Primary School Teachers: Becoming Aware of the Relevance of their own Scientific Knowledge

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Abstract

We present details of a physics course for prospective primary school teachers that is based upon the structures of figurative thought available already to young children. The structures referred to are those found in the Force Dynamic Gestalt of natural forces such as heat, water, wind, electricity, chemicals, or motion. The same structures figure prominently in the formal science of physics. We demonstrate how student teachers can profit greatly from an approach that builds on everyday language and everyday conceptualizations. Our experience shows that teachers trained in this manner become confident narrators of basic physical processes.

1. Introduction

Teaching science to children in primary school or physics to prospective teachers can be viewed as a single challenge. If the training of future teachers in the sciences does not clearly deal with how children's minds approach nature, the professional training misses important points and becomes an exercise in futility and frustration.

Therefore, we have developed an approach to physics for student teachers that is mindful of the cognitive development of children and the way humans develop imaginative approaches to understanding nature. The approach relies on figurative structures of the human mind that are used to conceptualize not only natural, but also psychological and social phenomena. These figurative structures are pervasive in common as well as paradigmatic languages (Lakoff and Johnson, 1999; Johnson, 1987; Talmy, 2000). In a different context, similar structures have been identified by Bliss (2008) in children's thought dealing with nature. Physics courses that contain elements of what we have built include those of Boohan (1996), Herrmann (2003), and Fuchs et al. (2008).

The concepts we are speaking of make use of three image schemas that form the basis of what Fuchs calls the gestalt of forces or, more formally, the Force Dynamic Gestalt (FDG) (Fuchs, 2007). The schemas are quantity (size), quality (intensity and its differences), and force or power. In physics, they correspond to the concepts of extensive quantity, intensive quantity, and energy, respectively. Basing one's conceptualizations of natural processes upon the figurative structures of the FDG is expected to provide a solid grounding for school science and beyond.

If student teachers learn that physics is not the representation of a truth "out there" but a representation of human imagination reflected in natural language, and if they accept that they possess the power of thought reflected in this language, they become inclined to believe in their own power to use good natural language to be good narrators of things happening in nature. As a consequence, stories are a good tool for teaching physics to young children. In stories, the well-known elements of narrative understanding combine with the characters of natural forces (wind, fire, water, chemicals, light, food, motion, etc.) creating a world easily understood by children of various ages (Fuchs, 2012)

In the following sections, we will describe the course for student teachers in detail. Then we show and analyse data that demonstrate the development of these students toward professionalism in their teaching of physical science to children in primary school.

The main question we are interested in is to what extent our course allows prospective teachers to become good scientific educators, with a positive inclination towards physics and a solid disciplinary knowledge anchored to didactic activity.

Our approach raises some issues that will be addressed in the Summary. Among these is the relationship between conceptualizations resting on figurative structures of the human mind on the one hand and misconceptions (as they have been identified in physics education research) on the other. Still other questions deal with natural language as a possible barrier to the traditional culture of science. Our answers support the claim that teachers—who are not scientists—can become strong narrators of good science if they learn to master the figurative structures underlying modern science.

2. The course

At the Department of Education and Humanities of the University of Modena and Reggio Emilia, a physics course has been taught to prospective primary school teachers (second year of the degree in Primary Education, first semester of the 2011-2012 academic year) using the approach afforded by the aspects of the Force Dynamic Gestalt (quantity, quality, force/power). These aspects span various topics of physics and form the basis of our metaphorical understanding of forces of nature.

The first part (Part I) of the course (30 hours, attended by about 60 students) is devoted to the introduction of the physical topics. The topics covered are:

- Figurative thought, image schemes and the FDG of natural forces
- Extensive and conjugated intensive quantities (extended potentials) related to a physical process
- Fluids (quantity: volume, quality: pressure)
- Motion (quantity: momentum, quality: velocity)
- Thermal phenomena (quantity: entropy, quality: temperature)
- Electricity (quantity: charge, quality: electrical potential)
- Chemical substances (quantity: substance amount, quality: chemical potential)
- Energy (balance between quantity and change in quality among coupled processes in a cause-effect chain).

For each topic we analyse extensive and intensive quantities and their mutual relations leading to the concepts of capacitance, resistance, current, and energy. The goal is to supply students with simple concepts powerful enough to scientifically interpret everyday situations that might also be encountered in school.

The second part (Part II) of the course (30 hours, attended by the same group of about 60 students) provides the introduction to measurements and error handling, and the proposal of some laboratory experiments, measurements, and (graphical) search for simple proportionality relation executed by the students in groups of 4-6. In the last few hours (8 over 30 hours), it covers methodological issues where we treat theoretically the design of didactical activities for ages 5-11 which respect the cognitive and linguistic skills of children.

After these two parts, students can prepare for the final (oral) exam by submitting:

- a summary of a lesson on the topics covered during a period of the first part of the course (group activity);
- a didactical unit for primary school about a physical argument using stories, experiments and general activities (individual activity);
- a story for physics education (individual activity).

The last (optional and not assessed) part (Part III) of the course (16 hours, attended by 22 of the previous students) is a practical laboratory-type course and is available to students after the exam, at the beginning of the second semester. The students are personally involved in working with stories for physics education. After an introduction about the interplay between story schema (Egan, 1986) and character schema (Fuchs, 2012) and the analysis of some case studies taken from the stories presented for the exam, every student is invited to:

- review and correct the story created by him/herself and one created by another student for the exam;
- design a didactical unit around a given story (the course teacher gives the students a story about heat and asks them to design a didactical path for a primary school class, specifying activities, scheduling, materials, grouping, setting etc., and explaining every choice made);
- write a new story;
- discuss the new story with the course teacher;
- revise the new story according to the suggestions of the course teacher.

The focus of this paper is on two different groups of students: (A-students), i.e., all students that attended the compulsory parts I and II of the course; and (S-students), i.e., the students that attended parts I, II and III of the course (they are a subset of the A-students).

3. Method

The central question we are concerned with is whether or not our course is effective in allowing prospective teachers to become good scientific educators. We try to answer this question by investigating three main points:

Inclination towards physics and perceived personal skills

Effective knowledge of physics

Ability to design didactical activities for children

The data is obtained from the analysis of:

- voluntary anonymous *questionnaires* given to students where they had to rate their agreement to some *statements* on a discrete scale from 1 to 4, and had to answer some *open questions*;
- the *stories* produced by the S-students at the end of Part III of the course.

Ideally, we would have liked to give the same questionnaire to the A-students twice: first before the beginning of the mandatory parts of the course, and then after these parts (after the exams). Due to time constraints, we were only able to give the questionnaire to the A-students (which includes the future S-students) after the exam. To make up for the lack of pre-course data, we asked the students to answer the statements twice: once for their current state, and once for what they would have answered if they had been given the questionnaire before the course as well. Effectively, then, we asked the students to estimate the change effected in their ratings for the statements as a result of the course.

We gave the S-students the same questionnaire once again after the third part of the course. Here, we asked them to rate an effective perceived change (PC) in their answers to the statements effected by the final laboratory part of the course.

The numbers of returned questionnaires are: 32 for A-students and 18 for S-students. In what follows, we list and briefly describe the statements and open questions given to the students.

3.1 Inclination towards physics and perceived personal skills

3.1.1 Questionnaire statements concerning:

S*tudents' feeling on relevance of physics in their life:*

SR1: Physics is useful for everyday life;

SR2: Physics is useful for my work.

Statements concerning *how students see nature and science:*

SI1: Physics has improved my curiosity towards nature;

SI2: Physics has improved my curiosity towards technology;

SI3: Physics has improved my curiosity towards scientific knowledge.

Statements about *students' feeling toward physics:*

SF1: Physics is difficult in general;

SF2: Physics is difficult to understand for me;

SF3: Physics is interesting.

3.1.2 Open questions about students' inclination toward Physics:

QI1: Has your inclination towards physics changed after the course (on a scale 0 to 4)?

What was your inclination towards physics before the course?

What is it now?

QI2: Has your vision of your work as a teacher changed?

Describe how and in what sense it has changed.

QI3: Has your way of explaining an everyday natural phenomenon changed after the course (on a scale 0 to 4)?

Describe in which way it changed and how you would have described the same phenomenon before the course.

3.1.3 Two questions concerning students teachers' perceived suitability of the physics they have learned to teach children:

SS1: It is possible to teach physics well, using natural language.

SS2: Children cannot understand physics, because they are not capable of abstract thinking.

3.1.4 Two open questions about students' perceived suitability of the physics they have learnt to teach children:

QS1: Is it possible to teach physics to primary school children?

If yes, how?

If no, why?

3.2 Effective knowledge of physics

For the authors, the effectiveness of the new knowledge of the students is related to their ability to approach everyday experiences in a scientific way. So, here, the disciplinary knowledge is evaluated through the students' ability to describe nature using appropriate metaphorical and natural language.

The questionnaire presented two open questions about thermal phenomena that are part of our everyday experience:

QK1: This winter is particularly cold. What shall we do if the rooms of the house do not get warm enough?

Which analogy could you use to explain your reasoning to a friend of yours?

QK2: The recipe to make a cake requires the cake to be baked in the oven at 180°C for 40 minutes. You want to prepare two cakes for a birthday party and you decide to bake both cakes at once. Do you have to change anything about the oven settings or baking times?

Which analogy could you use to explain your reasoning to a friend of yours?

3.3 Ability to design didactical activities for children

The didactical ability was assessed in terms of:

3.3.1 the stories produced by the students;

3.3.2 an open question presenting a situation as it might actually arise at school:

QD1: As a teacher, you want to organize a school trip to a wind farm where electricity is produced by the wind. How can you prepare your students for the trip?

How would you organize the visit to the wind farm?

What can you do in the classroom after the trip?

4. Data and findings

Before presenting the results concerning the three points outlined above to answer our central question, we will briefly summarize the results obtained from the questionnaires. In the following table, we list the results for the statements described above. For each statement, we present the following average ratings given by the students: (ARP) Average Rating for the "Pre-Test", i.e., their estimate of what they would have answered had they been given the questionnaire before the course already; (PC1) average Perceived Change in rating effected by the mandatory part of the course; (AR1) Average Rating after the mandatory part (AR1 = ARP + PC1); (PC2) second average Perceived Change effected by the voluntary laboratory course (S-Students only); (AR2) Average Rating after the voluntary part of the course (S-students only) (AR2 = AR1 + PC2).

	A-students			S-students	
ITEM	ARP	PC1	AR1	PC2	AR2
SR1	1.53	1.87	3.4	1.33	4.73
SR2	1.5	2.03	3.53	1.39	4.92
SI1	1.83	1.6	3.43	1.45	4.88
SI2	1.43	1.3	2.73	1.17	3.9
SI3	1.53	1.3	2.83	1.34	4.17
SF1*	1.7	1.47	3.17	1.33	4.5
SF2*	1.69	1.38	3.07	1.16	4.23
SF3	2.03	1.24	3.27	1.17	4.44
SS1	1.8	1.63	3.43	1.55	4.98
SS2*	2.39	1.08	3.47	0.52	3.99

Table I. Student average rating and differences to the questionnaire statements.

* marks the ratings complemented to 5 (see text).

A positive response to the course and our approach by the students should result in a positive PC1 and PC2: for the averages, this is the case for every item. Only 4% of the A-students and 2% of the S-students have given negative responses (negative changes), a vey low fraction of students that is decreasing with the progress of the course.

Comparing the ARs of the A-students (AR1) and of the S-students (AR2), we can see, in general, another marked increase. This is consistent with the fact that using stories for physics education has strengthened their trust, both with regard to natural language as a powerful means for physics education, and to the perceived cognitive competences of the children.

The open questions have been analyzed in various ways, depending upon the topic of the question, as discussed below.

4.1 Inclination towards physics and perceived personal skills

4.1.1 Questionnaire statements concerning the students' feeling of the relevance of physics in their life (SR1, SR2).

The PC1s of the A-students are the highest, and the ones of the S-students (PC2) are among the highest of the entire list of statements. This is a strong message from the students about their PC. In particular, they declare a strong relevance of physics for their future work of teachers; that means our goal has been achieved, considering their lack in scientific knowledge as a result of their previous studies.

Statements concerning *how students see nature and science* (SI1, SI2, SI3).

In this case the PCs are medium. This indicates a significant PC, with a preferential interest for natural and life studies compared to technological or scientific studies.

Statements about *students' feeling toward physics* (SF1, SF2, SF3).

The SF2 PC2 of S-students is the lowest and the SF2 AR1 of A-students is among the lowest of the entire list of statements confirming the difficulties of students with physics. This, with the results on the previous statements, creates a picture of these prospective teachers as positively inclined toward physics, though they are aware of their structural lack regarding disciplinary contents.

4.1.2 Open questions about students' inclination toward Physics.

QI1.

All A- and S-students declare a positive change of inclination towards physics, with an average of 3.90 and 3.47, respectively. 8 S-students (44%) explicitly stressed that, after the compulsory part of the course, they had already changed their inclination. [Except for two students (one of whom claims an interest in physics without ever having studied it, whereas the other shows a generic optimistic inclination), all respondents say they had difficulties with physics and a negative feeling toward physics before our course.]

We found the following taxonomy of student difficulties and inclination towards physics. With the same items, we analyzed the A- and the S-students' claims concerning their inclination towards physics before the course. Table II reports the occurrences of the various items.

	ITEM	occurrence
Difficulties	Complicated	7
	Abstract, theoretical, use of formulas	16
Inclinations	Lack of interest	5
	Feeling of fear/hate	4
	Not suitable for children	2

A- and S-students' answers concerning their inclination towards physics after the course can be classified as reported in Table III.

ITEM	occurrence
Concrete, relevant to life, able to explain everyday phenomena	24
Interesting (in general)	2
Other positive answers	8

QI2.

100% of students say that a change has occurred after the course with regard to their vision of their future profession. The reason they give for this change is the range of perceived skills they developed during the course (as reported in Table IV).

ITEM	occurrence
Use of stories for science education	10
Use of experiments and experiments for children	10
Explanation (generic)	16
Design of activities and teaching strategies	8
Use of elementary concepts	3
Simplification to match the abilities of children	8

QI3.

The main difference in the A- and the S-students' opinions before and after the course consists, in particular, in the relevance of physics for explaining everyday life, compared with the previous prevalent opinion about physics as an abstract and theoretical subject.

4.1.3 Two questionnaire statements concerning students' *perceived suitability of the physics* they have learnt to teach children (SS1, SS2).

The SS1 PC2 of S-students is the maximum of the entire table, meaning that the practical laboratory part of the course, in particular, has contributed decisively to students' awareness of the power of natural language in teaching physics.

The SS2 values are typically extremes of all results. The PCs are the lowest and the ARP is the highest. Of course, a maximum value in ARP results in a minimum value in the PCs. This means that student teachers put trust in children's abstract thought. To evaluate the contribution of the course to this belief, we can analyze the single student ratings, and consider the students that give an ARP of 4 for SS1 (meaning that they are in total disagreement with the negative statement about children's abstract thought). Only 14% of A-students give an ARP less than 4.

4.1.4 Open questions about students' *perceived suitability of the physics they have learned to teach children* (QS1).

All of the A- and S-students believe that it is possible to teach physics to children. In the answers of A- and S-students, a "constructivist" approach to physics and to reality as something we have to interpret emerges; they trust the use of stories and natural language in teaching science, and the role of experiments as an opportunity of speaking, thinking, and reasoning about phenomena.

[We used a control group of students who would take the course the following year which we are not reporting on in this paper. It is important to mention, however, that the control group views physics as a collection of statements about a truth independent of humans—a truth out there—rather than something that has to be constructed.]

4.2 Effective knowledge of physics

QK1, QK2.

Let us analyze the two open questions together. The problems posed concern everyday life. The aim of these questions is to demonstrate the metaphorical use of the aspects of the FDG in the language of students which proves a scientific inclination instead of a superficial way of solving common problems.

First, we evaluated our students' explicit use of the terms "heat" and "temperature." In QK1, the frequencies are 61% for A-students, and in QK2 they are 77%. Then we analyzed the natural language employed. 54% of A-students refer to heat and cold using terms that denote a metaphorical use of the substance image schema. Of the A-students, 30% refer explicitly to heat as an agent that flows. Moreover, only 12% of A-students refer to warm clothes as barrier to the outer cold or as a source of heat.

Another indication of their mastery of physics is found in the answer to the request of an analogy to explain their reasoning to a friend. In QK1, 74% of A-students gave answers, and in QK2, the numbers were 50% (in most cases the students supply examples instead of analogies).

[These numbers may appear somewhat low to a scientist. Again, comparing to the control group, we get a different picture. The use of good scientific language is significantly higher for the A-students than for the control group.]

4.3 Ability to design didactical activities for children

4.3.1 Stories produced by the students.

The stories, created and revised during the optional laboratory part of the course have been analyzed according to the following criteria: appropriateness of (natural, not formal) language with children in mind, presence of a story schema that engages children affectively, presence of a natural force, presence and differentiation of the aspects of the FDG of natural forces. Table V reports the results found the 20 stories produced.

CRITERION	First version	Revised version
Presence of a story schema	85%	100%
Language appropriateness	90%	100%
Sentence length appropriateness	95%	100%
Presence of a natural force	60%	90%
Differentiation of FDG aspects	53%	73%

Many students produce stories with good story schemas already in the first version. They have more difficulties introducing scientific aspects (natural forces). Mostly, they are able to revise and correct their stories properly.

The language used is appropriate in 90% (100% after the revision) of cases, and sentences are of suitable length (95%, then 100%). Sometimes students tend to use some words taken from scientific formal language, but in the revision phase they agree that those words are unnecessary and that there are ways of explaining the same concept with natural language.

In few cases (10%), students introduce more than one main topic in the story (the task was to write a story on one topic), e.g. heat as well as water.

Referring to the aspects of the FDG, the preferred is force/power (present in 70% of the stories), then quality (65%), and finally quantity (55%). The aspects of the FDG are well differentiated in 53% of the cases (8 of 15 stories), and in 73% after the revision (11 of 15 stories).

The stories are mostly addressed to children age 3-5 (50%), or age 6-8 (45%); only 1 of 20 was written for older children of age 9-11.

4.3.2 Responding to a situation as it might actually arise at school.

QD1.

> All students, attending or not attending the course, are affected by the stereotype of a school trip with the intervention of an "expert of science." In this stereotypic view the teacher, or the prospective teacher, leave the class in the hands of the expert. The preparation of the trip consist in explaining the functioning of a wind farm, or renewable energy, etc.. Then, after the trip, they ascertain what the children have understood, collecting ideas of children. They might construct a model of a wind-mill, and make the children perform experiments with wind. To overcome this stereotype requires specific training so as to allow the teacher to remain the leader of the learning process.

5. Discussion and conclusions

The results of this investigation are preliminary. However they give us some valuable information.

First, starting with the figurative structure of scientific thought (Part I), rather than the disciplinary contents as they are usually found in the textbooks, allows the students—who often lack scientific grounding due to their previous studies or to their preconceived idea of the discipline—to become aware of their ability to understand and learn physics.

Moreover, the laboratory parts of the course (Part II and III) that have been described here provide the students with powerful knowledge of how children think. This is most important for future educators. The central role given to stories and to natural language provides bridge between the discipline and its didactics.

As a result of this investigation, the authors have obtained a clearer understanding of what to look for in the professional development of future primary school teachers. Our students express that they become aware of the power of natural language and narrative forms of science for comprehending nature. Our investigation has provided hints of a useful form of understanding of physical concepts and of the ability to make these concepts available in the classroom.

Let us now turn to some important issues that are raised by our approach to teacher education in the sciences, and by the changes proposed to how science can be taught in primary school classrooms.

Since the paradigmatic language of science is figurative at its core, there is no contradiction between learning about nature using the metaphors provided to us by our mind and learning to master important formal aspects of the sciences. At the level of image schemas and their metaphoric projections, common sense and science share a large set of concepts. The Force Dynamic Gestalt structures are as much elements of common thought as they are of formal theories of (macroscopic) physics (see Fuchs, 2007, 2010). This means that the ubiquitous problem of misconceptions does not arise here. It arises when figurative schematic thought is applied to concrete phenomena requiring detailed reasoning. At this point, reasoning may become faulty and lead to what are called misconceptions. Let us be concrete about the difference between basic concepts and misconceptions by considering an example. In a case involving engineering students, we have observed how they hesitated to put into a container a sensitive specimen previously heated. When asked, they replied that they felt the specimen could get even warmer and thus be destroyed. This reasoning follows from our bodily experience of putting on warm clothes—a living body gets warmer when wrapped up because of internal generation of heat. The concrete case of reasoning is incorrect; however, the underlying understanding of heat as a quantity that is contained in materials, can flow, and can be generated, is not. We can actually hope that, by learning about the powerful basic structures with which we conceptualize nature, reasoning may become easier. Our students understood quite readily that their hesitation was unwarranted and where the incorrect notion was coming from.

What about natural language and the culture of science? Are we not creating a rift between the science we wish our children to learn and their usage of language if we stress the utility of common language for science learning? Actually, the issue raised here is very similar to the one having to do with common sense notions and misconceptions: the problem lies elsewhere. Natural language using image schematic structures and their metaphoric projections are very much a part of formal science. What we are proposing here does not lead to language that is "unnatural" to the sciences, quite the contrary. As demonstrated in minute detail by the linguists Halliday (2004), Haliday and Martin (1993), and by Lemke (1990), it is science and science teaching that unnecessarily introduce "unnatural" language that alienates learners (this refers to the tendency to nominalize expressions, and to careless usage of language that hides rather than uncovers fundamental meaning relations, i.e., semantic relations). In our opinion, if we follow the lead of traditional science and science teaching rather than that of modern cognitive science, linguistics, and modern macroscopic physics, we do our children a disservice.

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6. Index of abbreviations.

FDG	Force Dynamic Gestalt
A-students	students that attended the compulsory part of the course and that filled in the voluntary questionnaire (32 in total)
S-students	students that attended the compulsory part and the optional laboratory part of the course and that filled in the voluntary questionnaire (18 in total)
AR1	A-students' average rating to a questionnaire statement (from 1 to 4)
AR2	S-students' average rating (scale extended effectively from 1 to 5)
ARP	students' average post-evaluated rating to a questionnaire statement (from 1 to 4)
PC	perceived change (by students) of a variable