on activities were combined. These studies produced indicators in line with the idea that appropriate and carefully chosen stories, combined with hands-on activities, may be a useful pedagogical approach to promote the attraction of young students to science and to teach some of its concepts. The hands-on activities, related to prior storytelling, seem to be a good way to involve students through listening, reading, imagining, understanding, making, and explaining, and thus can generate interest in science and scientific research. Furthermore, it is necessary to make a deeper assessment of the impact of those approaches on learning, development of scientific literacy, and the way young students perceive chemistry.
Keywords **Preschool/elementary/middle school science, storytelling, hands-on learning.**

Résumé **Histoires et activités pratiques pour sensibiliser les jeunes enfants et renforcer la compréhension de la chimie**

Cet article résume trois études de cas réalisées dans un centre de sciences portugais, une école primaire et une école maternelle, où histoires et activités pratiques ont été combinées. Ces études sont en accord avec l'idée que des récits appropriés et choisis avec soin, associés à des activités pratiques, peuvent constituer une approche pédagogique utile pour attirer de jeunes étudiants vers les sciences et enseigner certains de ses concepts. Les activités pratiques, liées au récit qui les précède, semblent être un bon moyen pour que les élèves écoutent, lisent, imaginent, comprennent, créent et expliquent, et peuvent donc susciter un intérêt pour la science et la recherche scientifique. En outre, il est nécessaire d'approfondir l'évaluation de l'impact de ces approches sur l'apprentissage, le développement de la culture scientifique et la façon dont les jeunes étudiants perçoivent la chimie.
Mots-clés **École maternelle/élémentaire, collège, science, narration, activités pratiques.**

The relevance of science in preschool and elementary education

The need to prepare young people for a future that will require proper levels of scientific and technological literacy has been incessantly growing [1-3]. It is doubtless that science education, in early school years, can offer a crucial contribution to the promotion of scientific literacy, fostering the development of a scientific attitude when approaching problems, through the comprehension of subjects, processes, and the nature of science. It has been seen as beneficial to introduce science to students who are in an early stage of development, where the understanding of numerous new concepts is taking place. Likewise, early contact with scientific phenomena will make it easier for children to understand the concepts underlying these phenomena in the future. At early levels of education, children enjoy observing natural phenomena and actively engaging in searching for explanations for what they see. The use of scientifically accurate language, appropriate to the children's cognitive development, can also promote a better understanding of scientific concepts and contribute to the expansion of scientific thinking [3-6].

Nonetheless, most mental models about facts and phenomena, at such young ages, are far from correct. However, its improvement can be boosted with the implementation of science-related activities with young children, and they can achieve reasonably sophisticated scientific understandings. The combination of storytelling and hands-on activities uses both logic, mathematical and narrative modes of thinking, and turns the learning process into a more complete and effective experience [3, 7].

The combination of storytelling and a hands-on approach

Storytelling has always been a powerful way to teach, drawing the listener's attention, interest, and imagination. Some strengths of the storytelling approach are [5, 8-9]:

- in a reasonably small number of words, stories transmit large quantities of information in a format that makes it easily assimilated by the listeners;
- a well-told story is capable of promoting mental skills that improve memory and trigger discovery, exploration, and reimagination processes, providing conditions for subsequent learning;
- storytelling can share experience and context, accommodating various perspectives and realities.

There seems to be an increasing unanimity that children's literature can be used to teach science and promote interest and positive attitudes towards learning science in the early years [10]. As an example, we can mention McKean's books [11-12], which meld pictures with chemistry activities. We can also refer the activities integrating the famous Harry Potter books with hands-on experiments [8], which generate excitement in elementary school students.

Hands-on activities are an educational experience in which people actively seek knowledge or understanding. They allow children to act in several different ways while they get a direct and visible reaction to their actions. So, hands-on activities

are seen as a successful way to teach young children [3, 13]. Activities can be improved according to communication rules, the development of science-related skills (observation and measurement), and increased decision-making and problem-solving, acting on the development of positive attitudes towards science. The combination of storytelling and hands-on activities can be a successful way to help young children build valuable links between theoretical knowledge and empirical evidence [3, 7].

Writing stories for young children and developing a set of hands-on activities

The "Storytelling with Chemistry" book

The book includes seven stories about chemistry, told in a simple and introductory way [14]. The stories combine real-world and fictional scenarios and try to emphasize the importance and application of chemistry in daily life. The stories include three characters: Tomás, the narrator, and the twins, Lina and Pepo, who are the main characters of the adventures. We highlight the stories *All in the dark* and *Aitch-two-o: A drop of water*, which were implemented, respectively, in the first two case studies, described in the next section.

All in the dark's storyline is the following: in the context of a birthday party, a balloon escapes through the window and flies up high in the sky. Lina and Pepo try to catch it and end up getting lost in a dark forest. They meet an owl, who helps them understand why the helium balloon has escaped. The owl also explains the chemistry behind the yellow lamps in street lighting, which went out and left the village in the dark. We can find two chemical ideas in this story: the introduction to the concept of density and a reference to the applications of the chemical elements helium and sodium. Based on the story, specific hands-on activities were designed. One of them is *lava lamp*, where liquid materials, such as colored water and oil, are mixed inside a glass jar. To the two immiscible liquids, effervescent tablets are added. The release of carbon dioxide "draggs" some of the colored water to the surface of the oil layer.

The chemical element sodium was introduced in the story followed by two hands-on activities involving this chemical element. The first one is *filling a balloon*. Baking soda is placed inside a balloon, which is inserted around the neck of a glass bottle that has previously been filled with some vinegar. The chemical reaction between the baking soda and the vinegar's acetic acid produces carbon dioxide, which fills the balloon. The second activity is *colored "flubber"*: polymers are made involving sodium tetraborate decahydrate [3].

The story *Aitch-two-o: A drop of water* revolves around the properties and the chemical composition of water, emphasizing the presence and applications of the chemical elements oxygen and hydrogen. Then, a group of hands-on activities related to water was carried out. The first activity is *red cabbage indicator*, where acid-basic daily life samples are identified by the different colors of red cabbage. The next activity is *surface tension*, where the challenge is to count the number of drops that can be placed on the surface of a medal until it overflows. Afterwards, the activity *ice in a minute* uses a supersaturated solution of sodium acetate to simulate the formation of ice. Following that, in *humidity*, the presence of water is tested through the use of anhydrous copper sulfate and objects impregnated with an aqueous solution of cobalt chloride II. The final activity is *magic water*, in which a redox reaction using a pre-prepared bottle with a mixture of sodium hydroxide, glucose and methylene blue take place [15].

Stories and related hands-on activities created by school chemistry students

A group of sixteen middle school chemistry students (divided into four smaller groups), that had previously experienced learning acid and base concepts through a storytelling approach, wrote four stories and organized related hands-on activities on the topics *atmospheric pressure*, *states of matter* and *changes of state*, considering the official learning goals set for preschool education in Portugal.

The stories were original and creative, emphasizing particular scientific-related contents. The story *The Adventure of Gutin, Tânia and Carlos* (group 1) follows a dialogue among a penguin, a turtle and a crab about the states of matter and the changes of state they found in their daily lives. As a hands-on activity, students designed a game of cards with images of several common materials for preschoolers to identify the physical state.

The story *Antonieto's day* (group 2) focuses on weather forecasts, highlighting the concept of temperature. As a hands-on activity, a homemade thermometer was proposed, using daily basis material (glass and straw) to explain how the concept of temperature and atmospheric pressure affects the weather forecast.

The story *John and chemistry* (group 3) describes an adventure of John and his friends in the kitchen, where the changes of the states of matter are explored.

Finally, the fourth story, *The life of an Eskimo* (group 4), focuses on the climate changes that have a central role in the adventures of Dimitri, the Eskimo, and Tobok, the dolphin. Groups 3 and 4 collaborated in the construction of a colorful model demonstrating the water cycle. The students used materials that were easily accessible in their daily life such as an aquarium, water and building blocks [7].

Case studies

We summarize here three case studies carried out in the last few years [3, 7, 15] using the stories and the hands-on activities previously described with a common purpose: to boost young children's awareness and comprehension of chemistry through storytelling and a hands-on activities approach.

It is important to note that, prior to the implementation of the case studies, the School/Science Centre Director, the students and their parents, as well as the teachers involved, were informed about the research objectives [16].

Children's drawings and painting activities can provide us with indicators about the child's emotions, thoughts, perceptions, concepts, reactions, preferences, and skills. Thereby, drawings may be used as a tool for assessing the knowledge acquired by a child. In these case studies, drawing activities and written records have been used to gather data [17-18].

Chemistry @ science center: "*All in the dark*" story and hands-on activities

A group of twenty-nine young students from an elementary school near Coimbra, in Portugal, aged 8 to 10 years old, participated in a study that took place in 2014-2015 at the science center "RÓMULO Centro Ciência Viva da Universidade de Coimbra" [3].

Figure 1 - Example of the students' drawings. The most pictured hands-on activity was colored "flubber" (A); students' drawings representing the students in storytelling moment and all hands-on activities carried out (B) (source: [3]).

To tell the story *All in the dark*, a celebratory atmosphere was created. Students wore hats and were given whistles and party balloons. Some volunteer students were invited to read and represent the story. In the end, students were asked questions about their understanding of the story, placing the emphasis in the chemical elements mentioned and the concepts covered. After the storytelling moment, students went to the space where the hands-on activities related to the story would be held. The activities were *lava lamp*, *filling a balloon* and *colored "flubber"* (as described before). Once all hands-on activities were completed, students were asked questions about their understanding of what they had experienced and started making their drawings. The children's drawings revealed which activity or combination of activities they enjoyed the most during the informal experience at the science center (*figure 1*).

The *table I* systematizes the themes and the foci of the drawings. Through the drawings, the students have proved themselves able to identify the product, the process and the parties involved (actors). According to students' drawings, the hands-on activity with the most impact was the *colored "flubber"*, maybe because it was the only one that had a product resultant of the experiment that could be saved. The second most depicted hands-on activity was the *lava lamp*, based on its chemical process. Students felt difficulties in showing, through their drawings, the relationship of each experiment with the story told. However, they illustrated the holistic vision of the experience that they lived, showing the multiple experiments and the storytelling moment.

It is important to emphasize that students have shown themselves to be aware of technical and scientific matters, becoming immersed in the human and social context of the process of building science and scientific knowledge [3].

Table I - Themes and foci of the drawings (adapted from [3]).

Drawings' theme	Drawings' foci				Total
	Product	Chemical process	Actor-centered	Story	
Lava lamp	-	2	-	-	2
Filling a balloon	1	-	-	-	1
Colored "flubber"	5	1	2	-	8
Multiple experiments	1	-	-	1	2
Indefinite or unidentified	-	-	1	-	1
Total	7	3	3	1	14

Chemistry @ elementary school: the story "*Aitch-two-o: A drop of water*" and hands-on activities

A group of thirty-eight young students from an elementary school in the north of Portugal, aged 8 to 10 years old, participated in a study that took place in 2017-2018 at their school, implemented by a group of researchers from the University of Porto [15]. A free association task was used to collect, at least, three words that students associated to water

Figure 2 - Using the adequate props, the story "*Aitch-two-o: A drop of water*" was told.

Figure 3 - Hands-on activities: *surface tension* (left) and *ice in a minute* (right).

before and after the story *Aitch-two-o: A drop of water* had been told. Using adequate props, the story was told (*figure 2*). Then, related hands-on activities, in which water had a central role tied to the story, were carried out with the active participation of the students: *red cabbage indicator*, *surface tension*, *ice in a minute*, *humidity*, and *magic water* (*figure 3*).
During the hands-on activities, students were requested to take notes on what they were observing, doing and thinking. Moreover, the students faced the challenge of making predictions of the phenomena, comparing their predictions with the obtained results in the hands-on activities, and then explaining the phenomena observed. The students had a kind of *lab notebook* and all their answers and notes were taken in it. The words that the students associated to water before and after the storytelling moment changed. Before the storytelling, the most common words were *rivers* and *sea* – words related to the liquid state of water in nature – and *drinking* and *thirst* – words related to physiological needs. After the storytelling, the most common words were *ice*, *vapor*, *clouds* and *rain* – words related to concrete examples of the three states of water –, but also their scientific names *solid*, *gaseous* and *liquid*. Students also referred chemical elements present in the water formula: *oxygen* and *hydrogen*. Only a few common words were used both before and after the storytelling moment: *rivers*, *rain* and *liquid*.
Students revealed a strong engagement in the hands-on activities. They were surprised when they saw changes of color in *red cabbage indicator*, *humidity*, and *magic water* (redox reaction) activities, and changes of state in the activity *ice in a minute*. Nevertheless, they showed some difficulties in interpreting the phenomena present in same activities such as: in the *ice in a minute* activity (with a supersaturated solution), nearly half of the students (47%) did not correctly integrate dissonant tactile and visual observations, i.e., the bottle containing the solution was hotter than was expected; however, macroscopically, considering the color and the crystal aspect of the solid, it seemed to be ice (dissonant result: hot ice!).
In the *magic water* activity (redox reaction), students had difficulties in the distinction between water and aqueous solutions, as only 10% of students understood that the mixture used in the experiment contained water, but it was not only water [15]. These preliminary results that come from an ongoing research emphasize the need to further improve the storytelling and related hands-on activities in order to better communicate chemistry to a young audience, considering not only their features – cognitive skills, social representations, context –, but also the very own specificities of chemistry science (such as complexity, use of difficult-to-understand language and a requirement of mathematical skill, and knowledge at a microscopic level so as to decipher the observed macroscopic evidence).

Chemistry @ preschool: atmospheric pressure, states of matter and changes of state

This study involved fifty-three students from two educational levels: sixteen middle school chemistry students, ages ranging from 13 to 14 years old, and thirty-seven preschool children, aged between 4 and 5 years old, and took place in a preschool in the north of Portugal in 2013-2014. The interaction between the middle school chemistry students and the preschoolers occurred on two separate days: groups 2 and 3 presented their stories and activities in the first day, for one hour, to preschool group A (eighteen children, aged 4); groups 1 and 4 presented their stories and activities two days later, also for one hour, to preschool group B (nineteen children, aged 5).
The preschoolers sat in a circle around the older students while the stories were told, complemented with projected images and animations. Then, the preschoolers participated in the hands-on activities. They were always very interested and curious, being very attentive during the storytelling and interacting with enthusiasm with the speakers at the end. During the practical activities, the preschoolers were equally responsive and proactive. All their drawings displayed some scientific elements related to the storytelling and the hands-on activities. That gives us good indicators that some scientific knowledge was transmitted from older to younger students. There is, however, an apparent tendency: the younger students (group A, aged 4) always chose to represent the characters of the stories, while the older students (group B, aged 5) showed a wider variety of elements. The drawings by group A also show consistency in the illustrations, as most of the students drew the water cycle. Regardless of the students' enthusiasm about the project, they still encountered difficulties in acknowledging the scientific content present in the stories told to them. These difficulties may be related to the novelty effect of the project and the short duration of its implementation. Additionally, it is important to stress that, in line with Wally *et al.* [8], we have also found that this type of activity is an opportunity for the young "teacher-students" to recognize that they actually do know more about science than what they might have thought [7].

Next steps: awareness and comprehension

Despite the fact that our samples are too small to allow generalizations, it could be said, however, that our studies produced indicators which seem consistent with the idea, expressed by several authors, that the use of appropriate and carefully chosen stories, combined with hands-on activities, is a valuable pedagogical approach to promote the attraction of young students to science and teach some of its concepts.
Projects where middle school chemistry students interact with students from preschool also contribute to enhance the cohesive image of the school as a community. The results that we have reached through the implementation of these three case studies raise new questions and suggest further research topics: to investigate if there will be any advantage

in using these stories to teach subjects in formal learning environments, comparing this approach with traditional teaching approaches; and to ensure that the combined storytelling and hands-on activities approach can be carried out systematically, by including follow-up moments and comparing the responses at oral, written, and plastic levels, including an adequate evaluation of the young children's awareness and comprehension of chemistry [19-20].

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Pedro Texeira's illustration for the story *Aitch-two-o* in the book *Histórias com Química* (see p. 44).