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Narrating Science – Physics for Non-physicists

Abstract: At first glance, physics and literature could not be more opposite: unequivocal terms, definitions and objectivity on the one side. Ambiguity, feelings and subjectivity on the other side. Both physics and literature also gain different social acknowledgment. While our society and economy are based on scientific and technical knowledge, it is to this day still no problem not to know the second law of thermodynamics (as C. P. Snow remarked about 50 years ago). Not knowing Shakespeare's works, on the other hand, would be extremely embarrassing.

What factors promote or prevent this development? And what role does school physics play here? This article attempts to answer the question of how we can use narrative-based learning environments for developing interest in school physics and improving learning outcomes. As a possible solution, we describe a subjective and literary form of access to the structure of physics for those people who have difficulties with a purely formal lead-in.

1 Poeticizing science? An introduction

Prima facie, literature and natural science clearly differ in their respective practices. Poets describe moments and courses of events, emotions, situations and relations. Although the objects of their contemplation can often be described in concepts, such as love, hate, pity or envy, they transfer them into lyrical or prose texts. Scientists, meanwhile, attempt to reduce momentary observations and courses of events as temporal and spatial processes to as few concepts as possible. Thus they transfer the *prose* of initial thought – the inner monolog of the struggle to understand, of laboratory log books or discussions with colleagues – to relational propositions and, eventually, to abstract symbolism. These propositions are intersubjectively verifiable, a criterion for them being scientific. The same is not necessary for poetry, prose and drama: different criteria apply to them.

Literature and natural science are also distinguishable by the recognition they receive from society. Physics as a science does not receive recognition from society in the sense that we may not have to hide scientific knowledge, but it is not really

needed in order to be a successful public person. This fact is attributed here to the key role of the school as an institution. School is key, if we are to hold out the prospect of ameliorating this problematic lack of recognition. In the following, the topic *natural sciences and literature* is considered from the perspective of science education. Thus we are addressing, in a wider sense, education in physics for all those who are inclined or compelled to deal with it. More specifically, we will examine the process of learning physics at school level, and what connects learning about physics with learning about literature.

2 Is there a lack of appreciation for the natural sciences in society?

Countless changes in our everyday surroundings can be traced back to scientific research and creativity. Technical innovation has always exerted a revolutionary influence on all areas of society. In the fourteenth century it was the inconspicuous compass that ultimately enabled seafaring nations to create a new world order, while in the nineteenth century the railways made the world move closer together. However, the specific scientific phenomena shaping current developments remain alien to the majority of people. The result is an increasing *black-box-effect* in our daily lives. While we are the *masters* of a continuous stream of new technologies, our ignorance of them increases with our exposure to them. That is, we are enthusiastic consumers of devices of astonishing capacities and performance levels but we rarely ask ourselves: “Where does this actually come from?” Even more rarely do we pursue this question seriously. This seems to be a clear indicator of low interest in scientific issues or simple helplessness in the face of highly advanced technology.

Society’s assessment of the natural sciences can be regarded as dramatic when we consider science in relation to the general concept of education. A much-quoted, provocative statement candidly declares: “While we do not have to hide knowledge in the natural sciences, it is not part of education in general” (Schwanitz 1999, 482). Subsequently, the author of the remark was criticized so vehemently for mapping his own horizon onto a generalized ideal of education (e.g. Fischer 2001) that his publisher decided to omit the quoted passage from later editions of his book. Nevertheless, this kind of perspective resonates in society. Public authorities sometimes demonstrate their scientific (and mathematical) ignorance in the public sphere – not always inadvertently or unwittingly. Nor is this a recent phenomenon. Fifty years ago, C. P. Snow proclaimed in a famous lecture on the *mutual incomprehension* of what he postulated to be two distinct cultures:

I now believe that if I had asked an even simpler question [instead of asking about the Second Law of Thermodynamics] – such as, What do you mean by mass, or acceleration, which is the scientific equivalent of saying, *Can you read?* – not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had. (Snow 1959, 16)

A peculiar situation arises from the following phenomenon: the *hard sciences* in particular are in fact credited, despite the occasional pretense at abhorring them, with being highly relevant to society. A reluctance to engage in physics or chemistry, combined with a recognition of the significance of these subjects, gives rise to a feeling of a lack of competence that is a kind of inferiority syndrome, a condition we will also encounter in the classroom situation.

From the perspective of the natural sciences, we have to ask whether the situation is really that desperate. Why does the public sector as well as social media regularly strive to present scientific topics to wider audiences? Some of the *media scientists* hosting TV and live shows or video channels have gained celebrity status. Regardless of the quality achieved in these shows, they appear to satisfy an existing demand – not just from specialists – for information and education. In this sense there is no indifference when it comes to the natural sciences and their results. Therefore, it is crucial to make resources available to people that actually help them in their understanding of scientific concepts. This would include, on the one hand, “faces”, entertainers and role models, who set the example of being enthusiastic about science; and on the other hand, good stories and images that develop in the minds of the audience, tying in with what is already familiar or known.

3 Unfulfilled expectations: Science at school

Having considered society as a whole, we should now focus attention on those who are already part of society but who have not yet unfolded their full formative and creative potential, namely children and adolescents at school. How much do young people recognize, accept and favor the natural sciences, and specifically physics, as school subjects?

In students’ perceptions there are, arguably, two kinds of natural science. The first they know from the media, an exciting one that lets us send a manned spacecraft to Mars within the foreseeable future, that continues to speed up our computers, makes our computer screens ever sharper, etc. Then there is a parallel science, that seems completely unconnected with the former: physics as it is

taught in the classroom. In what follows I will address physics as a school subject, which is probably primarily responsible for students' scientific image of the world, as well as the attitudes they hold toward physics throughout their lives.

For a longitudinal insight, as it were, let us first of all look back at a twenty-five-year-old survey of students at secondary schools (grade 7 to 10) in Baden-Württemberg (Muckenfuss 1995). In this sense, the study is not representative. However, several similar studies from the same period yield similar results. The students were asked to name their three favorite and three least favorite subjects. Among the three favorite subjects, physics almost made it to the mid-table. In the result of the three least favorite subjects, however, physics placed first! As a side note, it must be said that the big subjects, German and mathematics, polarize students most. The runaway leader among the favorite subjects was sports (Physical Education). Particularly painful from the perspective of physics is the fact that elementary-school children on the verge of attending secondary school come to physics and chemistry with high expectations. This is clearly borne out by the surveys of student interests. However, these expectations are increasingly frustrated with every additional school year. From year five to eight the stocks of physics and chemistry are in freefall, only to stagnate at the lowest level until the end of school! Over the same period, we see a steady increase in students' assessment of the significance of physics for society. The aforementioned inferiority discrepancy widens with every school year and evidently prepares students for the assessment of physics in society as a whole.

The Sasol survey (Sasol Olefins & Surfactants GmbH 2005), conducted ten years later, can be seen to fit in almost seamlessly with the earlier studies. The upper age spectrum of the surveyed students represents the range of the youngest students from a decade earlier. What is striking is the similarity in the resulting ranking: Physical Education is still by far the most popular subject, while physics and chemistry bring up the rear. These are stable findings! The international study known as PISA 2006 falls squarely in the same period. The latter survey yielded, among other things, evidence that fifteen-year-old students from all of the participating countries on average ascribe high importance values to the natural sciences (cf. OECD 2007). Here too, was a clear discrepancy from the markedly lower subjective value of the natural sciences and scientific thinking.

Another ten-year leap finally takes us almost into the present. While no current surveys regarding the popularity of school subjects are available, we can, however, obtain relevant information, on the popularity of subjects from a study by the *Deutsche Physikalische Gesellschaft* (DPG). In 2013, the DPG collected and analyzed data from all over Germany on the provision of instruction and the electoral behavior of students concerning their choice of physics courses

(Heise 2014). More than 210 schools took part in the survey. The study revealed a significant difference between girls and boys regarding their choice of scientific subjects of priority in secondary schools (grade 7 to 10) where such a choice existed. It is striking that at the grammar school level (grade 11 to 12 or 13, in Germany called *Gymnasium*) the proportion of boys choosing physics remains more or less unchanged. Girls choose quite differently. The difference indicates a serious problem that is surely related to the widely accepted image of the natural sciences. This image seems hardly compatible with the expectations entertained by female students. Even if they have chosen physics or chemistry for the last two years of school and achieve good grades in these subjects, they often *veer off the road at the last minute* and decide against studying natural sciences at university. Schools squander a great number of opportunities here to draw on this talent pool in order to produce the next generation of scientists. That is a problem for society, since in Germany there is great demand for young people with excellent qualifications in science and cutting-edge technologies, and precious little by way of supply. What is more, it is a cultural loss in the sense that this effect, having been caused at school, appears to enhance the aloof image of the natural sciences, which is already ingrained in the majority of the population.

4 Symptoms and findings: An interim conclusion

The majority of people have little to do with physics or related fields once they leave the education system. Some of them accede to key positions and thus shape society as a whole. The findings on recognition, ignorance or outright disapproval of physics within societal as well as scholastic contexts give little cause for satisfaction. To put it in a nutshell: while physicists enjoy respect they are rarely regarded as role models. School seems to play a crucial role in this situation, since graduates make up the adult population. After all, school is the place where most people have their only – or only direct – encounter with physics. It is true that physics is rationally accepted as a part of the curriculum. It does not, however, speak to its addressees on an affective level. Thus most students would endorse the statement that physics, while it is arguably important and useful, does not fill them with enthusiasm!

Even without going into a thorough analysis, we can conjecture a number of causes for this situation. Many physical concepts – particularly those of modern physics – can only be grasped after strenuous effort, if at all. The vast majority of society is excluded from this knowledge. Additionally, there is the association of physics with danger and destruction, which has been an element of public opinion

since the emergence of nuclear physics. It is a disturbing factor even for experts. Thus the physicist Hans-Peter Dürr (who died in 2014), who had been assistant to Werner Heisenberg and a PhD student with Edward Teller, reported the unsettling insight that it was precisely *his beautiful physics* that had spawned the atomic bomb.

Literature has it easier. We can enjoy literature profoundly; draw energy, joy and knowledge from it, even if we are neither authors nor scholars of literature. The same holds true for the visual arts and music. In general, this cannot be said of physics and people without any specific physical and mathematical training. Herein lies a serious difference regarding the attention people are prepared to bestow on a subject. This gives rise to the question of whether a novice or layman can derive any pleasure from physics at all. From a didactic point of view, this question could prompt an investigation into possible ways of raising levels of motivation and interest, thus leading us back to school as an institution. For it is precisely here that most people have their first (and often last) contact with physics. Therefore, the attitude of society as a whole is essentially shaped by the individual's experience with school physics. This may hold equally for other disciplines. But it is of crucial importance to physics because physics plays a negligible role in the area of active leisure time. Thus we may presume that school is the key to reducing the existing imbalance between the contribution physics makes to culture and its acceptance in society.

Of course, this is not the first time this ambivalence has been addressed. Ways to resolve it have been sought for decades. From the deficit in motivation and interest surrounding physics, as we have described it above, derives an almost traditional effort to improve the teaching of physics at school level. These efforts, which have exclusively targeted the content of teaching, focusing on the question of what is to be taught, have so far accomplished no change. It is of at least equal importance to consider the *how* of teaching physics. The question of how to teach physics leads to a plethora of methodical approaches. In the remainder of this essay I want to present one specific option from among these, connected to literature and the targeting of affective changes.

5 Physics and literature: Windows offering insight

Literature and science have been in a very much longer, but also very much closer relationship with one another than is commonly expected of two such differing ways of seeing the world. Scientists often tell the story of their discoveries

and solutions in *factual accounts*, such as personal diaries and laboratory notes. Often we can recognize ideal-typical moments of stories. The *narrative* of a solution process for a scientific problem typically contains descriptions of actions that are justified by beliefs, theories or causal relations. Stories may describe difficulties encountered, complications met and expectations thwarted. Even the violation of norms can illustrate comprehensive innovation. For example, the observation of the rotating plane of oscillation of a Foucault pendulum may disturb every-day-concepts. Competing versions of argumentation may place the narrative under the proviso of a perspective (cf. Kasper 2007, 54). It is precisely such features that make proceedings worth telling.

However, even *real* literature has always reported on spectacular discoveries in contemporary science. Moreover, literature makes reference, among other things, “sensational scientific controversies, hermeneutic hierarchies and other questions of method within the subject” (Thums 2011, 44). Here, the natural sciences acquire emotions and a face. We find anchors for identifying with people and we begin to find more importance in the field of natural sciences. In this way, cultural significance and educational value can be ascribed even to fictional representations. Contemporary literature has always been considered a medium capable of making science more popular. The art of the writer consists in making their readers go along with changes in perspective. Writers make readers take on the role of, for example, a scientific researcher, and compare their own thinking and feeling with that of the protagonist.

Whether this can be harnessed for teaching natural sciences at school depends, most of all, on the actual gains for learning processes that can be derived from insights into the inner world of real (historical) or fictitious personalities. It seems that adolescents are particularly susceptible to the subjective experience of turning nature into a projection surface for their own inner states.

We may assume that at least some proportion of students is open-minded toward a subjective, emotional approach to nature in parallel to the factual, objective approach. They may find the approach of getting to know the inner worlds of strangers, the thoughts and emotions of other people, and comparing them to their own, more accessible than traditional pedagogy. A path of subjectivity and aesthetics that meets this need can lead to the gates, but also into the heartland, of physics. A possible way will be shown in what follows. Enrichment through an affective component could therefore counteract the long-lamented rejection of the subject.

At this point, it is perhaps apt to pause and become aware of a contradiction. Subjectivity and aesthetics are not the most prominent features of physics teaching. Physics as a discipline is characterized by its logical structure and

mathematical relations. The textbooks for schools and universities lack a human face, to say nothing of human emotion, in presenting the subject's results. It seems to be the point of science to exclude the subjective. The proposed subjective-aesthetic approach to nature appears diametrically opposed to this: an approach which makes students susceptible to emotion, one which contains a human component, one which has not been purged of error or struggle, and one which does not exclude moral values.

Let me head off one possible misunderstanding straight away: physics as a discipline is so successful precisely because it is scientifically objective, because it has broken away from subjective and emotional dependencies. An introduction to this way of seeing the world has to remain among the goals of a school that professes to provide a well-rounded education. Of course, not every person finds easy access to it. Accessing the conceptual edifice of physics is not a smooth or plain undertaking. Sometimes the very entrance is dimly lit and there are occasional snares and pitfalls. Some will never find the entrance at all. But perhaps they could, if only we built alternative avenues and bridges.

One such bridge could be built by narrative, and in that sense literary, arrangements. The literature market seems to uphold this claim. Despite having suffered through physics classes, many people are fascinated by narrative fiction as well as biographies in the field of the natural sciences. Contemporary science bestsellers, such as Dava Sobel's *Longitude* or Lisa Randall's *Knocking on Heaven's Door*, bear this out. Such popular scientific titles aside, great numbers of literary works with strong connections to scientific themes have been successful over the years, as far back as the novels of Jules Verne in the nineteenth century. A current example is provided by Thomas Lehr's novel *42*, a philosophical thriller that confronts its readers with questions about modern physics.

Apart from the evident appeal scientists have to writers, there are examples of a clear need for poetic means of expression in physics. The American physics Nobel laureate Richard Feynman formulated the intuitively difficult relation of mass and energy in a haiku:

Principles
You can't say A is made of B
Or vice versa
All mass is interaction.

(Gleick 1992, 5)

In spite of such examples, the possibility of this connection's viability continues to amaze. It would seem that physics and literature are characterized, in their very features and techniques, by an almost binary semantics: objective – subjective; rational – irrational, quantitative – qualitative; unambiguous – ambiguous.

Identical objects could hardly appear more different when presented in physics and in literature. Like almost no other phenomenon, the rainbow has spurred poets and writers to similes and fantasies. The colorful rainbow, depending on rain and sorrow for its very existence, is employed in literary descriptions as a symbol, subject to cultural context, of peace, hope or love. Physics, by contrast, achieves its *demystification* when it explains the rainbow as an optical phenomenon in the atmosphere caused by dispersion.

Similarly, we are familiar with two moons: the moon of the poets and the moon of the physicists. What is to the former a *serene companion*, *wanderer's escort* or a *blessing of lovers*, the latter (in this instance the astronaut James Lovell, who visited the moon in 1968) describe as follows: "Okay, Houston, The moon is essentially gray, no color; looks like plaster of Paris or sort of a grayish deep sand" (James Lovell at a press conference in 1968, NASA; cf. Brooks, Greenwood and Swenson 1979). The educational theorist Martin Wagenschein, who also holds a PhD in physics, raises the hypothetical question of what people, if asked, would consider to be the *real* moon. The answer is obvious since "the moon of the poets is a perfect, if welcome, delusion." We submit to the scientific moon "because of the precision of its data [...] the correctness of which can be verified by anyone" (Wagenschein 1983, 156). However, the commitment to one of two moons only succeeds by the *authoritarian* act of suppressing the other and leads to an impoverishment (cf. Wagenschein 1983). It is, after all, necessary and instructive to gain an understanding of what the one rainbow has to do with the other, or what the one moon has to do with the other.

It is against this background that we will consider the question: How can physics and literature be combined to their mutual benefit in the didactic context? Perhaps a mathematical metaphor is helpful here: if the natural sciences, or the subject of physics, represented the sides of a square, then the diagonals would be the realm of literature. Mathematicians describe the two lengths as incommensurable although they belong to the same geometrical figure. Arguably, the worldviews exhibited by physics and literature are also incommensurable although both belong to the same culture. Yet a last point needs emphasizing. Physics and literature should be understood as two aspects of the same culture that are of equal value. Likewise – at least here, we can carry the analogy of the square further – they have points of contact! I only mention these points of intersection as points of departure for alternative approaches to the so-called hard sciences.

In the beginning, natural science, like so much else, is language. Initially stammering, science begins with the inner language of the people in the lab or at the computer. Later they look for, arrange, and order concepts, comparing and analogizing. By good fortune, such processes sometimes survive in the

form of autobiographical texts, lab logs or, as already reflected on, correspondence with colleagues. At this point, we are still firmly in the realm of internal perspectives. During this stage, namely in the transition from prose report to scientific account, emotions are still very much part and parcel of physics: amazement, wonder, admiration and frustration. In short, this is one of the points of contact between literature and physics that is worth pursuing. Another intersection is what natural philosophers and proponents of Romantic Physics at the end of the eighteenth and the dawn of the nineteenth century called for and lived as the *poeticizing of all sciences*. One intriguing example is Novalis' unfinished novel *Heinrich von Ofterdingen*.

One pedagogically useful point of contact between literature and natural science is a certain stage of scientific development: that during which a problem or a phenomenon has already given rise to the first distinguishable scientific models or theories which, by necessity, compete with one another. Usually this competition forms the point of departure for vigorous debates, conducted by rigorous technical arguments, which occasionally play out on a political or personal level.

The subject-didactic value of these discourses lies in the remarkable fact that historical and individual developments in knowledge and concepts often move along parallel lines. To err is part of the phylogenetic as well as the individual development of cognition. Historical errors on the part of the natural sciences are lurking in almost every law of physics and in many of the boxed textbook phrases that students are meant to commit to memory. Packed inside them are stories about the paths researchers have traced through the labyrinth of science, which have sometimes led them astray or into dead ends, stories about the roads to success, or the roadblocks, and the allurements that often put the goal out of sight; stories about what the researchers felt along the way. Hence, these are stories not yet purged of the human element of natural research. An understanding of the natural sciences – not just of their results but also of their processes – cannot be achieved by guiding students along the shortest or most *correct* path through the labyrinth. Rather, it can be achieved by allowing them to grasp the structure of the maze as a whole, preferably by allowing them to acquaint themselves with it by walking it *in their own shoes*. Such access to nature (and the science of it) requires a kind of mediation that includes – in addition to the essential techniques that are inherent in the culture of the discipline: the experimental, deductive, inductive and mathematical methods – narrative components. Narrative sections of physics courses in a wider sense could be created by *unpacking* the stories hidden behind the formal condensations (cf. Kasper 2011, 160).

An example from the historical development of knowledge of the phenomenon of geomagnetism is provided by no less a figure than Christopher Columbus himself. Fortunately, the logbooks of his voyages have survived, affording us the

chance to share a momentous personal experience: the actual discovery of magnetic declination on his first voyage in 1492. In Washington Irving's literary biography of Columbus, based on Columbus' logbooks, we find the following passage on this discovery:

On the 13th of September, in the evening, being about two hundred leagues from the island of Ferro, Columbus for the first time noticed the variation of the needle; a phenomenon which had never before been remarked. He perceived about night-fall, that the needle, instead of pointing to the north star varied about half a point, or between five and six degrees to the northwest, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm, but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the very laws of nature were changing as they advanced, and that they were entering another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues, and without this guide, what was to become of them in a vast and trackless ocean?

(Irving 1834, 640)

A description of the situation of the discovery of magnetic declination that provides even more drama is found in the German translation of the logbook. According to this version, Columbus faced the threat of open mutiny and being thrown overboard.

Donnerstag, den 13. September [1492]: Wüsste ich nicht, dass der Allmächtige seine schützende Hand über mich hält, müßte nun auch ich den Mut verlieren. Ich stehe einem Rätsel gegenüber, auf das vor mir wohl noch kein Seefahrer gestoßen ist. [...] Die Magnethadel wies, anstatt auf den Nordpol zu zeigen, ungefähr einen halben Strich nordwestlich. Eine Erklärung? Ich weiß keine! [...] Freitag, den 14. September: Je weiter wir nach Westen fuhren, desto mehr weicht die Nadel ab. [...] "Die Grundgesetze der Natur gelten nicht mehr," hielt er [Juan de la Cosa] mir schreiend vor. Hinter de la Cosa standen die anderen. [...] Von ihren finsternen Gesichtern war nur zu deutlich abzulesen, dass sie planten, mich über Bord zu werfen. Ich versuchte, ihnen die Abweichung zu erklären – vergeblich!

(Grün 1983, 83–84; additions by LK)

We know, of course, that Columbus was not thrown overboard and that a short while later he made the discovery with which his name is associated to this day. A heron appeared in the sky above the ships with exquisite timing, indicating the vicinity of land and thus sparing the captain from mutiny. This little snippet alone raises fruitful questions for vivid science teaching. What caused the aberration or declination of the compass needle in the first place? How was Columbus able to measure it? What is the explanation for the change in declination on the ship over the course of his East-West Atlantic crossing?

A far more complex example from the realm of physics is provided by the concept of heat, which had been contentious for centuries. This historic and well-

documented process is reflected in almost all its facets in the inadequate physics conceptions of today's students at schools and universities. That is the reason, above all others, why this example lends itself perfectly to narrative, drama and, most of all, introductions to the essence of natural sciences. The instance in question is a moment in the eighteenth century that is compelling in light of both its scientific and human interest. I have in mind the first (of several) highlights in the controversy between proponents of phlogiston hypotheses and those advancing a kinetic explanation of heat. It is also one of the roots of the movement toward the emancipation of women. The protagonist of this story is Émilie du Châtelet, also known as divine Émilie. Probably a highly gifted child, she grew up in the wealthy conditions of Parisian aristocracy and, as a young woman thirsting for education, pushed the limitations of her times. Women were barred from entering universities. Émilie, however, was privately educated by prominent teachers, such as the mathematician and philosopher Pierre-Louis Moreau de Maupertuis. Moreover, she conducted an affair with Voltaire that lasted many years. They lived together in a chateau (which belonged to her tolerant husband!) where they built a laboratory and a scientific library to match the universities of their time. In 1737 the Paris Academy announced a handsome sum of prize money for the best scientific essay on the subject *The Nature of Light, Heat and Fire*. Voltaire, a fervent advocate of Newton's ideas, entered the competition. Unbeknownst to him, Émilie also took part. In her anonymous essay, she proposed ideas that basically anticipated the postulation of thermal radiation, ideas that were implemented in experiments by William Herschel some eighty years later. Incidentally, neither Voltaire nor Émilie won the academy's prize, which went to Leonhard Euler. Both of their essays, however, were included in a volume containing the best five contributions. I have described elsewhere how this material may be developed, on the basis of a fictitious dramatic classroom example, into a concrete idea for teaching (Kasper 2014).

6 Scientific controversies as dialectic approaches for learning processes

Regarding the dynamics of the development of scientific cognition, there are structural similarities between the history of the natural sciences and individual learning processes. In both cases knowledge is developed discontinuously. In science, stages of competing theories are often dominated by the formation of ever-more auxiliary hypotheses to the theory until the theory is no longer feasible and a paradigm shift occurs. Strictly speaking, this is about the competition

of a series of theories, or progressive systems of theories (cf. Lakatos 1974). Such series of theories develop if the occurrences of anomalies necessitate the amendment of the theory by adding auxiliary hypotheses to protect or isolate the heart of the theory or even by semantic reinterpretations of concepts. The necessity of such auxiliary hypotheses for *ailing* theories is almost programmatic for scientific development. Famous examples include the Ptolemaic system of cosmology and, more recently, the Bohr atom model. It is not rare for the formulation of an anomaly to become part of the hard core of a rival theory. Often such processes of paradigm shift generate well-documented controversies. So let us take these debates, let us stage and prepare them for the classroom, for a kind of teaching that actually picks up the students from where they stand. Let us walk with them the detours, which were taken in history and which are perhaps necessary to help them accomplish their very own conceptual shift.

Fostering metaconceptual knowledge depends heavily on providing an appropriate learning environment: “To help students to increase their metaconceptual awareness it is necessary to create learning environments that facilitate group discussion and the verbal expression of ideas” (Vosniadou 2001, 186). What is formulated here is the need for a linguistic-communicational appraisal of technical themes. A possible way of implementing this consists in a dialectical approach to physics teaching, for example by staged controversies. What we offer the students are proposals rivalling their own inadequate concepts. For this approach to succeed it is important for teachers to be familiar with the *hard cores* of students’ notions and to perceive the construction and structure of their *insulating protection*. Only then can we be successful in developing competence by means of conflict-inducing processes. Fictitious controversies (based on historical facts) implemented in multimedia are suitable for the design of correspondingly appropriate lessons (cf. Kasper 2008). The didactic value added to the subject of physics consists in both an “increased metaconceptual awareness” concerning the development of models and knowledge, and a process of developing technical concepts. To engage learning processes it is of crucial importance to focus, above all, on the epistemic features inherent in the controversies. These include, for example, challenging premises and assumptions, and a usually open-ended as well as *soft* rationality, which transcends purely inductive and deductive logical rules of inference, e.g. by allowing prudence as a criterion for rationality (cf. Dascal 2006, 29).

Finally, I would like to counteract the impression that controversies apt for staging in classrooms can only be found in history. Addressing current scientific debates, which are focused mainly on ethical issues and which are yet to be resolved, provides excellent potential for scientific as well as social education.

Examples of such contentious issues are found in discussions of nuclear energy, cold fusion, pre-implantation genetic diagnosis, creationism and intelligent design, anthropogenic climate change, the (un)restricted use of nanotechnologies and many more.

7 Conclusion

Many people find a formal or objective access to contents of physics as a school subject quite difficult. So they will often leave the school without adequate concepts in physics and with a lack of interest in scientific questions. On the other hand, physics as a science is successful because it is free from all subjective and emotional dependence. Nevertheless, we see in story-telling-based learning environments, enriched with subjective and emotional perspectives, an alternative way, which facilitates entry to the edifice of physics for students. For this purpose, the development of fictitious learning units based on real scientific debates and real competitive scientific theories may be particularly suitable. Apart from mediating actual physics content, the ‘human aspect’ of science is revealed, and it helps to increase students’ metaconceptual awareness. Therefore we see in this approach an important contribution of physics to general education and maturity.

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