STORIES IN PHYSICS EDUCATION

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Abstract. Narratives are at the basis of every effort of making sense of human experience. Stories are a particular type of narrative particularly suitable for children because they involve them affectively and cognitively. This contribution deals with the opportunity of using stories for physics education in primary school. It is introduced a disciplinary approach suitable to be shaped into stories, relying on cognitive linguistics results, as well as some elementary features of the stories are compared to the fundamental characteristics of scientific inquiry. Hints are proposed for possible research programs and some examples of stories, coherent with this program, are presented and discussed.

1. Introduction
It is out of doubts that children love stories. A fact presented to children in form of a story gains a great attraction and becomes very interesting to their eyes. The emotions that stories stimulate make the children fully involved, not only affectively, but also cognitively (Egan, 1986). Stories, however, are not only to be mentioned when speaking about children, since they represent, in a more general meaning, the way humans express their thought through language. As the stories frame the narrated facts into a certain structure and with a certain sequence, in an analogous way also concepts and thoughts are explicated within a certain structure and sequence. When we explain a scientific theory or a model, we organize our talk in a suitable way, with assumptions, logical connections, references, and support of experimental observations: everything follows a coherent sequence, necessary and sufficient to support the thesis. A mathematical theorem is expressed as a logical path we have to follow, starting from the hypotheses, to show the evidence of the thesis. From this point of view, stories and theories or models in physics are not two distinct species; rather they are the ends of a spectrum of how humans create meanings.

From this qualitative consideration, we could start to fund the use of stories in physics education as form in which to shape the disciplinary contents and the way they are presented and taught to children.

Not every type of story, however, is adequate to host science contents, as well as not every approach to science is suitable to be framed into a story form. On one side, the contents to be delivered have to be suitable to be shaped in narrative form; on the other side, the stories have to meet certain conditions to be suitable for the construction of meanings.

In this contribution both aspects will be treated, that of the stories and that of the contents: in the next two sections will be introduced a disciplinary framework coherent with the basic forms of language as they are recognized and studied in cognitive linguistics, then will be evidenced features of stories that make them akin to the process of scientific inquiry; in the further next section will be proposed general hints for possible research programs and experimentations of the production and use of stories for physics education; finally, will be illustrated and discussed examples of stories developed according to this program.

2. The disciplinary framework for physics education in primary school
Cognitive sciences and cognitive linguistics in particular (Lakoff and Johnson 1999; Johnson 1987) evidence recursive and pervasive patterns, called image schemata, we use to express our thought with language and to understand the world. An image schema is a recurrent pattern, shape and regularity in, or of, our actions, perceptions and conceptions (Johnson 1987). We extract these structures from bodily experiences: they are developed very early in the life and are already present in a rudimental form also in small children. They are simple yet have enough internal structure so that more elaborate mental structures can be built upon them. In other words, they make reasoning possible (Johnson, 1987).

Image schemata are more general than every particular mental image we form; this means that any effort to represent them, even schematically, trivializes them. We have the concept of triangle, but whenever we draw a triangle, we reduce its generality. Moreover, image schemata are more basic than any proposition, explainable with a definite statement; rather they emerge with analog fashion from our thought.
These recurrent patterns are relatively few in number and we use them in a variety of situations. In synthesis, image schemata are real abstractions, gestalts: structures simpler than the sum of their parts. Tab.1 reports the most important image schemata evidenced by Johnson (1987), Croft and Cruse (2004), Evans and Green (2006).

<table>
<thead>
<tr>
<th><strong>POLARITY</strong></th>
<th>light-dark, warm-cold, female-male, good-bad, just-unjust, slow-fast, high-low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPACE</strong></td>
<td>up-down, front-back, left-right, near-far, center-periphery. Other: contact, path</td>
</tr>
<tr>
<td><strong>PROCESS</strong></td>
<td>process, state, cycle</td>
</tr>
<tr>
<td><strong>CONTAINER</strong></td>
<td>containment, in-out, surface, full-empty, content</td>
</tr>
<tr>
<td><strong>FORCE / CAUSATION</strong></td>
<td>balance, counterforce, compulsion, restraint, enablement, blockage, diversion, attraction</td>
</tr>
<tr>
<td><strong>UNITY / MULTIPLICITY</strong></td>
<td>merging, collecting, splitting, iteration, part-whole, mass-count, link</td>
</tr>
<tr>
<td><strong>IDENTITY</strong></td>
<td>matching, superimposition</td>
</tr>
<tr>
<td><strong>EXISTENCE</strong></td>
<td>removal, bounded space, object, substance, fluid substance</td>
</tr>
</tbody>
</table>

Tab.1 Main image schemata form specific literature

Children, in this sense, are abstract thinkers, since they make sense of reality employing image schemata, the same used by adults, just less featured or differentiated. They and we speak about natural, emotional, and social phenomena using metaphorical projection of image schema (Lakoff and Johnson, 1980). The abstract elementary concepts developed by the children’s minds should not be regarded as obstacles for scientific thought; on the contrary, these concepts share the same seeds of adults’ formal science and are to be regarded as resources to build upon.

Fuchs (2007) has identified an important gestalt, named Force Dynamic Gestalt (FDG), particularly relevant to scientific understanding. It is structured with three main aspects that we use to understand the most diverse complex phenomena, from psychological ones - fear, happiness, pain - to social ones - justice, the market -, and that can be strictly related to basic and simple concepts useful to explain the behaviour of various natural phenomena, such as those involving fluids, electric charge, heat, motion, and chemicals.

The FDG has the aspects of fluid substance, polarity of verticality, and force. The image schema of fluid substance has the character of an amount or quantity, and is related to the scientific concept of extensive quantity. The verticality image schema has the character of intensity or scale, and corresponds to the scientific concept of intensive quantity or generalized potential. Finally, the image schema of force, that summarizes various more simple schemata of direct manipulation (see Tab.1), is related to causation and the scientific transversal concept of energy (Fuchs, 2007).

So, we think to and speak about the increase of temperature of a pot of water while it is heated on a heater in the same way we think to and speak about the increase of the level in a glass while we pour water, or in the same way we think to the rise of electrical potential while we charge a capacitance. Again, we refer to heat as a fluid substance that flows from hot to cold things in contact, in a similar way as we speak about water or air that flow from a high-pressure vessel connected to low-pressure one. Water, heat and electric charge, in these examples, are conceptualized as fluid substance-like quantities with a qualitative vertical scale of intensity.

The physics contexts that are usually regarded as distinct fields of knowledge, especially in the school curricula, with this approach are seen in a unitary fashion, evidencing their analogical structure of contents. Every context has its characteristic extensive quantity that accumulates into containers; the current of such quantity flows through the container boundaries directed by a negative difference of the conjugate generalized potential; the scientific concept of capacitance relates to the way in which the potential increases when the extensive quantity accumulates into a container; and the concept of resistance relates to the way in which the potential difference
increases to increase the current intensity. Tab.2 shows the analogical correspondence between the main experience contexts relevant for primary school physics education.

<table>
<thead>
<tr>
<th>Context</th>
<th>Substance-like</th>
<th>Potential</th>
<th>Capacitance</th>
<th>Current</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluids</td>
<td>Volume</td>
<td>Pressure</td>
<td>Section</td>
<td>Current</td>
<td>Hydraulic impedance</td>
</tr>
<tr>
<td>Heat</td>
<td>Entropy</td>
<td>Temperature</td>
<td>Specific heat</td>
<td>Thermal current</td>
<td>Thermal resistance</td>
</tr>
<tr>
<td>Electricity</td>
<td>Electric charge</td>
<td>Electric potential</td>
<td>Capacitance</td>
<td>Electric current</td>
<td>Electric resistance</td>
</tr>
<tr>
<td>Motion</td>
<td>Momentum</td>
<td>Velocity</td>
<td>Mass</td>
<td>Force</td>
<td>…</td>
</tr>
</tbody>
</table>

At primary school level, physics education has the general aim to help children to identify, differentiate, and recognize and master the relationships among the aspects of the FDG.

3. Stories and scientific inquiry
The connection between image schemata and phenomena are the metaphors we produce, through imagination, expressing the affinity among the various experience contexts. When we want to express our thought to ourselves or to someone else we are forced to put in a narrative form (verbal and sequential) what is an imaginative pattern in our mind. At the basis of every effort of making sense of human experience there is the narrative thought, which searches for meanings and establishes relations (Bruner, 1986).

Narratives are spontaneous and natural tools, very appropriate to the human being. Historically they appeared with the development of oral cultures, well after writing. In the child they appear very early, without external influence or instruction. Over time the child refines his ability of employing this tool and learns the mechanisms that regulate narratives in order to produce them more and more effectively. Many research efforts are devoted to the study of narratives, especially by humanists, but also by scientists.

A particular kind of narrative is the story form. We know that children love stories: let’s discuss if and how such a tool may be useful for physics education purposes.

The most common and basic features of stories can be summarized as follows (Mandler, 1984; Egan, 1986, 1988).

1. Stories have a general structure called story grammar or story schema. If we listen to someone speaking, not necessarily we feel the speech as meaningful and interesting for us, and this even if he is treating a particular argument and does not beat around the bush. A narrative results meaningful for us when it is dressed in a form that attracts our attention, that is affectively attracting. Stories build upon, engage, and strengthen affective meaning. Basically, a story consists in a beginning that is set up by a problem created by a polarity, a middle part where the problem is elaborated, and an ending where the problem is solved. It is ultimately a technique for organizing events, facts, ideas, characters, and so on, whether real or imagined, into meaningful units that shape our affective responses. As the events of the story proceed, the story tells us how to feel about the whole picture.

2. A story tells about a limited world, with a created and given context. It is a simplified and delimited environment where events stand out and are clearly focused so as we can grasp the necessary information and search for their meaning. The story form provides a suitable environment to exercise imagination. Things become meaningful within contexts and limited spaces.

3. Stories are narratives that have an end. A story does not necessarily end when we are told that all lived happily ever after, but when we have grasped all the presented events and situations and we know how to feel about them. A narrative is a story because its ending balances the initial tension and completes all what was elaborated in the middle. Stories grant us the satisfaction of being sure how to feel about events and characters.

To answer the question about the utility of stories for physics education we can draw a sort of parallel between the peculiarities of the story form listed above and those of scientific inquiry.
1. An investigation is an action that develops in time. It starts from a problem, it provides for the elaboration of information, and ends with a solution of the problem. Not all data are appropriate for a given inquiry, but only those ones that are coherent with the need of clarification and rational understanding the problem rises. An inquiry is the story of the information that involves us cognitively. Affectivity and cognition are two ways of grasping things.

2. Within an investigation, the interest is focused and the object of the study is limited. In order to converge to a solution, the investigation field must be defined and limited, the phenomenon object of inquiry have to be insulated form the rest of the world, and, in some cases, it can be reproduced and studied in the laboratory. A circumscribed world and the laboratory work favor the research.

3. An investigation does not end arbitrarily, but when all needed information is known and it is organized in a coherent and meaningful picture. We do not feel to have finished an inquiry until we have arrived to a satisfactory solution of the initial and of all open problems. Completeness and coherence are the final goals of any inquiry.

As a story is a search for affective meaning in a context, analogously, science is a search for rational meaning of a phenomenon. As, over the primary school years, children interests evolve from affective to rational values, the story form can fairly be regarded as the suitable environment to match both kinds of meaning. Stories could be used as a vehicle to guide the children in their growth between the affective needs of early childhood and the developing interest in rational and scientific understanding of the world of higher ages. Stories can be employed at all grades of primary school as transversal educational tools that develops together with children.

4. Hints for education research
Joining the disciplinary approach to physics and the methodological value of stories discussed in the previous two sections, we may argue that well crafted stories can be tools useful to clarify and make apparent the aspects of the FDG and their relationships about an object of interest. This makes our thought clear to ourselves and to the listeners of our stories.

Telling good stories about natural phenomena, i.e., using a correct natural language for it, is the first step toward a useful conceptualization of the processes of nature. A story is in general narrated in natural language, but if one seeks to clarify the aspects of the FGD, he needs and makes use of a language which becomes increasingly clear, accurate, unambiguous, and, finally, formal.

For the purpose of science education, stories can be either told by the teacher, or told by the children, or both. The functions are different, of course, and fairly important. In the rest of this paper stories will be treated in their particular value for the teacher side.

Just a little parenthesis about children storytelling. We have observed that children are competent narrators even in the early childhood: stories can be used by the teacher as instrument for the assessment of the children learnings. This is a valuable function of stories. In fact, a scientific education driven by the cognitive processes that occur in the children minds rather than oriented to the mere acquisition of contents, as outlined in the second section, cannot be assessed with the conventional instruments (tests, problems, …) suitable to quantify notion knowledge and scientific competence. The children thought can be accessed and qualitatively evaluated through the analysis of their discourses, through the observation of the language naturally employed to explain their stories of any type (concerning fantastic facts, or explaining an experimental inquiry). In this sense, grids of language analysis, either from a syntax point of view, or from a semantic point of view, can be useful (Laurenti et al., 2011; Mariani et al., 2011).

Back to our focus, stories to be told by the teacher in primary school have to be suitably designed, with developing structure, content, characters and language according to the children mind development and age.

Research efforts should be addressed to the development of the story form from early childhood up to the last years of primary school. With increasing age of the children:

1. the story structure should change from simple and elementary to articulated and complex, hosting pupils activities (experiments, texts, drawings, games, …) and teacher intervention (discussions, explanations, …)

2. the content should concern increasingly abstract topics (water, food, …, heat, …, energy)
3. in the first years, the affective characters of the story can be fantastic characters, then, in the last years, some of them could remain as friends of children, but the effective central characters should become the natural phenomena and the physical quantities.

4. language should become more and more precise and specific to the particular cases, as well as decontextualized referring to general conceptual organizers. This research program contributes to overcome the notion of a dichotomy between narrative and paradigmatic thought. In contrast to Bruner (1986), narrative and paradigmatic forms of understanding represent a polarity that opens up a spectrum between the poles of narrative and paradigmatic thought. At the same time, this program works in the direction of giving a unitary fashion to primary school instruction, and of strengthening the marriage between sciences and humanities.

In the next section, will be synthetically presented the stories produced within the project “Piccoli Scienziati” (Little Scientists), developed at the University of Modena and Reggio Emilia in the last three years, proposed to a large number of teachers in training courses in various Italian Regions, and experimented by the teachers themselves in their classes (see Corni et al. 2011).

5. The Pico’s stories

Lots of examples of use of stories are present in science education literature, most of them with historical background (Jung, 1994; Kipnis, 2002; Tselves and Paroussi, 2009; Aduriz-Bravo and Izquierdo-Aymerich, 2009; Klassen, 2010; Kubli, 2000; Lehane and Peete, 1977; Lebofsky and Lebofsky, 1996; Ellis, 2001; Sallis et al., 2008).

The Pico’s stories (Corni et al., 2011) - Pico and his friends at the Luna Park, Rupert and the dream of a swimming pool, and The Rupert efforts and the mountain trip (Fig.1) - are designed to be used at the various levels of primary school according to the above research program.

They are animated stories in slideshow format that tell the adventures of some friends in various situations. They are correlated by two cases full of materials – toys, simple models, devices of everyday use – for experimental and laboratory activities. Each character of the stories has evident features in which a child, according to his temperament and disposition, can easily identify with. Pico is the archetypal child, lively and creative, who may become a scientist. He acts as mediator between the story world of characters and the real world of children. He is always present in the story scene and promptly intervenes in the problematic situations. He poses the right question at the right time and involves children in the solution inviting them to make hypotheses, draw pictures and schemes, perform experimental activities with the help of the materials of the cases. A second key character is Blackbird that flies high and looks at the situations from different points of view. Rupert, a frog, pretty, ingenuous and a bit unlucky, is the carefree child that, together with his bear friends Thomson and Aelmo, undergo to various vicissitudes and adventures. In the following, the features of the three stories will be synthetically presented with reference to the variables evidenced in the previous section concerning the education research. The structure concerns the complexity of the scene and the presence of children and teacher activities, the content relates to the aspects of the FDG, the characters are the effective entities over wich the children attention is focused, and the language concerns the linguistic competencies needed.

5.1 Pico and his friends at the Luna Park (1st – 2nd grades)
The friends buy ice creams, exchange ice cream balls and reflect on the quantities and flavors. Then they buy drinks and reflect on their quantities and on their levels in various glasses.

**Structure.** The scene is still and and centered on the friends.

**Content.** Identification and differentiation of the aspects of quantity and intensity of substances.

**Characters.** The friends who want to have fun at the Luna Park. The story is centered on their wishes.

**Language.** Elementary and with common terms.

### 5.2 Rupert and the dream of a swimming pool (3\textsuperscript{rd} – 4\textsuperscript{th} grades)

Rupert wishes to place a swimming pool in his garden. It positions the pool at various heights and tries to fill it by connecting with pipes to a nearby aqueduct.

**Structure.** The scene is structured and focused on essential elements (aqueduct, pool, pipe). Children are invited to do experiments with a model apparatus.

**Content.** Identification and differentiation of difference of potential, current, resistance and their relationships in the context of water.

**Characters.** The Rupert's problem to be solved.

**Language.** Elementary with the introduction of terms of common language like to empty the pool, water flow, water level.

### 5.3.1 The Rupert efforts and the mountain trip, part I (4\textsuperscript{th} – 5\textsuperscript{th} grades)

Rupert struggles to push a wheelbarrow full of flower pots to embellish the pool. He tries various strategies, using the wind and an inflated balloon.

**Structure.** The scene is complex and offers various cues. Children are invited by Pico to study and explore (following some worksheets) a hairdryer and toys (a car and a balloon) to understand their functioning and to find the way to better employ them to obtain a result.

**Content.** Identification, differentiation of differences of intensive quantities and currents of substances in interactions (wind generated by the hairdryer with the car; air blowon by an on board inflated balloon with the car); relationships between current and changes in potentials of the cause (wind) and of the effect (motion).

**Characters.** The wind and the car in the experimental activities. Rupert and his wishes are on the background.

**Language.** Precise and specific to express clearly the various conditions met.

### 5.3.2 The Rupert efforts and the mountain trip, part II (second part)

Rupert and his friends go for a mountain trip and see and experience various natural phenomena (rivers flowing downhills, a melting glacier, a dam with an artificial lake, a landslide, operating wind mills, a lightning during a storm, food, photovoltaic panels, …). The story is an adventure to discover nature.

**Structure.** The numerous scenes are rich and offer many cues. Children are invited by Pico to discuss about natural phenomena and their effects on one another.

**Content.** Decontextualization and generalization of the relationships between differences of potential and currents in the interactions.

**Characters.** Natural phenomena. Rupert and his frined are on the background.

**Language.** Specific to every phenomenon, but more and more decontextualized referring to potenci and currents.

### 5.4 Results of experimentations with children

The results of the use of the swimming pool story in fourth grade classes have been evaluated (Corni et al., 2010) with reference to the following research issues:

1. children involvement in problem solving,
2. transition from the description to the interpretation levels,
3. identification of the relevant variables,
4. generalization of meanings.

#### 5.4.1 Children involvement in problem solving

By analyzing the children's drawings evolution, context items are less and less present and sidelined in the background, while elements that relate to the problematic situation are highlighted
and centered. The drawings made by each child evidence a gradual ability to identify and focus on significant story objects.

5.4.2 Transition from the description to the interpretation levels
The analyses of children drawings and texts show (see Fig.2) a gradual shift from phenomenological description to formulation of hypotheses and interpretations.

5.4.3 Identification of the relevant variables
During the evolution of the story, children begin to identify some concepts, mainly those of water level difference, current and resistance. The learning analysis of every child shows a generally increasing trend with some fluctuations.

5.4.4 Generalization of meanings
Generalization is a high goal and it cannot be reached effectively with a single activity or series of activities limited in time. However, two children in particular have developed a remarkable level. They represent and explain by words that if the pipe is full of water, its shape does not influence the water flow, even if in some points the pipe is lifted above the water level of the aqueduct. This conclusion is not directly deducible from the story and the provided activities with the hydraulic model.

6. Conclusions
Support for the use of stories in physics education has been outlined. Research in this direction must be conducted in order to define how to design stories, how to employ them in the didactical practice, and what results can be obtained. The project “Piccoli scienziati” has started a research program since three years ago and some encouraging results are now being obtained.

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