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Communicating science through the Comics & Science Workshops: the *Sarabandes* research project

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Abstract

The aim of this paper is to analyze the impact of Comics & Science workshops where forty-one teenagers (designated Trainee Science Comic Authors [TSCAs]) are asked to create a one-page comic strip based on a scientific presentation given by a PhD student. Instrumental genesis is chosen as the conceptual framework to characterize the interplay between the specific characteristics of a comic and the pieces of scientific knowledge to be translated. Six workshops were conducted and analyzed. The results show that the TSCAs followed the codes that are specific to the comic strip medium and took some distance with the science integrity. Nevertheless being involved in the creative process allowed them to understand the reasons for certain choices of science illustration or storytelling. This approach can foster the emergence of a critical mind with respect to reading science stories created in other contexts.

Keywords

Informal learning; Representations of science and technology; Science education

Introduction — context

Science communication / education and science comics: review of the literature

An increasing number of science communication projects promote and use narrative media to help the target audience discover the scientific universe — its methods as much as its contents — through the prism of art. Theater, literature, cinema or the novel are some of the artistic forms that are used to communicate science in order to make it more attractive and appealing. In all cases, the goals of the project depend heavily on the specific characteristics of the chosen artistic medium. As an example, the theatrical narrative has been adopted for plays involving well-known scientific controversies, such as the discovery of oxygen [Djerassi and Hoffmann, 2001], the life of famous scientists, such as the Brecht's *Life of Galileo* Brecht [2015], and even explanations of scientific principles, such as the second law of thermodynamics [Stoppard, 1993]. Whatever the chosen medium, stories have been used to explain and recreate science, with the aim of entertaining, informing and/ or educating the public. Nevertheless, the overwhelming majority are used by teachers in an educational context. This communication method has proved to be a popular and relevant tool for transmitting accurate scientific information that will be remembered [Negrete and Lartigue, 2010].

Visual arts, such as comics and graphic novels, are based on a sequence of juxtaposed panels (single drawings depicting a moment) that usually represent individual scenes. These panels are often accompanied by brief, descriptive prose and a written narrative [McCloud, 1993]. This complex interplay of text and images is an effective and relevant medium for promoting scientific literacy *via* education and communication [Thomas, 1983; Girault, 1991; Tatalovic, 2009]. Comics and graphic novels have the potential to effectively convey the biographies of famous scientists [see, for example, the graphic novels published by GT Labs in the United States; Papadimitriou et al., 2010; Ottaviani and Myrick, 2011] and/ or scientific concepts, in the form of illustrated courses [Gonick and Huffman, 2005; Auerbach and Codor, 2016]. Other references can be found in Tatalovic [2009], who provides a very complete overview of comics that communicate science from the 1980s to 2009.

Although it has been widely claimed that comics have an important role to play in science education [Tatalovic, 2009; Lo Iacono and de Paula, 2011; Auerbach and Codor, 2016], very few studies have evaluated their effect on science learning. A notable exception is the work of Laveault and Joly [1987], which analyzed the effects of using cards to present concepts in comic strip format in teaching mathematics and, more recently, the comparative study conducted by Hosler and Boomer [2011], in which the authors assessed the pedagogical effectiveness of a biology comic book called *Optical Allusions*.

Most research that addresses the interplay between science comics and science education focuses on the use of existing comic books in the classroom [Chevallier, 2013; Hosler and Boomer, 2011; Arguel, Bonnefond and Matricon, 2017]. From this perspective, students are readers and their cognitive activity depends upon the identification of the scientific information conveyed in the comic books, the search for coherence, and the memorization of scientific information associated with a picture or a sequence. Consequently, the acquisition process relies heavily on the choices (text, drawings, narrative, page layout, etc.) made by the authors. The teacher plays the role of guide who facilitates the identification and elicitation of the relevant information.

Some authors provide a counterpoint to this educational practice, and have called for students to be more involved in the creation of comic strips, or books, in the classroom [Wright and Sherman, 1999; Morrison, Bryan and Chilcoat, 2002]. For the latter authors, "constructing a comic book requires students to determine what is most important from their readings, to re-phrase it succinctly, and to organize it logically" [Morrison, Bryan and Chilcoat, 2002, p. 760]. This "story-retelling" strategy appears to be a fruitful educational approach that holistically combines language, science and the arts.

Several experiments have been designed that involve students in the translation of scientific knowledge into comic strips [Gonzales-Espada, 2003; Lo Iacono and de Paula, 2011; Albrecht and Voelzke, 2012; Arregui and Otegui, 2016]. In most cases the creation of comics is valued as a powerful way to motivate students to take an interest in science, but the authors provide very little information regarding how these comics represent science (and scientists). In general, there are few critical analyses reporting how and why the specific scientific concepts were selected and transformed into this medium, and what the students actually learned from the activity. As Tatalovic [2009] points out, "Research into these comics and their audiences embrace the use of comics as an exciting way of communicating science (. . .). But none of them actually address critically the content of these comics or science itself. What image of science do these comics contain? Who decides what image of science goes into comics? How do these comics represent science and the scientists, and how might this affect the readers beside the reported excitement of children of using comics in science classes?" [ibid., p. 13]. These questions partially motivate our research.

Aim of the research and research questions

The SARABANDES research project

Since 2011, the French Stimuli Association for science communication has supported the creation of short, science-based comic strips through the organization of *Comics & Science* workshops. A group of volunteers aged 12 to 16 years (designated as Trainee Science Comic Authors [TSCA]) create a one-page comic strip about science, during a 12-hour workshop held in their leisure time. The workshop begins with a presentation by a scientist (a PhD student) of an aspect (scientific content and/ or process) of his/her research to the TSCAs. This material is then translated by the TSCAs into the form of a one-page comic strip. More precisely, they are asked to create a comic strip inspired by the PhD student's presentation; at the same time, they are totally free to select the aspects they want to adopt and the narrative, the text, and the visual organization. They are helped in the process of creation (both visual and narrative) by a professional comic artist and a science communicator [Bordenave, 2012]. The artist explains the basics of comic design (characters, expression of emotions and feelings, composition of a frame, sequential movement, etc.). The science communicator participates, with the scientist, in the dialogue with the TSCAs; he/she explains the basics of writing a script, and helps the TSCAs to combine the design and the knowledge they want to present in the comic strip. At the end of the workshop, each TSCA exhibits their comic strip, and explains what motivated their choices, their intentions, etc. All of the comic strips are then scanned.

Between 2014 and 2016, six of these *Comics & Science* workshops were studied in the context of the SARABANDES[1] project. The main aim of SARABANDES was to characterize how scientific information is disseminated and transformed when translated by a student into a one-page comic strip. The workshops were conducted jointly by the Stimuli Association and a French science education research team.[2] Specifically, the analysis focused on the terms of the dialectic operated by the TSCAs regarding the constraints and possibilities (narrative, layout, sequential drawing, text in balloons, etc.) of the comic form, and those of the science to be translated. The contents and the nature of the interplay between the various actors participating in the workshop were also taken into account.

[1] The *Stimuler l'apprentissage et la réflexion par des ateliers de bande-dessinée* (Stimulate learning and thinking through comics & science workshops) is a research program supported under the PICRI French Regional Grant (2014–2016 - RIDF).

[2] The *Laboratoire de didactique André Revuz* (EA 4434).

Conceptual framework: instrumental genesis

From a conceptual point of view, the creation of a science comic strip by the TSCAs can be examined in the light of the instrumental genesis framework [Rabardel, 1995; Rabardel and Beguin, 2005]. The concept of instrumental genesis encompasses both the evolution of an artifact (a comic strip with its own specificities and constraints), and the creation of use schemes, both of which participate in the emergence and development of a learning and mediating instrument (here, a science comic strip). The concept of use scheme draws on Piaget's definition of scheme [Piaget, 1952]. According to Piaget's approach, the human being constructs the world through the development of schemes on the basis of two mechanisms: assimilation and accommodation. Assimilation means the integration of exterior elements into existing schemes (corresponding to Rabardel's intrumentalization). Accommodation means that new schemes have to be developed in order to take into account new informations (corresponds to Rabardel's instrumentation).

In the context of our work, the schemes at work in the creation of the comic strip are a response to all the constraints linked on the one hand to the codes and rules of the comic strip as an artifact that the TSCA must identify, understand and manage, and on the other hand to the functions attributed to the one-page comic strip as an instrument and devised by the TSCA (the comic strip must make readers learn something, make them laugh, frighten them, etc.). The schemes at work are also a response to the functions that the staged scientific knowledge will perform on the comic strip structure. The assimilation of certain codes, specific to narrative writing in the comic form, will be all the easier as these codes are close to the natural thinking or scientific prior knowledge of the TSCA and compatible with certain specificities of the scientific knowledge at stake. Accommodation activity will depend on the functions assigned to the one-page comic strip.

In that respect, the creation of a one-page comic strip as an instrument for the TSCA to convey scientific knowledge can benefit from a kind of kinship between the specificity of the artifact and certain patterns of natural thinking. For example, the comic book (in its classical form) is organized according to the arrow of time (reading from left to right and from top to bottom), which can encourage the narration of scientific knowledge or processes that are themselves temporally organized. In this case, it can be expected that the scheme mobilized by the TSCA will generate a scientifically non-corrupt content insofar as his or her own thinking naturally organizes the events in a chronological manner (including when they occur simultaneously [Viennot, 2001]). On the other hand, some of the characteristics of comics may make difficult to preserve a form of integrity in the scientific content (visual transcription, etc.). For example, comics encourage anthropomorphism, thereby encouraging another natural thinking trend of lending life, intentions, and words to objects devoid of these properties [Kallery and Psillos, 2004]. Comics would then reinforce these trends. Consequently, it is possible that the functions that the TSCA projects on his or her one-page comic strip (a comic strip that makes you learn, laugh, cry, etc.) require the mobilization of narrative and visual elements that deliberately do not conform to the specificities of the scientific knowledge at stake. Such an emancipation from scientific rationality will have to be questioned because it will not necessarily be a sign of an erroneous appropriation of knowledge.

Finally, it is assumed that it is the mastery of a complex set of graphic and narrative codes, and scientific elements that will allow the TSCA to create a one-page comic strip that will have meaning for an outside reader. The analysis of the choices made by the TSCA will allow us to trace back to the elements that have brought about assimilation and accommodation, and consequently, cognitive activity.

Research questions

In this paper, the focus is exclusively on the instrumentalization process: how a generic comic strip evolves into a science comic strip. The one-page comic strips that were generated were considered as the result of an evolution of the artifact based on the interplay between the following elements: the rules and constraints applied to a generic comic strip; the intentions of TSCAs regarding the generated science comic strip; the epistemic specificities of the PhD student's presentation, and the TSCA's choices regarding the elements in the presentation to be translated into the strip. As mentioned above, the analysis was guided by a general question regarding the dissemination and transformation of the PhD student's presentation when translated by a TSCA into a science comic strip. This perspective led to the following research questions (RQ):

- RQ1: To what extent, and how, does the comic strip artifact shape the translation of the elements of PhD student's presentation into a narrative?
- RQ2: What is the scientific validity of the elements of knowledge contained in the generated comic strip? How are the PhD student's presentation and the scientific elements contained in the comics connected? What is the role of these elements in the form and substance of the comic strip?

Methodology of collecting and analyzing data

The use of the instrumental genesis framework shaped how data was collected and processed. The instrumentalization process requires comparing the generated panels with the PhD student's presentation, consideration of the elements provided by the TSCAs themselves, and a comprehensive study of the interplay between all of the actors who guided the TSCAs during the creation process.

Method of collecting data

Six, full-day (12–18 hours) *Comics & Science* workshops were held that focused on three academic disciplines (physics, mathematics, and biology). A total of 41 TSCAs took part. These workshops provided the following data used in the analysis (Table 1):

- The 41 comic strips created by the TSCAs who participated in the workshops (WS 1–6) (data D1).
- Transcripts of the verbal exchanges regarding the elements presented in these strips, taken from video recordings of the workshops (data D2).
- Transcripts of a selection of the 41 post-workshop audio recordings, in which the TSCAs presented their work and explained their choices in terms of the science, technical drawings, narrative, intentions, etc. (data D3).

Table 1. Distribution of the 41 science comic strips generated for each workshop (WS) and discipline.

<table>
<tr><td colspan="2">Physics Physics of the Sun</td><td colspan="2">Mathematics Cryptography</td><td colspan="2">Biology Micro-organisms</td></tr>
<tr><td colspan="2">Main content and aim:
General overview of the solar system and beyond (exoplanets), including the physical and chemical properties of the Sun. Presentation of detection and analysis instruments and devices. Description of the everyday professional activity of an astrophysicist. Elements of the history of science.</td><td colspan="2">Main content and aim:
The overall theme of the workshop was cryptography. The PhD student gave a general, historical presentation of the field and described a few encoding (Caesar, Vigenère, asymmetric encryption) and decoding (key systems, letter frequencies) methods. This presentation was a new initiative within the Sarabandes Project because TSCAs were asked to encrypt a sentence using various methods, then try to decipher a text, used encoding–decoding software.</td><td colspan="2">Main content and aim:
WS5: the difference between bacteria, fungi and viruses, with a focus on microalgae (ecology, sampling and observation).
WS6: environmental microbiology with a focus on bacteriophages (structure, ecology and observation) and the everyday professional activities of a microbiologist.</td></tr>
<tr><td>WS1: 18 hours November 2014 to April 2015</td><td>WS2: 14 hours October 2015</td><td>WS3: 14 hours April 2015</td><td>WS4: 14 hours April 2016</td><td>WS5: 12 hours April 2015</td><td>WS6: 14 hours February 2016</td></tr>
<tr><td>11 comic-strips</td><td>9 comic-strips</td><td>7 comic-strips</td><td>2 comic-strips</td><td>3 comic-strips</td><td>9 comic-strips</td></tr>
</table>

Three topics (the physics of the Sun/ cryptography/ micro-organisms) were selected by the authors of the present research. This choice was guided by the need to identify topics that included elements which were compatible with the expected process of creation. Notably, we initially sought elements (contents, processes) that could be drawn, told, personified, rephrased, etc. In the next stage, we selected several topics of active research (per discipline) that could be illustrated by an available and open-minded, volunteer PhD student.

Two workshops were held on each topic. This was in order to expand the corpus to be analyzed. This structure also made it possible to identify inter- and intra-discipline patterns and singularities in the choices of the TSCAs.

Methodology of data analysis

The analysis was broken down into two steps, involving eight researchers from different disciplines (three physics education researchers, two mathematics education researchers, one biology researcher/ science communicator, one comic artist, and one researcher in the educational sciences — all are authors of this paper).

- Step 1: a analysis grid was developed in order to characterize and classify the elements found in the 41 panels (data D1). Categories were generated in an iterative process that was based on the definition of *a priori* and *a posteriori* categories. More precisely, a first set of categories was defined based on the specificities of the comics considered as an artifact (Who is the hero? What is the genre of the narrative? etc.), and from the content of the PhD student's presentation (What are the scientific contents/ processes? Is the content scientifically correct? etc.). A second set of categories emerged from peer review analyses of the comic strips and specifically concerned the interplay between the narrative and the scientific content. For example: does the strip include content that answers a scientific problem? Is the scientific knowledge necessary to understand the comic strip? This grid made it possible to quantitatively evaluate the different elements in each strip, to look for inter- (or intra-) discipline trends, and to highlight the differences between the PhD student's presentation and the content of the strips.

– Step 2: for each of the six workshops, the complete corpus from one, randomly-selected TSCA was analyzed. This included his/her first draft and final comic strips, all of his/her interactions with the PhD student, the comic artist and the science communicator, and his/her post-workshop feedback. The aim was to follow, step-by-step the dynamics of the creation process and understand the elements of the PhD student's presentation through the TSCA's choices (the genesis perspective). From a methodological perspective, this consisted in tracing, for a given element in a comic strip (a drawing, text, scenario, etc.) its history as it developed during the workshop, based on the transcripts (data D2 and D3).

The analysis presented below consist of descriptive analyses of the 41 comic strips. These record the literary genre and the nature of the protagonists. They also highlight the place and the nature of the elements of the PhD student's presentation, and their relation with the comic strip's narrative, drawings, and text. Then, some of the choices made by the TSCA are reconstructed based on analyses of the overall process of creation from a more holistic perspective. We also identify the repetition of certain aspects in the descriptive analysis in order to expand our analysis.

Data analysis

The generated comic strips included a wide range of fictional narratives. Thirty five percent (N=41) were clearly intended to be humorous, while 27% described an adventure (Table 2). Fewer strips could be categorized as "didactical" (17%): in these instances, the pedagogical intention (transmitting scientific information) prevailed over attempts to tell a story. Other genres or fictional universes were poorly represented (thriller, documentary).

Like genres, a wide variety of characters was observed in the narratives (Table 3 and Figure 1). Most (32% of all drawn figures) were archetypal fictional protagonists: policemen, thieves, super-heroes, extraterrestrials, famous comic characters (Tom & Jerry, SpongeBob). Scientists and researchers made up 26% of protagonists, while 15% were teachers or students (including avatars of the TSCA him/herself). While 21% of characters were the studied scientific object: micro-organisms, viruses, bacteria, the Sun, the Earth, stars, or the planets (examples are provided in Table 2), this was only observed in the physics and biology workshops. This is unsurprising since science communication media often

Table 2. Distribution of genres observed in the comic strips.

Genre (%)				
	Physics WS	Biology WS	Maths WS	Total WS
Funny / Humorous	25	42	50	35%
Adventure / Heroic	36	17	17	27%
Thriller / Suspense	10	8	25	13%
Documentary / Biography	4	25	0	8%
Didactic (lesson)	25	8	8	17%

Table 3. Distribution of the type of characters presented in the comic strips.

Type of characters (%)				
	Physics WS	Biology WS	Maths WS	Total WS
Scientist / researcher	13	44	0	26%
Archetypal story figures	39	19	78	32%
The TSCA him/herself or their avatar	9	19	22	15%
The studied scientific object	26	15	0	21%
Historical character	10	0	0	6%

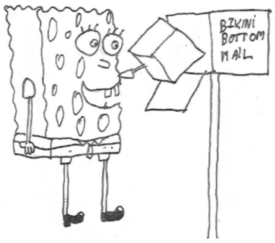
rests upon anthropomorphic representations of inanimate objects and nonhumans [Jurdant, 1993; Pramling and Säljö, 2007], while the comic strip format is very compatible with the staging of characters of any kind.

For example, when animated (in 7 of the 20 physics comic strips), the Sun often talks about his lifespan — which makes him depressed, sad, etc. This allows the TSCA to introduce an informative narrative regarding characteristics specific to the Sun (included in the PhD student's presentation) to the reader (see the top of Figure 2). In the same way, 50% of biology comic strips involved talking, and often 'dangerous' micro-organisms (see the bottom of Figure 2). It should be noted that when the micro-organisms speak, what they say reflects their biological behavior rather than human rationality.

In the physics and biology workshops, when a scientific object was not personified, the narrative was often grounded on a discovery, a scientific process or an exploration that placed a researcher or a scientist in a scientific environment (the laboratory).

In the mathematics' workshops, human characters were presented in all comic strips, and the narrative was founded on code breaking or encryption activities; no mathematical objects or concepts (numbers and operators, for example) were drawn as a character. This was a remarkable observation: mathematics comic strips were the only ones where the majority of the narratives (6 out of 9) were based on the exact process given in the PhD student's presentation, specifically where TSCAs were involved in code breaking and encryption activities (see Figure 3).

(a) Tessa — Maths WS.
"Well, well, what do we have here?"



(b) Amin — Maths WS.

(c) Bastien — Physics WS.
"Hey Sun, do you want to get some info about you?"
"Yeah!"

(d) Yasmine — Biology WS.
"Why do they move around so much?" "So, Dr Revilo, are you making progress in your research on the bacteriophage virus and leptospira bacteria?"

(e) Noah — Biology WS.
This is war!

(f) Yara — Maths WS.

Figure 1. Examples of protagonists (policeman, SpongeBob, the Earth and the Sun, male and female researchers, a warrior virus and bacteria, students and a teacher).

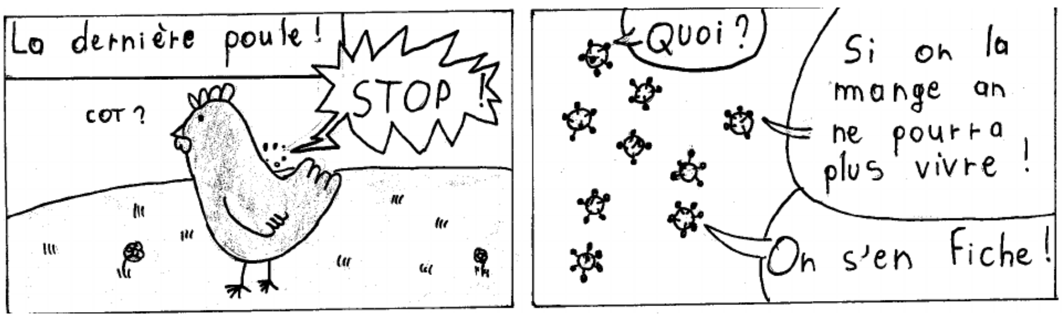
Generally speaking, the elements of the PhD student's presentation (scientific information about concepts and/ or processes) fulfill different roles and are found in different places in the narrative. They can be gathered into three distinct groups.

– Group 1 (27%): although scientific information is stated, it does not participate in the narrative (other information is presented in some cases, including incorrect information). Readers are presented with some scientific facts: for example, the lifespan, mass, distance from the Earth, and chemical composition of the Sun; what micro-organisms are; the phagotherapy process; and even the daily life of a researcher working in a laboratory and their constraints. Yet, this scientific information seems to be unrelated to the understanding of the story. For example, in Figure 4, Tom the cat's monologue is an archetypal representation of a scholar delivering a lecture.

– Group 2 (32%): scientific information is stated and participates in the narrative. In other words, the comic strip gains its meaning from the scientific information that is delivered (Figure 5). In some cases, the scientific information must be known in order to understand the aim of the narrative, or needs to be discovered.

– Groupe 3 (41%): while no scientific information is delivered, a characteristic aspect of the presentation can be recognized in the drawing (Figure 6). For

(a) Marc — Physics WS.
"Thank you, doctor. I have the impression I'm halfway through my life, I'm 4.5 billion years old, worn out, tired".



(b) Arthur — Biology WS.
The last hen… "Stop!" "What?" "If we eat it we can't live anymore" "Who cares!"

Figure 2. Examples of animated characters.

example, the 'energy' of the Sun that is described in the physics workshop becomes a source of energy that transforms a 'giant' into a super-hero in Amin's comic strip. The process of creation embodies a desyncretization process where partial pieces of knowledge (often reduced to words or exact copies of the images used by the PhD student) are extracted to fit within an autonomous narrative that is very different to the original presentation. If this partial knowledge is part of a consistent, coherent scientific argument, it becomes a singular and independent element used by the TSCA to maintain the initial integrity of the scientific knowledge.

Mounir's comic strip (Figure 6) is a remarkable example of the latter. Here, Mounir 'plays' with the distance between the Sun and the Earth, which was one of the scientific facts delivered by the PhD student. Using a visual perspective effect (an artifact of comics), the Sun–Earth distance is reduced to few meters. This allow the narrative to be developed and come to an end: the protagonist grasps the Sun in order to avoid a fall. Nevertheless, the real value of this distance (i.e. 150 million kilometers, or eight light minutes) is neither translated nor provided to the reader, and a first reading of Mounir's comic strip does not make it possible to know what scientific knowledge he has learned.

Figure 3. Mohamed's complete cryptography comic strip — Mathematics WS.
Beginning of the course."Hey psst!" "Caesar cipher... Too bad for you, I can decode it!" "Without the key, it might be difficult" "Need some help? Ahahah!" "Sir, the key is 'C"' "Oh oh! You just have to shift the letters by 3, so A corresponds to C..." "Then it means "I.T. J.U.S.T. R.A.N.G. ..." "See you tomorrow Sir!"

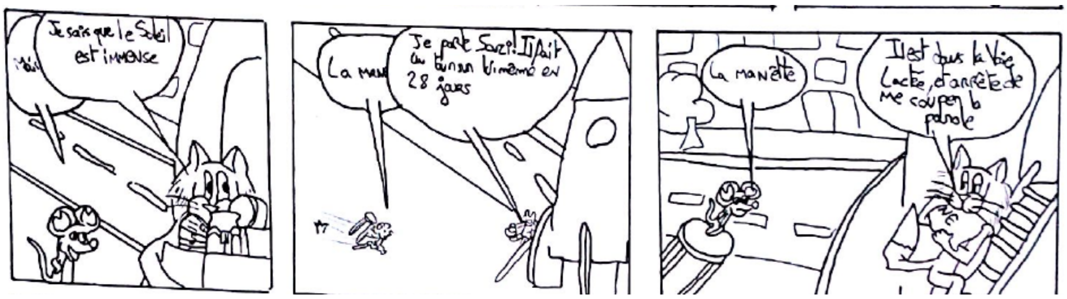


Figure 4. Part of Dos Reis's comic strip — Physics WS.
"Bu. . . " "I know that the Sun is huge" "'The lev. . . ' I'm talking mouse! It turns round and round in 28 days", "The lever" "It is in the Milky Way, and stop cutting me short!"

Figure 5. Part of Yara's comic strip — Mathematics WS.
"Don't worry, he won't understand that it's encrypted with the Caesar cipher shifted by 4 letters", "What . . . ?"

The comprehensive analysis of the workshop transcript enables us to get to the root of this choice. While working on his scenario, Mounir tells the comics strip artist who is helping him about a visual effect he has experienced in his bedroom at home: "In my bedroom there's a basketball hoop and sometimes, when the Sun goes down, I can see a funny effect through the window! It's as if the Sun had passed through the hoop! This is what I want to show; something like that". Mounir even drew three boxes to show how he visualized the effect (Figure 7). The evocation of the Sun is a reminder that acts as a motor for the creation of his narrative. From an instrumentalization point of view, the resource of the comic as an artifact allows Mounir to play with perspectives.

Sometime later, as his comic strip is almost completed, the science communicator asks Mounir to describe his scenario and to point out which elements of the PhD student's presentation influenced his choices:

– Mounir: Actually, my story is about a fool who believes he can touch the Sun. But as Melanie [the PhD student] said, this is impossible because the Sun is *light years away*! But anyway, the fool believes that the Sun is just in reach because of an optical effect and he decides to stack a pile of garbage in order to reach it"

– Science communicator: Light years away? Are you sure?

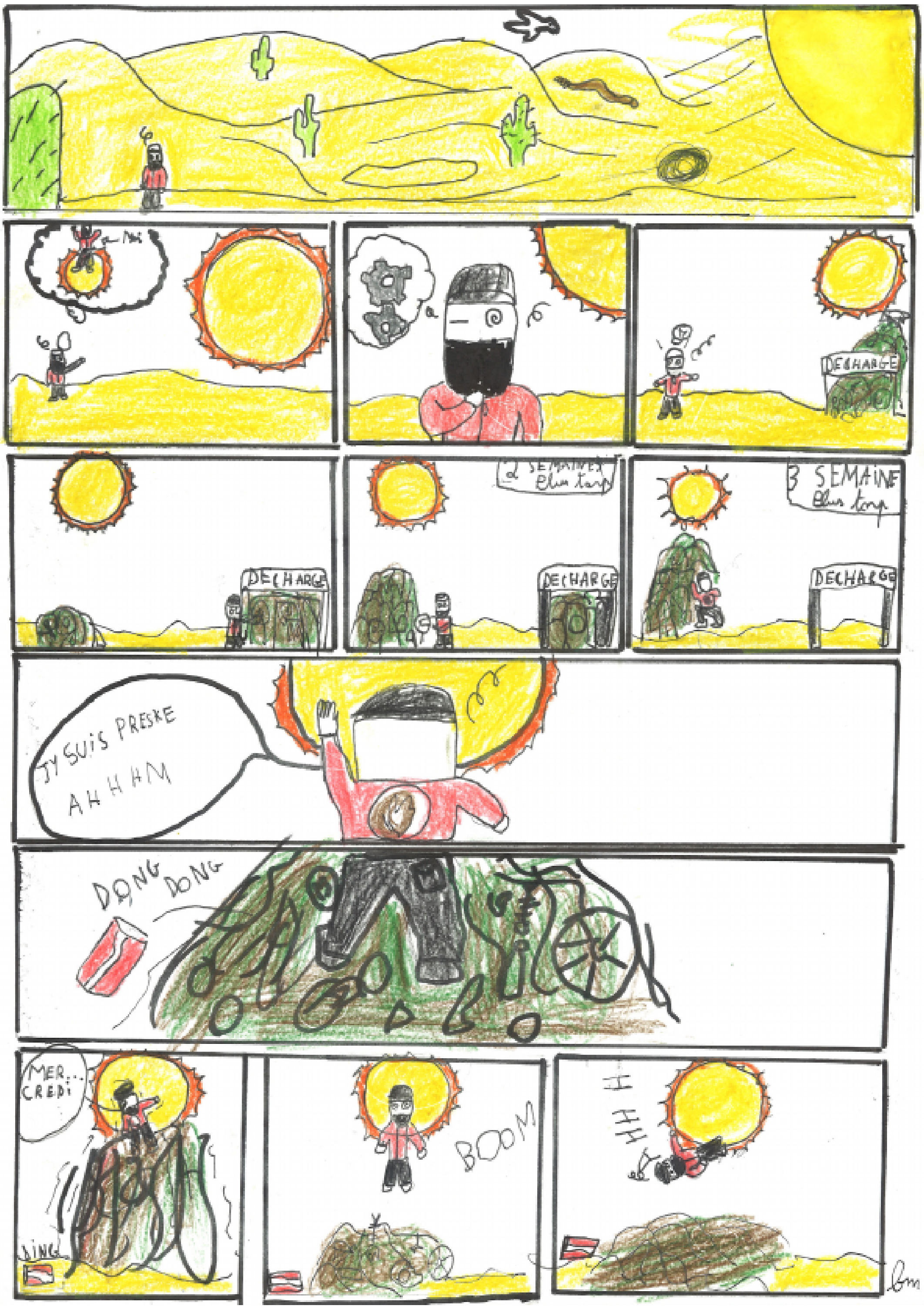


Figure 6. Mounir's comic strip — Physics WS.
Landfill. 2 weeks later. 3 weeks later."I'm nearly there. . . oh oh oh!", "Damn. . . it!"

– Mounir: Well, Melanie said that the light coming from the Sun takes eight minutes to reach the Earth. So yes, it is very, very far.

Mounir faced a common problem resulting from the ambiguity of measuring astronomical distances in (light) time units. He actually retained the correct value

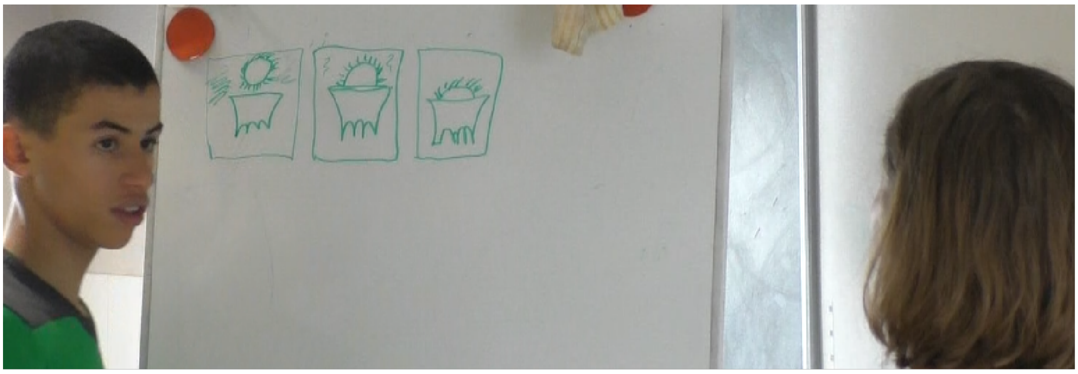
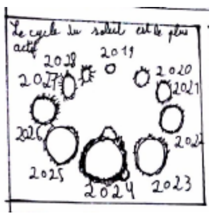
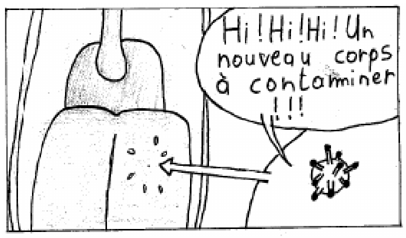


Figure 7. Mounir presenting his initial scenario to the professional artist.



(a) Thierry — Physics WS.

(b) Yasmine — Biology WS.



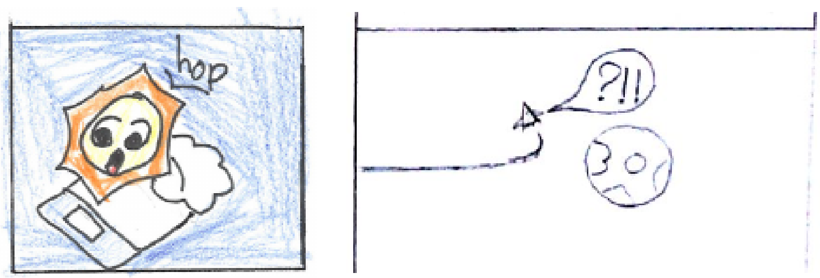
(c) Arthur — Biology WS.
"Ha ha ha, a new body to contaminate!!"

Figure 8. Examples of scale perspectives.

(eight minutes) for the time taken by light to travel between the Sun and the Earth, but did not associate this quantity with a distance. It could be that eight minutes seems, to him, a small quantity that is incompatible with his representation of the Earth–Sun distance as a significant quantity.

With respect to the validity of the translated scientific information, several aspects can be distinguished. Most of the written information (text in balloons) shown in the comic strips of groups 1 and 2 is scientifically valid, as are the drawings of micro-organisms that reprise the images presented by the PhD student. The names of code breaking and encryption processes are consistent with the cryptographic information delivered. When they need to stage different time and distance scales, the TSCAs use the usual drawing resources (a telescope, a microscope, etc.) in order to present impossible visual effects and to provide the reader with the necessary distance and time perspectives (see Figure 8).

In some cases, valid scientific information is incorrectly translated into an image. Two such cases are shown in Figure 9: in Bastien's drawing the scale is a conventional representation of a weighing instrument. Ayssun's case is more problematic: his drawing suggests that he has not fully understood that the gravitational force is always attractive. In fact, for a spacecraft to be deflected, its trajectory must take it away from the planet.



(a) Bastien — Physics WS.

(b) Ayssun — Physics WS.

Figure 9. Examples of erroneous scientific information.

Results

The one-page comic strips generated can be considered as the result of an instrumental process in which an artifact (the general concept of comic) becomes an instrument (a one-page scientific comic strip to-be-read) through a dual cognitive activity of assimilation and accommodation. This activity engages the TSCA in the recognition and exploitation of a certain number of rules and codes specific to graphic narration but also in an activity of selecting elements of a scientific discourse. This set becomes the material from which the final comic strip is built. According to the purposes that the TSCA projects on its comic strip, the dialectic between the properties of the artifact and the elements of scientific knowledge in play is declined according to various ways which also depend on the activated schemes.

For example, the classical structuring of a comic strip is based on an organization in time corresponding to a chronological sequence of boxes from left to right and top to bottom. Cryptographic one-page comic-strips use this property and value stories in which the decryption time of a coded message corresponds to the reading time of the comic strip. Cryptography is based on the fact that a coded message must not be able to be decoded too quickly by someone who does not have the encoding key. This was stated and worked out by the PhD student at the beginning of the mathematics workshop. The narrative necessity of a fall and the humorous dimension sought by many TSCAs also lead to the elaboration of a comic-strip where disappointed protagonists decode an encrypted message too late.

The kinship between comics narrative and some aspects of natural thinking allows TSCAs to clearly state that the notion of "long duration" is a founding principle of the cryptographic process. In other words, the temporal organization of boxes constraint prestructures the TSCA's action, thus increasing their assimilation capacities [Rabardel, 1995]. This feature is also evaluated when events are not to be simultaneous (for example, a coded message should not be sent together with the decryption key, which some TSCAs have both understood and appropriately staged).

From a similar perspective, the fact that the comics narrative is based on moments and actions that are not shown (ellipses) allows some TSCAs to speed up time and move the reader from one place to another, from one scale to another. For example, scale changes (zoom effects) allow to preserve and show the real appearance of certain viruses or bacteria (what microscopic laboratory imaging produces).

Another characteristic of comic strips is also assimilated by the TSCAs: a large proportion of inert or non-human objects are endowed with speech and thoughts.

Again, there seems to be some kind of relationship between what the artifact encourages and natural thinking. This kinship prestructures the action of creating the one-page comic strip but does not limit it. On the contrary, when confronted with biological rationality (delivered by the PhD student), creative action is directed towards narratives that turn away from uncontrolled anthropomorphism. For example, in Arthur's comic-strip viruses behave like viruses as long as they continue to contaminate the host hen regardless of the consequences for the latter, but they also take into account the possibility that the hen may be the last, which in fact they don't "know" (our human vision tells us they might be aware of this). Viruses are a kind of "virus-human being" mix that could be a typical example of a mature assimilation/accomodation of the content staged according to the constraints of the instrument.

Finally, the presence of speech bubbles in the boxes allows almost linear scientific narration, close to the PhD student discourse. It then becomes easy for the TSCA to produce a didactic comic strip, where the intention is to "make readers learn".

In all cases, there is an assimilation of a set of elements linked to the chosen narrative form (comics narrative) and the scientific discourse, and an accommodation of these elements within schemes that organize these elements according to the goals assigned by the TSCA to its creation. This accommodation sometimes leads to distortions of the scientific content (not always) when the narrative elements have taken over. This does not mean that the student has learned or retained anything wrong. Indeed, humor occupies a special place, and irony is often used to mock both the scientists and their knowledge. The codes used in comics allow the TSCA to break the rules that govern the usual spaces for the transmission of scientific knowledge (school, for example). Even if they are asked to respect certain scientific standards (in particular when it comes to using common sense), they are free to do whatever they think is necessary to maintain the coherence of their chosen story and the impact of the ending. In this paradoxical process, order must submit to the authority of the codes of the artefact, which becomes the driver of the creation of a new object. This kind of tension is clearly seen in Mounir's comments on his choices concerning his story, "This is a comic strip! You can't go too far with science (...). I'm not going through calculations and numbers! For me a comic strip isn't a documentary!".

In other words, the Comics & Science workshops are the venue for a sort of competition, where different types of knowledge (on science, on comics) must be learnt. The TSCAs sometimes have to arbitrate between two, recently-acquired pieces of knowledge: telling a good story in an appropriate way, or repeating a valid scientific fact. By deliberately discarding a scientific fact in order to tell a good story, the TSCAs somehow take this scientific knowledge into account. Therefore, it could be said that they validate it.

Conclusion and perspectives

The aim of this paper was to analyze the impact of the Comics & Science workshops. Forty-one teenagers (designated Trainee Science Comic Authors [TSCAs]) were asked to create a one-page comic strip based on a scientific presentation given by a PhD student. Instrumental genesis was chosen as the conceptual framework; specifically the instrumentalization process, which made it possible to characterize the way in which an artifact (a comic) evolves into an instrument (a science comic strip). In other words, we focused on the interplay between the specific characteristics of a comic (its narrative, layout, sequential drawings, dialogues, etc.) and the pieces of scientific knowledge to be translated. Six workshops (two each in physics, biology, and mathematics) were conducted and analyzed through a set of 41 comic strips, and transcriptions of the audio and video-recorded workshops.

The results showed that in the workshops, the TSCAs adopted and followed the codes that are specific to the comic strip medium: characters are archetypal of comic books, the tone tends to be humorous, inanimate objects talk, etc. In this context, the knowledge delivered by the PhD student is selected and staged according to various modalities — and scientific integrity is not always respected. In fact, at times the TSCA was confronted with an intractable difficulty when he/she wanted to 'recycle' scientific knowledge into a comic strip narrative. He/she was obliged to disintegrate this knowledge, select certain elements, leave other parts of it behind, twist some of the information, etc. If the dialectical interplay between the comic strip and the scientific discourse was at the origin of these distortions, it is not necessarily a sign of an imperfect or erroneous appropriation of the knowledge that was delivered. This is supported by the finding that some of the incorrect information represented in the comic strips was sometimes correctly used by the TSCA in his/ her oral exchanges with the science communicator. Analyzed from the angle of instrumental genesis, these distortions can be seen as the result of a process of accommodation through which the TSCA generates a readable narrative work that conveys particular functions. Analyzed from the angle of instrumental genesis, these distortions can be seen as the result of a process of accommodation through which the TSCA generates a readable narrative work that conveys particular functions.

Our analysis of assimilation and accommodation processes has been limited to a few aspects of a complex reality. Comics & Science workshops are rich in interactions (especially between peers) that have not been taken into account to a great extent. Similarly, we found it difficult to integrate the role played by the PhD student since his / her presence and interactions with the TSCAs varied not only from one workshop to another, but also within the same workshop, from one TSCA to another. Nevertheless, the richness of the collected data and possible angles of analysis will allow us to refine our analyses in order to enrich the dimensions of the instrumental genesis at work. In particular, it would be interesting to capture the role that emotions play in the creative process, as the first script writing activity required of the TSCA relies on the writing of a story that "arouses emotion". Considered as a support for the cognitive activity of memorization [Falk and Gillespie, 2009], the emotion aroused by the workshops (the chosen scientific theme, the creative process, the interactions between peers, the playful dimension, etc.) or desired by the TSCA (the one he/she would like its comics strip to provoke to its reader) could usefully join our conceptual framework.

Finally, the fact that TSCAs are involved in the creative process allows them to understand the reasons for certain choices of illustration or storytelling in their scientific comic strips. We argue that this approach can foster the emergence of a critical mind with respect to reading science stories created in other contexts.

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