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Full Length Research Paper

The science of telling stories: Evaluating science communication via narratives (RIRC method)

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It is quite reasonable to claim that narratives can include, explain and recreate science and that this means of science communication is generally popular. This idea seems to be supported by the fact that many contemporary authors who include science as a theme in their work receive a good reception among the public (at least in Britain). Novels like Fermat's Last Theorem by Simon Singh, Longitude by Dava Sobel and Neuromancer by William Gibson stayed on the best seller lists for weeks. Plays like Copenhagen by Michael Frayn, Arcadia by Tom Stoppard, Oxigen by Carl Djerassi and Ronald Hoffmann, Diary of a steak by Deborah Levy as well as Blue heart by Caryl Churchill enjoyed complete sell-outs in London and other cities in Britain. The explanation for this popularity seems to be that narratives are amusing, attractive, and interesting. Therefore, we can maintain that they are popular. But are they also a long-lasting way of transmitting knowledge? But do people remember scientific information conveyed by this means better than they remember the traditional formats like paradigmatic textbooks? These are questions that need to be addressed. The RIRC method compares narrative and paradigmatic ways of communicating scientific information, exploring their effectiveness by comparing memory (learning) for narrative and paradigmatic information. This work provides an interdisciplinary approach and a novel methodology to measure the success of communication using narratives as compared to other text formats.

Key words: Science communication, science and narratives, science communication evaluation, RIRC method.

INTRODUCTION

Knowledge carried within a story differs in the way it is presented by Western scientific tradition, because of the classical Greek heritage; the creation and communication of true knowledge, has been held to be the province of a logical and formal style of discourse (Olson, 1990). Rationality has been identified with a type of discourse that puts forward hypotheses, reports evidence, and systematically infers conclusions. The notion that there is a distinct type of rational discourse appropriate for producing knowledge is the foundation of (advocacy of) a single, unified science for all scholarly disciplines (Olson, 1990). The word 'story' carries certain connotations of falsehood or misrepresentation, as in the expression, 'that is only a story'. Poetry, drama, and storied narrative are considered unable to convey true knowledge. Instead, they are limited to communicating and generating emotional experiences, and, because of this, are seen as misleading vehicles for the transmission and representation of information. However many scientific and mathematical hypotheses start their lives as little stories or metaphors, reaching their scientific maturity by a process of conversion into verifiability, formal or empirical, and their power at maturity does not rest upon their dramatic origins (e.g. Einstein´s relativity theory) (Miller, 1996). Thus, the creation of hypotheses in contrast to their testing remains an interesting mystery (Bruner, 1986).

Narrative knowledge is more than emotive expression; it is a legitimate form of reasoned knowing. This is the interpretation of Bruner (1988), who denoted the

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traditional logical-scientific mode of knowing as paradigmatic cognition, while denoting storied knowing as narrative cognition. Paradigmatic cognition has continually been identified as the only cognitive mode for the generation and transmission of valid and reliable knowledge. However, although the idea that more than one mode of rationality exists has long been ignored, it has in fact for centuries been part of human culture (e.g. The Bible) (Polkinhorne, 1988; Lanza et al., 2006). Both modes of thought provide different ways of organizing experience, constructing reality and communicating knowledge. They are at the same time complementary and irreducible to one another. According to Bruner (1996), the universality of these modes of thought suggests that they have their roots in the human genome or that they are givens in the nature of language. They have varied modes of expression in different cultures, which also cultivate them differently. No culture is without them, though different cultures privilege them in various ways. It has been the convention of most schools, says Bruner (1996), to treat arts of narrative – song, drama, fiction, theatre, etc. - as decoration, something with which to grace leisure, sometimes as something that is morally exemplary. We frame the accounts of our cultural origins and our most cherished beliefs in story form. It is not just the content of these stories that grips us, but their narrative artifice. We represent our lives, to ourselves and others, in the form of narratives. In psychology it is now recognized that personhood implicates narrative, and that "neurosis" is a reflection of either an insufficient, incomplete, or an inappropriate story about oneself.

In Bruner's view, narratives are also important in culture cohesion. For example, without a sense of the common "trouble narratives" that a society's law translates into its common law writs, it becomes arid. Those "trouble narratives" that appear again and again in mythic literature and contemporary novels and are better contained in that form than in reasoned and logically coherent propositions. Finally Bruner proposes that if narrative is to be made an instrument of mind on behalf of meaning-making, it requires work on our part: reading it, making it, analysing it, understanding its craft, sensing its uses and discussing it.

PARADIGMATIC COGNITION

The primary procedure of paradigmatic cognition is to classify a particular instance as belonging to a category or concept. A concept is defined by a set of common attributes that is shared by its members (Amos et al., 1995). This kind of thinking focuses on what makes an item a member of a category. It does not, however, focus on what makes it different from other members of that category. The power of paradigmatic thought is to bring order to experience by grouping individual items into a category. This analysis builds categorical definitions by continually testing their power to order the data. Paradigmatic reasoning is common to most quantitative and qualitative research designs.

Paradigmatic reasoning is a primary method by which humans conceive their experience as ordered and consistent. This produces cognitive networks of concepts that allow people to construct experiences as familiar, by emphasizing the common elements that continually reappear. The networks, however, are abstractions of our experience. By providing a familiar and decontextualised knowledge of the world, they allow us to manage the uniqueness and diversity of each experience as if it were the same as previous experiences. We are able to learn a repertoire of responses to be applied to each conceptually identified situation (Amos et al., 1995).

NARRATIVE COGNITION

Narrative cognition is exclusively directed to understanding human action (Bruner, 1986; Mitchell, 1981; Ricoeur, 1992). Human action is the result of the interaction of a person's previous learning and experience with his/her present situation as well as future expectations. Unlike objects, in which knowledge of one can be substituted for another without loss of information, human actions are unique and not fully replicable. Whereas paradigmatic knowledge is focused on what is common among actions, narrative knowledge focuses on the particular and special characteristics of each action. One attribute of narrative reasoning is that it operates by noticing the differences and diversity of human behaviour. Whilst paradigmatic knowledge is retained in individual words that name a concept, narrative knowledge is preserved within emplotted stories. Storied memories retain the complexity of the situation in which an action was undertaken along with its emotional and motivational meanings. Hearing a storied description about a person's movement through life's episodes touches us in a way that evokes emotions such as sympathy, anger, or sadness (Bruner, 1988).

The collection of storied experiences provides by means of analogy a basis for understanding new action episodes within our experience. The more varied and extensive is an individual's collection of storied explanatory descriptions of previous actions, the more likely is it that one can draw on similar remembered episodes for an initial understanding of the new situation and also the more likely that one will appreciate it and study it for elements that make the new one different from the recalled instance. Today many scientists believe that both paradigmatic and narrative cognition generate useful and valid knowledge and that they are part of the human cognitive repertoire for reasoning and thereby making sense of reality (Gardner, 1983; Negrete et al., 2004).

MEASURING

A great amount of effort has been placed in producing science communication, but how much is the public actually learning from science communication's contributions? This is an important question that many organisations are trying to answer. For people involved in science communication, its evaluation has four benefits: (i) preparing for an evaluation before an event occurs or is presented provides feedback on what is intended to be achieved; (ii) providing information on the outcome of an event, the response to the presentation of material and suggestions for its improvement; (iii) helping to know the audience better (Coalition on the Public Understanding of Science –COPUS-, 2002) and (iv) providing quantitative and qualitative evidence of the degree of success of the intervention.

How can we measure the success of communicating science?

The vast majority of studies of science in the media have focused on newspapers and television programs because they are the most effective way, in terms of time and money, to study a mass medium. Moreover, almost every assessment of the effectiveness of scientific knowledge transmission is done through tests of factual knowledge and comprehension (Gregory et al., 1998). In contrast, very little has been reported about the effectiveness of narratives. Memory is one possible way of assessing learning (Sternberg, 2003), and therefore of judging the success of communication efforts. In this sense studying how memorable are different ways of presenting information represents a fundamental task for science communication. It is important to evaluate materials that not only need to be understood by the general public, but also must be retained in the long term as a part of the learning process.

The aim of the method that Negrete (ref) designed is to assess the amount of knowledge remembered and learnt by individuals who have been exposed to scientific information in narrative format, in comparison to other texts containing the same scientific factual information (paradigmatic). The method includes variables that reflect the different levels of understanding and uses them to measure the ability to Retell, Identify, Remember and Contextualise information (RIRC). The RIRC method uses different memory tasks in order to evaluate an individual's capability to retain scientific information. The tasks involve implicit and explicit memory. While explicit memory implies a conscious recollection, implicit memory, uses previous experiences that are not conciously and purposely recollected (Schacter, 2001). Different memory tasks involve different levels of learning. Although recognition memory is usually much better than recall (Standing et al., 1970), these tasks generally imply deeper levels of learning than does recognition. Recognition memory is sometimes associated with receptive knowledge, and recall memory with expressive knowledge. Differences between receptive and expressive knowledge are also studied in areas other than memory, such as in language work, intelligence studies, and cognitive development.

The RIRC method adopts some of the techniques and fundamentals used in the "vignette" method and in narrative enquiry (Amos et al., 1995), but there are important differences which need clarification. The stories used as stimuli in this research belong to fictional literature. There is an explicit aesthetic intention, which is achieved generally by means of fiction or narrative tropes. They were not necessarily constructed as human testimony in eliciting an open end response (development of values). Stories in the present research are used as tools for communicating scientific information to individuals, not as tools for organising information provided by an individual. Nevertheless, the vignette method provided important information about (a) the type of data that could be obtained by using stories, (b) the time taken for a respondent to read the stories, (c) the optimal length of a story, (d) the number of stories that can be read in one session, and (e) the possible mode of analysis used for the information.

THE RIRC METHOD

The RIRC method uses three basic tasks for measuring explicit memory: declarative knowledge, recognition, and recall. Additionally, one task for measuring implicit knowledge has been included: procedural knowledge (Table 1). Declarative knowledge refers to recalling facts. Recognition implies selecting or identifying items that an individual learned previously (e.g., in multiple choice). Retelling deals with producing a fact, a word, a story or some other item from memory. Finally tasks involving procedural knowledge are those wherein which learned skills and automatic behaviours, rather than facts, are to be remembered. These groups of memory tasks were selected in order to obtain a measure of how individuals retain and learn information, and the different levels of understanding involved when information is provided in varied text formats.

In the following section we present an example of how we applied the method in several studies where the method was used to contrast narrative and paradigmatic capabilities in conveying scientific information. This section describes in some detail the methodology used in these studies. In the last section of this paper we will briefly refer to some of the general results obtained in these studies. (For more information regarding details of the findings see Negrete, 2005 and Negrete, 2009).

The RIRC method as applied in the studies comparing the effectiveness between narrative and paradigmatic ways of communicating science.

Our research on novels and drama suggested to us that nowadays the public is indeed attracted to narratives. But how efficient are narrative texts when compared to factual ones in communicating science? And by which of these two forms of representation is the information obtained better understood and longer lasting in our memory? These two questions needed to be addressed.

The methodology designed by Negrete includes a comparison between factual and narrative information remembered at two different times (via the RIRC method). Two stories were used: Nitrogen by Primo Levi and Crabs take over the Island by Anatoly Dnieprov. This methodology was tested on a sample of first-year

Table 1. Tasks for measuring explicit and implicit memory.

Task for explicit memory	Description	Example
Recognition (Identifying)	Select or otherwise identify an item as being one that you learned previously.	Multiple choice
Recall (Remembering)	Produce a fact, a word, or other item from memory.	Fill-in the blank
Free-recall (Retelling)	Repeat the items on a list in any order in which you can retell them.	A list of facts or a story
Tasks involving procedural knowledge (Contextualising)	Remember learned skills and automatic behaviours rather than facts.	'Knowing how' skills

sociology students of Bath University (UK) (2002 and 2003) and several studies in México using comic strips as stimulus (See PCST-10, 2008 Denmark proceedings).

Development of the stimuli

The narratives

The original length of the two short stories (Nitrogen by Primo Levi and Crabs take Over the Island by Anatoly Dnieprov), approximately 10,000 words each, did not allow the study to be performed as required for the test (The original stories can be consulted in Dnieprov, 1969 and Levi, 1985). This consisted of a one-hour session to read two short stories and to answer two measures. The stories were therefore condensed to be around 1,500 words in length in order to fit the time restrictions of the test.

The criteria implemented in condensing the stories were to delete all the passages within the narrative that were not central to the plot. Simultaneously, however, the aim was to preserve as much as possible those parts of the story where scientific facts or theories were mentioned. From a literary and a stylistic point of view, it was also important to preserve as much as possible of the wit, irony, metaphors, humour and any other literary tropes which give the story its particular identity and momentum. The final form of the two adapted stories used in the tests can be consulted in the appendix of this paper.

The lists of facts (paradigmatic stimuli)

The paradigmatic stimuli consisted of a list of all the scientific facts mentioned in each story. The facts were transformed into individual sentences, presenting such facts in plain textbook style - the extreme opposite of the narrative form - (Tables 2 and 3). The questionnaires included two basic forms of question: multiple choice (identify), straightforward, and open-ended questions (recall). There was also a section where the participants were asked to retell the stories or to recall the lists of facts (free-recall), and a section in which they were presented with a hypothetical situation in order to explore procedural knowledge. To formulate each question, a short narrative with the hypothetical situation was presented to participants. Then a brief explanation of the problem was provided (in a paragraph or two). The narrative description was always related to the scientific theme of the story and to the list of facts. The hypothetical questions also were intended to evaluate their capability to put the information in context, to use the information or, in the broadest sense, to learn the information.

Each respective measure (stories and lists of facts) had the same number of questions regarding the participant's capability to retell, identify, remember and contextualise new information. This allowed for a comparison of the effectiveness of each of the stories to communicate science at different levels of remembering and learning (Table 4). General structure of the measures, see also the Appendix for Nitrogen and Crabs measures).

Procedure

In the first session, the group of participants was randomly divided into two symmetrical groups (according to the seats that the individuals spontaneously took in the auditorium). The stories, lists of facts and measures were placed face down on each of the participant's desk. Then the volunteers were asked to turn the pages, read the first stimulus and then answer its corresponding measure. The participants were required not to go back to the stimulus materials once they had started to answer the measures. Once they finished with the first stimulus and its corresponding measure, they were asked to continue with the second stimulus and its measure. The entire group completed the whole test in less than an hour.

In the second session, which occurred one week after reading the stories and lists of facts, the individuals that participated in reading the stories were provided with the same "narrative" measure of the first session while those that read the list of facts were provided with the one corresponding to the factual group. They were then asked to answer the measures concerning the stimulus material (Table 5).

Coding and marking

Identifying and Remembering tasks in both groups were evaluated by comparing the participants' answers to the lists of facts and stories provided as stimulus. Retelling in the factual group was marked according to the number of facts that an individual was capable of reproducing in the answers from an original list of ten. Retelling in the narrative group was marked according to the number of scientific facts that an individual was able to mention (without prompting) when retelling the story (the expected answers can be deduced from Tables 2 and 3). Contextualising in both groups was marked according to an individual's ability to mention the scientific facts and also by his/her ability to use these in a systematic way in order to solve the specific problem required in the

Table 2. List of facts of Nitrogen story and the correspondent quotation on the stimulus story.

Paradigmatic	Narrative
Fact sentence	**Quotation of the story**
Nitrogen	
1) Alloxan is a hexagonal ring of Carbon, Oxygen, Nitrogen and Hydrogen.	Alloxan is a hexagonal ring of oxygen, carbon, hydrogen and nitrogen; it is a pretty structure!
2) Alloxan can be obtained from Uric Acid.	The sole accessible preparation (for alloxan) was the oldest: it did not seem too difficult to execute, and consisted in an oxidizing demolition of uric acid.
3) Alloxan structure is solid, stable, symmetrical and well linked.	Alloxan… It makes you think of something solid, stable, well linked. In fact it happens also in chemistry as in architecture that "beautiful" edifices, that is, symmetrical and simple…
4) Alloxan can be used to produce a permanent dye for lipsticks.	The client...He had read that alloxan in contact with the mucous membrane confers on it an extremely permanent red colour… a layer of varnish like lipstick, but a true and proper dye.
5) Nitrogen enters our body via the food we eat.	Nitrogen… it passes miraculously from the air into plants, from these into animals, and from animals to us; when its function in our body is exhausted, we eliminate it…
6) Uric Acid is abundant in reptile and bird waste.	…uric acid, very scarce in the excreta of man and mammals, constitutes, however, 50 percent of the excrement of birds and 90 percent of the excrement of reptiles.
7) Birds and reptiles eliminate nitrogen by packing it in form of solid uric acid. For these animal groups, water is important to keep; they can not use it as a vehicle for nitrogen elimination.	…other animals, for whom water is precious (or it was for their distant progenitors –birds and reptiles-), have made the ingenious invention of packaging their nitrogen in the form of uric acid, which is insoluble in water, and of eliminating it as a solid, with no necessity of having recourse to water as a vehicle.
8) Pollina (Italian word for chicken waste) is highly valued by country people because it is a good fertiliser.	First of all, the *pollina*-that's what the country people call it, which we didn't know, nor did we know that, because of its nitrogen content, it is highly valued as a fertiliser for market gardens-
9) Nitrogen is the same in any substance; it does not change its properties.	…The trade of chemist teaches you that matter is matter, neither noble nor vile, infinitely transformable, and its proximate origin is of no importance whatsoever. Nitrogen is nitrogen…
10) To obtain alloxan it is necessary to use organic chemistry techniques.	… or perhaps my inexperience with organic preparations was boundless. All I got were foul vapours, boredom, humiliation, and a black and murky liquid which irremediably plugged up the filters and displayed no tendency to crystallise, as the text declared it should. Best to return among the colourless but safe schemes of inorganic chemistry.

measure. These hypothetical questions (contextualising) were constructed with the scientific information extracted from the stories. Each participant had to solve a given problem by using the knowledge acquired from the stories or lists of facts. In each case the participant was expected not only to provide facts but also to use the scientific information in a systematic way to provide a solution for a problem. The expected answer was either a narrative description of an experiment, a process or the research in which the scientific information provided within the story, or a list of facts was used in order to solve the problem. The following are examples of the content of possible answers to the contextualising questions included in the measures (see Measures in the appendix):

Nitrogen

Question 9: Use the sea birds' excrement to fertilize the poor soil in order to increase the chances to obtain a good harvest.

Question 10: Use the group of alchemists working with organic matter (organic chemistry) and trying to convert it into gold. In the second part of this question, using bird or reptile waste to gather nitrogen and try to produce Alloxan for the face pigment.

Crabs

Question 9: A strategy to make big crabs mate only with other big crabs so the population will not diminish in size (human selection). To move the big crabs to the other beach in the island (isolating them to the small ones) and try to breed them there.

Question 10. To build a battery with sand and water and charge it by constructing a parabolic mirror with the mirrors found in the refuge.

Table 3. List of facts of Crabs story and the correspondent quotation on the stimulus story.

Paradigmatic	**Narrative**
Fact sentence	**Quotation from the story**
Crabs	
1) Darwin developed the theory of evolution by natural selection.	"Yes, but Darwin's is a biological theory, the theory of natural selection of evolution and so on. . ."
2) A battery can be constructed with water and silicon.	"What do they have to drink water for?" I asked. "That's the way they fill up their storage batteries. In the sunlight, the solar energy is converted into electricity by means of a silicon battery and the mirror on the crab's back. It is sufficient to recharge the storage battery and for handling day-time operations.
4) Sand contains a high proportion of silicon.	"The silicon they need for the batteries come from the sand which is pure silica" said he.
5) Solar energy can be converted in electricity with a parabolic mirror.	In the sunlight, the solar energy is converted into electricity by means of a silicon battery and the mirror on the crab's back.
6) Solar energy can be stored in a battery.	… the solar energy is converted into electricity by means of a silicon battery and the mirror on the crab's back. It is sufficient to recharge the storage battery and for handling day-time operations.
7) The survival of the fittest means that an organism that is better adapted to the environment will survive, so his genes are represented in the next generation.	"What do you mean by fittest? They're all the same. As far as I can see, they simply multiply, reproducing copies of themselves… The more refined replicates will be those that quite accidentally accumulate peculiarities of design that will make them more viable. In that way, we will have generations of stronger, faster and simpler creatures. … they will devour one another and reproduce new versions again and again.
8) Organisms in natural environment accumulate small changes in their genetic material and this is sometimes reflected in their external appearance. Some of these small changes result better adapted to the environment; this is one of the mechanisms in which species change from generation to generation.	The more refined replicates will be those that quite accidentally accumulate peculiarities of design that will make them more viable. In that way, we will have generations of stronger, faster and simpler creatures.
9) Some physical characteristics of an organism that can represent an adaptive advantage are size, strength and mobility.	In that way, we will have generations of stronger, faster and simpler creatures. … These were a remarkable generation of mechanical crabs, smaller in size and capable of amazing speeds!
10) In nature the environmental conditions determine whether one organism is fitter than other.	The more refined replicates will be those that quite accidentally accumulate peculiarities of design that will make them more viable (in the environmental conditions). In that way, we will have generations of stronger, faster and simpler creatures (fittest).

Questionnaires (measures).

The scores of the correct answers for the questions regarding each of the memory tasks were added. In this way four marks were obtained (RIRC) from each participant in each story or list of facts. The marks ranged in Retell, from 0 to 10 scientific facts reproduced; in Identify, from 0 to 3 correct answers; in Remember, from 0 to 4 correct answers and in Contextualise, from 0 to 2 correct answers. The measures (scores) were analyzed at three levels: each measure separately, comparison between stories and between lists as well as between each story and its respective list. These results were also compared with the ones obtained the following week.

RESULTS OF A STUDY PERFORMED AT BATH UNIVERSITY UK WITH THE RIRC METHOD

The results of this section refer to a sample of 40 first-years sociology students of Bath University, UK (2003). The statistical test used for this study was student's t test. In the first session the factual group performed better in all the tasks, and in general terms the standard deviations of the narrative group were higher than the factual

Table 4. General structure of the measures.

Questions	Number of questions	Intention of the question
Retell the story (Remembering)	1	To measure how much the participant remembered about the story as a whole and which parts of the story were better remembered (science *vs*. narrative).
Multiple-choice (Identifying)	3	To assess how much of the information given in the story the participant was able to identify.
Short answer (Remembering)	4	To test how much of the scientific information the participant was able to remember and retell.
Hypothetical situation (Contextualise)	2	To determine if the participant was able to put the information in context and apply or extrapolate the knowledge (learning).

Table 5. Structure of the sample.

	Group 1 (Narrative)	Group 2 (Factual)
Session 1	Two stories (2792 words) Two measures (10 questions)	Two lists of facts (332 words) Two measures (10 questions)
Session 2	Two measures (10 questions)	Two measures (10 questions)

ones. Altogether there was a better performance from the factual group in terms of score and homogeneity in the first session. The second session showed important changes in the way people retain information. With the exception to recall Nitrogen, in the rest of the tasks, the differences in performance between the narrative and the factual groups diminished. The initial tendency of the factual group to accomplish better all the tasks changed, and the narrative group performed better in the second session in three out of eight tasks, equally in two and worse in three (Table 6).

The behaviour of the groups in the different tasks matches Sternberg's observation that recognition memory is usually much better than recall (Sternberg 2003). It is interesting, though, that the factual group experienced a statistically significant decrease in score in all the tasks from one session to the other (t= (15) =5.899, p<.001), while the narrative group presented a gradual drop in performance (which was not significant) and in some of the cases scored even better in the second session.

Despite a more homogeneous performance by the factual group, in most of the tasks the differences between the first and the second session's standard deviation augmented in the factual group and diminished in the narrative one. The dispersion of the data suggests that while the information presented as lists of facts loses uniformity in time, the information presented in narrative forms tends to retain better homogeneity. The results suggest that in time the differences between the performances of the groups tend to diminish (Figure 1).

DISCUSSION AND CONCLUSION

The results of the studies performed with the RIRC method as a whole suggest that science can be learned through literary stories. In particular, they suggest that narrative information is retained for lengthier periods than factual information and that narratives constitute an important means for science communication to transmit information in an accurate, memorable and enjoyable way. The RIRC method proved to be a valuable tool to evaluate memory, understanding and learning via different memory tasks. Assessing the capability of individuals to retell, identify, remember and contextualise scientific information (a combined measure of memory tasks) provides a means to explore quantitatively and qualitatively the differences between narrative and paradigmatic modes of conveying science this allows for a more comprehensive analysis and offers interesting elements to evaluate success in communication.

The RIRC method enables one to perform a qualitative analysis on the stories reproduced by the participants in the retell memory task. In some of the studies performed with the RIRC method, the narrative structures of “Nitrogen” and “The Crabs take over the Island” stories were studied and contrasted with the narratives retold by the participants. This methodology was based mainly on Propp’s analysis (1968), adding elements of other techniques for analyzing narrative structures proposed by contemporary authors (Gusfield, 1989; Perinbanayagam, 1991; Atkinson, 1990; Potter et al., 1987). However, because of the limitation on length, it was not possible to

Table 6. Performance of the narrative and factual groups in the second session.

Crabs	Retell	Identify	Recall	Context	
Stories (%)	49	70	63	66	% *
Facts (%)	49	77	70	52	% *
Stories	1.73	0.79	0.99	0.20	STD
Facts	1.30	0.34	0.50	0.20	STD
Nitrogen	**Retell**	**Identify**	**Recall**	**Context**	
Stories (%)	52	97	59	45	% *
Facts (%)	30	78	67	47	% *
Stories	1.28	0.31	0.70	0.25	STD
Facts	1.62	0.25	0.73	0.27	STD

*The percentage represents a measure of how close to the ideal the groups performed.

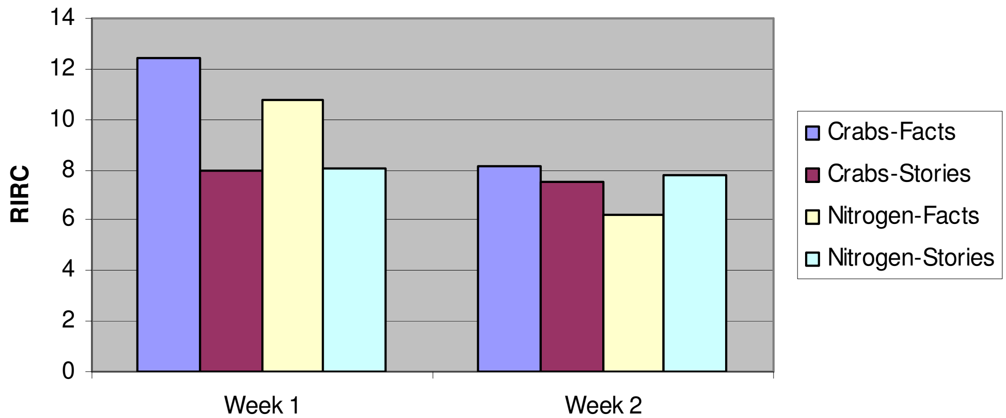

Figure 1. Comparison between facts and stories in the two different periods. The Y-axis represents an aggregated mark of the four tasks for measuring memory in one variable (retelling, identifying, recalling and contextualising (RIRC).

include the analysis and results in this paper (for qualitative analysis results see Negrete, 2009). This method has also been used to compare different narratives. This is the case of an investigation of the use of popular comic strips as a tool to communicate HIV medical information in Mexico. We used the RIRC method in order to assess individual's ability to learn scientific information presented to them in comic strip format (See PCST-10, 2008 Denmark proceedings). The studies mentioned in this paper employed short stories written by famous authors, albeit they contained significant cuts for the purpose of the sample testing. The stories have a proven track record in terms of their literary qualities and were already translated into English. This saved a significant amount of time with respect to the process of creating new stories. However, this resulted in restricting ourselves to a fixed theme and a predetermined amount and complexity of science information within each story. For any future experiment, it would be desirable to write new original stories in order to gain complete control over the scientific themes involved, the information to be divulged, and the amount and level of detail contained.

Because of their length, short stories were used in this research as an example of narratives. This enabled the participants to read a complete story, or even two stories in one session. The methodology examined in this paper refers only to short stories (and comic strips), but the underlying idea of comparing factual information and fictional stories would also apply to other narrative genres such as drama, novel and other narrative forms. In future research it would be interesting to adapt the methodology in order to evaluate the communication capabilities of other genres and media.

For comparison purposes, the two extremes of written information were taken: fictional narrative in short stories and facts presented in lists. A number of intermediate written forms, however, do exist such as scientific journalism and popular science writing. Again, contrasting these other formats would offer an interesting future research task. The work at hand provides an interdisciplinary approach and a novel methodology to measure the success of science communication using narratives compared to other text formats. The RIRC method provides important feedback before and after a presentation of narrative materials in terms of its capabilities to help people understand, learn and enjoy science. These elements in turn provide essential guidelines to improve the materials and allow a better understanding of the audience interested on this subject. The method provides quantitative and qualitative evidence (data) of the effectiveness of narrative materials in conveying science. Given the proven popularity of novels and drama containing scientific information, as well as our findings regarding their efficiency in conveying information in a long-lasting way, we believe that the presentation of scientific information through narratives such as stories, novels, comics and plays should be considered an important means to convey information in the repertoire of science teachers and communicators. However, more work on this area has to be done, including conducting larger surveys of the general public for lengthier periods. For the time being this work proposes a methodology that offers several interesting points of departure for future research in communicating science via narratives.

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APPENDIX

Nitrogen

The client explained to me that he was the owner of a cosmetics factory and he wanted to produce a certain kind of lipstick. He needed a few kilos of alloxan. He would pay a good price for it, provided I committed myself by contract to supply it only to him. He had read that alloxan in contact with the mucous membrane confers on it an extremely permanent red colour, because it is not a superimposition, in short a layer of varnish like lipstick, but a true and proper dye, as used on wool and cotton. I gulped, and to stay on the safe side replied that we would have to see: alloxan is not a common compound nor very well known, I do not think my old chemistry textbook devoted more than five lines to it, and at that moment I remembered only vaguely that it was a derivative of urea and had some connection with uric acid. I dashed to the library at the first opportunity and hastened to refresh my memory as to the composition and structure of alloxan. Alloxan is a hexagonal ring of oxygen, carbon, hydrogen and nitrogen; it is a pretty structure! It makes you think of something solid, stable, well linked. In fact it happens also in chemistry as in architecture that "beautiful" edifices, that is, symmetrical and simple, is also the sturdiest: in short, the same thing happens with molecules as with the cupolas of cathedrals or the arches of bridges. Alloxan was known for almost seventy years, but as a laboratory curiosity: the preparation method described had a pure academic value, and was made from expensive raw materials which (in those years right after the war) it was optimistic to hope to find on the market. The sole accessible preparation was the oldest: it did not seem too difficult to execute, and consisted of an oxidising demolition of uric acid. Just that: uric acid, the stuff connected with gout, intemperant eaters, and stones in the bladder. It was a decidedly unusual raw material, but perhaps not as prohibitively expensive as the others.

Subsequent research taught me that uric acid, very scarce in the excreta of man and mammals, constitutes, however, 50% of the excrement of birds and 90% of the excrement of reptiles. I phoned the client and told him that it could be done, he just had to give me a few days' time: before the month was out I would bring him the first sample of alloxan, and give him an idea of the cost and how much of it I could produce each month. The fact that alloxan, destined to embellish ladies' lips, would come from the excrement of chickens or pythons were a thought which didn't trouble me for a moment. The trade of chemist teaches you that matter is matter, neither noble nor vile, infinitely transformable, and its proximate origin is of no importance whatsoever. Nitrogen is nitrogen, it passes miraculously from the air into plants, from these into animals, and from animals to us; when its function in our body is exhausted, we eliminate it, but it still remains nitrogen, aseptic, innocent. We -I mean to say we mammals- who in general do not have problems about obtaining water, have learned to wedge it into the urea molecule, which is soluble in water, and as urea we free ourselves of it; other animals, for whom water is precious (or it was for their distant progenitors), have made the ingenious invention of packaging their nitrogen in the form of uric acid, which is insoluble in water, and of eliminating it as a solid, with no necessity of having recourse to water as a vehicle. I returned home that evening and informed my wife that the next day I would leave on a business trip that is, I would get on my bike and make a tour of the farms on the outskirts of town in search of chicken shit. She did not hesitate; she would come along with me. But she warned me not to have too many illusions: finding chicken shit in its pure state would not be so easy. In fact it proved quite difficult. First of all, the "pollina" -that's what the country people call it, which we didn't know, nor did we know that, because of its nitrogen content, it is highly valued as a fertiliser for truck gardens - the chicken shit is not given away free, indeed it is sold at a high price. Secondly, whoever buys it has to go and gather it, crawling on all fours into the chicken coops and gleaning all around the threshing floor. And thirdly, what you actually collect can be used directly as a fertiliser, but lends itself badly to other uses: it is a mixture of dung, earth, stones, chicken feed, feathers, and chicken lice, which nest under the chickens' wings. In any event, paying not a little, labouring and dirtying ourselves a lot, my undaunted wife and I returned that evening with a kilo of sweated-over chicken shit.

The next day I examined the material: there was a lot of gangue, yet something perhaps could be got from it. But simultaneously I had an idea; just at that time, in the Turin subway gallery an exhibition of snakes had opened: Why not go and see it? Snakes are a clean species, they have neither feathers nor lice, and they don't scrabble in the dirt; and besides, a python is quite a bit larger than a chicken. Perhaps their excrement, at 90 percent uric acid, could be obtained in abundance, in sizes not too minute and in conditions of reasonable purity. This time I went alone: my wife is a daughter of Eve and doesn't like snakes. The director and the various workers attached to the exhibition received me with stupefied scorn. Where were my credentials? Where did I come from? Who did I think I was showing up just like that, as if it were the most natural thing, asking for python shit? Out of the question, not even a gram; pythons are frugal, they eat twice a month and vice versa; especially when they don't get much exercise. Their very scanty shit is worth its weight in gold; besides, they - and all exhibitors and owners of snakes - have permanent and exclusive contracts with big pharmaceutical companies. So get out and stop wasting our time. I devoted a day to a coarse sifting of the chicken shit, and another two trying to oxidise the acid contained in it into alloxan. The virtue and patience of ancient chemists must have been superhuman, or perhaps my inexperience with organic preparations was boundless. All I got were foul vapours, boredom, humiliation, and a black and murky liquid which irremediably plugged up the filters and displayed no tendency to crystallise, as the text declared it should. Best to return among the colourless but safe schemes of inorganic chemistry.

Crabs take over the Island

Remind the captain that we expect him back in exactly twenty days." the engineer ordered the sailors of the Turtle-Dove who had brought the last wooden box from the ship into the island. "Why the deuce did we have to come all this way to a solar hell with those machines of yours?" I asked Mr. Cookling He laughed out loud, opening his mouth wide and exposing a full set of dentures. "Oh, don't worry about that, we'll be needing the sun pretty soon. We've got an amusing experiment under way here to test the theory of - what's his name -" here he paused.- Oh yes, the English man, Darwin, Charles Darwin." "Let's first get a look at the map. The rest of the cargo will have to be spread out over a variety of sites. That's the way the experiment goes," he explained. During the next three days, Cookling and I carted the pieces of metal to different parts of the island. When we finished we returned to the tent for the last box. "Open this one with particular care," Cookling ordered. What appeared was the strangest -looking instrument I ever saw. It resembled a large metal toy in the shape of a crab. In addition to six big segmented appendages, there were two pairs of slender tentacles that terminated in a half-open "maw" which jutted out of this monstrosity of a beast. On the back, slightly depressed, was a tiny parabolic mirror made of highly polished metal with a dark-red crystal in the centre. "Pick it up and put it on the sand", Cookling said. In about two minutes I noticed the mirror on its back slowly begin to turn towards the sun. "Look, its coming to life, come on, Cookling, what's all this about? Why did we come here after all?" "To test Darwin's theory." "Yes, but Darwin's is a biological theory, the theory of natural selection of evolution and so on. . ." I mumbled. "Exactly!" He said but I interrupted: "Look, our hero's decided he needs a drink of water!" The toy crab was crawling towards the water. It lowered its proboscis and was obviously sucking up water. After quenching its thirst it crawled out into the sun again and came to a halt. Almost on the shore, was the first of the piles of metal bars. When the crab had come within about ten yards of the pile, it suddenly seemed to forget all about the sun, made rapidly for the pile and came to a halt right near one of the copper bars.

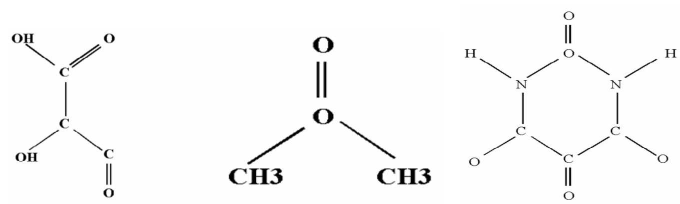
Next morning I went where we left our beauty the day before. Near the pile of metal bars were two crabs, both exactly like the one that we had extracted from the box the day before. "Did we actually miss one under the pile of bars?" I exclaimed. Cookling squatted, chuckling and rubbing his hands. "It was born here last night". They were using their slender front tentacles to contact the bars and produce electric arcs that melted off chunks of metal. Then they pulled the pieces through their wide-open jaws. Something hummed inside these steel beings. On the platform of the first crab was a third crab almost completely assembled. I was struck dumb. "Why these creatures are multiplying," I screamed. "Exactly, the sole purpose of this machine is to manufacture duplicates of itself. It's a replicating device," explained Cookling. "What do they have to drink water for?" I asked. "That's the way they fill up their storage batteries. In the sunlight, the solar energy is converted into electricity by means of a silicon battery and the mirror on the crab's back. It is sufficient to recharge the storage battery and for handling day-time operations. At night the robot is powered by the energy stored up during the sunny day. "So they can - work day and night?" "But there isn't any material for silicon batteries in these piles of metal" I ventured. "The silicon they need for the batteries come from the sand which is pure silica" said he. We returned to the tent in the evening, and by that time there were six robots hard at work on the pile of metal, and two more were basking in the warm rays of the sun. "What are these creatures for? I asked Cookling. "For war". These crabs represent a terrifying tool of sabotage. Yesterday we began with a single crab. Right now there are eight out there. In ten days we will have ten million crabs. These crabs will be able, in short order, to gobble up all the metal the opposing side possesses: tanks, aircraft, and all the metal in the country. Everything will be used up to reproduce crabs. And, as you know, metal is in war a strategic material of the highest priority.

One fine day Cookling stated triumphantly. "The most exciting thing is about to take place. All the metal has been devoured." All metal cubes, bars and rods had been turned into mechanical robots that were now swarming over the island. "There it is: the first real fight!" shouted the engineer with glee and clapped his hands. "Why the need for this fighting? Pretty soon they'll start devouring each other!" "That's just what is required! The survival of the fittest!" I thought a bit and then objected. "What do you mean by fittest? They're all the same. As far as I can see, they simply multiply, reproducing copies of themselves. Can you imagine what would happen if every new item came out different from the original but like its immediate predecessor? "So what? All the better in fact. The more refined replicates will be those that quite accidentally accumulate peculiarities of design that will make them more viable. In that way, we will have generations of stronger, faster and simpler creatures. All I need to do is wait until my mechanical beings eat up all the metal on the island and begin a war in which they will devour one another and reproduce new versions again and again. That is how I will get the ultimate devices I need." Within minutes the site had turned into a fierce battleground with more and more crabs crashing into the melee. These were a remarkable generation of mechanical crabs, smaller in size and capable of amazing speeds! They no longer felt the need of the traditional procedure of charging their batteries. They found the solar energy that their much larger mirrors were absorbing to be quite sufficient. With an amazing ferocity they swung out at several crabs and slashed them to shreds, taking two or three at a time. By noon, the entire beach around our tent was one grand battlefield. Robots from all over the island had converged on this spot. In the new warfare, one heard the crackling of numerous electric sparks, the banging of metal against metal and a grinding and crunching and ringing of machine against machine. Though for the most part the offspring was low-slung and extremely mobile, a new kind of device was emerging. The fresh species was larger than ever before. They were ponderous in their movements but possessed enormous strength and definitely had an edge over the tiny devices that were heedlessly throwing themselves into the assault. When the sun began to set, there was a sudden change in the movements of the smaller machines: they crowded to the western side and slowed down. "Oh, my God," exclaimed Cookling, "they are all doomed! These creatures are without storage batteries and life in them will cease as soon as the sun sets". Which is what happened. As soon as the sun dropped low life ceased altogether. Instead of a host of ferocious aggressive beasts, the place was an enormous graveyard of lifeless metal. Then the big crabs lumbered forth and ponderously took to devouring the little crabs one by one. On the platforms of the giant progenitors, offspring of fantastic proportions was in the making. Cookling's face darkened. This kind of evolution was not in his calculations. Unwieldy mechanical crabs of such dimensions would definitely be a poor weapon for sabotage in the enemy rear.

Next morning, when I waked up, the engineer was still sleeping in the hot sand. I noticed a tremendous crab emerging from the bushes at the edge of the plateau. It was taller than I and its paws were long and heavy. The prehistoric mammoth of a machine stopped over Cookling and fell back on its haunches. The next instant, a cloud of sand shot up out of the mound. It was Cookling. Stung by the mechanical beast, he jumped up and tried to get away. But it was already too late. The thin tentacles had already wrapped themselves round his meat neck and were pulling him up into the maw of the robot. Cookling hung in the air helpless, throwing his arms and legs in every direction. Then I drew myself up onto its back. For an instant, my face was level with Cookling's distorted features. His teeth, I realized suddenly, Cookling had steel teeth! The crab began to jerk Cookling's pallid face and bulging eyes were now at the entrance to the construction maw. What happened then was terrible indeed to be told. Days passed by as I lay motionless on the shore peering into the distance from time to time, waiting for the return of the *Turtle-Dove*. Once, a huge shadow moved over me. I raised my head with great difficulty and saw that I was lying between the claws of a robot crab of tremendous proportions. It had come down to the beach and appeared to be scanning the coastline in wait of something.

Nitrogen Questionnaire

1. Retell the story in your own words,
2. Which of these molecules is Alloxan?



3. From which substance can alloxan be obtained?

Citric Acid Lactic Acid Uric Acid

4. What are the characteristics of the geometrical structure of alloxan mentioned in the text?

Stable, solid, volatile, asymmetrical.

Solid, stable, symmetrical, well linked.

Well linked, malleable, symmetrical, unstable.

5. Why was the owner of the cosmetic factory interested in Alloxan?

6. How does nitrogen enter our body?

7. In which animal groups is the concentration of nitrogen in the excreta more abundant?

8. Why do these groups get rid of nitrogen in packages of uric acid?

9. Suppose you are a castaway on a remote island in the Caribbean Sea. It is a volcanic island, there are plenty of tropical animals but just one human being, you. From the shipwreck you managed to collect on the beach different items for survival purposes, among them a bunch of corn seeds. The soil in the island is rather poor, it is formed basically of volcanic ashes, so chances for germination of your seeds are low. What would you do to increase your chances to obtain a good harvest?

10. Suppose you are a time traveller. You were sent to the middle ages on a mission to retrieve important historical information. Everything was going according to plan until the King found out about your existence. Attracted by the rumours that you were coming from the future he appointed you to his court. As a way of proving

your identity and loyalty to him, he set you the task of producing a permanent red colour to be use as a mask in his army to intimidate the enemy. He has warned you that your predecessor served as food for the lions because the red that he produced dissolved in the first rain and irritated the combatant's eyes so the enemy massacred his army. The entire group of alchemists in the kingdom is at your orders.

11. The first question the King asks you is which group of alchemists will you be using: the ones working in converting stones and metals into gold or those concentrated in converting rats, pigeons, ants and other living matter into the precious metal?

12. The second question is: what is your tentative plan?

Crabs questionnaire

1. Retell the story in your own words (here a complete blank page was offered for the answer).

2. Which of these is the author of the biological evolution by natural selection?

Buffon Cookling Darwin

3. Which of these materials you need for constructing a battery?

Water and salt salt and silicon water and silicon

4. Which kind of competition was the original experiment aiming for?

Inter-specific: among individuals of different species.
Intra-specific: among individuals of the same species.

5. Which substance is abundant in the sand?
6. How can solar energy be converted into electricity?
7. How can solar energy be stored?
8. What does "the survival of the fittest" mean?
9. Suppose you are a castaway on a remote Galapagos Island. It is a volcanic island in which there is only scarce vegetation and just one human being, you. There are two beaches, in one of them there is a population of one crab species, which, since you arrived this place has been your only source of food. The adult crabs differ in size and you have noticed, in your many spare hours, that when they breed the size of the offspring is somewhere between the size of each of the parents. At first sight the dimension of the crabs in this environment does not provide any advantage in mating or survival, so there is a wide range of size in the population. Nevertheless, only the big crabs are worth catching for food. You realise that as you have hunted the larger ones they have become more and rarer in the population, so the average size is reducing each generation. What would you do in order to reverse this situation and guarantee the availability of big crabs?
10. A world war is taking place and you have been taken prisoner by evil forces in North America but you managed to escape to the Sonora desert in Mexico where you found friendly people and a refuge to hide in. This is a very remote village called El Reverso. The landscape is sand dunes, cactus and some desert wildlife that you have been taught by locals to hunt for subsistence. In the refuge you have some water reserves, basic commodities like soap, razors, mirror, toothpaste etc. You also have a radio and a lantern but there is no electricity or batteries in the town and the ones you brought inside the electrical appliances are all dead. You urgently need to tune into the BBC international transmissions on your short wave band radio to be aware of the war's progress. What would you do in this scenario?