

Physics, Society and the Promotion of Young Physicists

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At the annual council meeting of the European Physical Society EPS in March 27, 2009, delegates from several countries (Germany, Italy, France, Poland, Croatia, Hungary, Czech Republic, Ukraine) complained of tendencies in their countries to substitute the traditional physics lectures at secondary schools by courses of 'Integrated Natural Science', merging physics, chemistry, biology etc. The delegates commissioned the EPS presidency to intervene at high European political institutions against the downgrade of physics. Even if Switzerland successfully rejected similar efforts in the mid-1990s, we should nevertheless ask why politicians tend to misvalue the importance of physics at secondary schools? An often heard criticism is that the contents of the lessons do not reflect modern physics, and thus let physics appear as a discipline being not distinguishable from natural science as it was taught at the end of the 19th century.

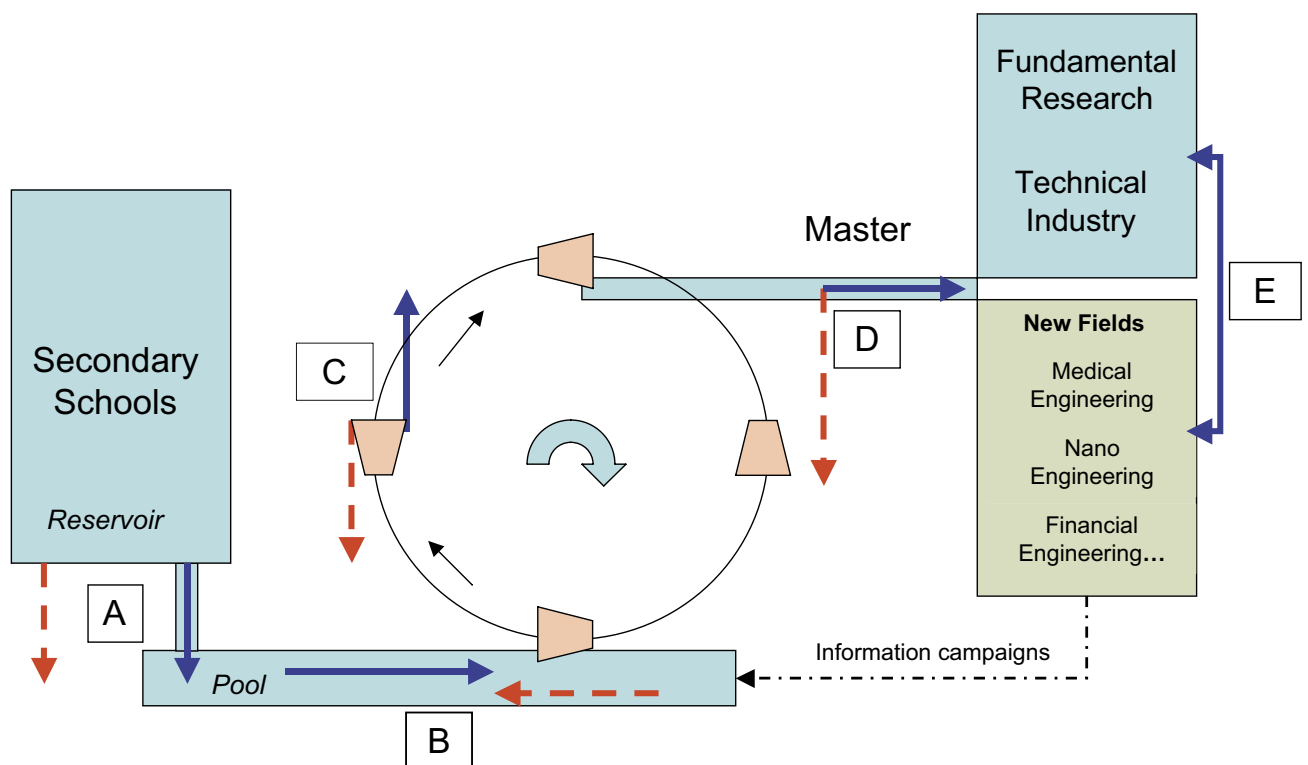
We are, therefore, well advised to take this criticism as a cause to reconsider the entire process of guiding students from secondary schools to the master level at universities, and from there to their profession in research and industry. We need to identify the weaknesses in this process and we need to ask how to eliminate them in order to obtain a maximum performance, i.e. to motivate brilliant students to choose physics for their studies and to keep them with us into their professional careers.

The Water Mill Model

In the following figure we visualize this process as a *water mill*. We start by considering the secondary school system as a *reservoir* to fill the *pool*, from which the physical institutes at the universities recruit their students. We describe thereby the university as a *wheel to pump* most efficiently students from the pool up to the master level, from where they may move to industry etc. The goal is an optimization of the quantity and quality of the *student flow*.

The blue arrows in the figure express the promotion flow of students, which we have to optimize, while the red dashed arrows indicate undesired leaks or losses. The promotion and the leaks have both to be understood, and appropriate means to accelerate, respectively, to fix them have to be found.

In our model we identify five critical processes: At the secondary schools, the reservoir, we have to confront *all* students with the important role, which physics plays in our high-tech society. A part of these students with the necessary skills can be encouraged to take up studies in natural sciences or engineering. This is *Process A*. These students then fill the pool below the wheel. Now we must



convince as many of them as possible to go for physics (*Process B*). In *Process C* we have to ask, how to increase the efficiency of the physics studies, and in *Process D*, how to bridge the gap between university and industry, or in other words, how to intensify the knowledge transfer in both directions. Finally, in *Process E*, we should treat a problem of growing importance with which physicists in industry are faced, the insufficient knowledge of the latest achievements in physics and engineering research and their inherent potential to be used for applications.

We start our analysis of the critical processes by presenting below an interesting and promising idea to tackle the problems of Processes A and B. Examples of Processes C through E will be addressed in the forthcoming issues of these SPS communications.

Processes A and B can in fact be approached from two sides, which we may call *pull* and *push*. On the *pull* side universities and in cooperation Swiss academies actively try to recruit future students. Examples are the SATW

Tec-Days, where external experts inform the students at the schools about today's fundamental and industrial research activities, and the Saturday Morning Physics events held at the University of Basel, allowing the students to get in touch also with the location of modern research. On the *push* side the encouragement for physics comes from within the schools themselves. As there are many more opportunities and much more time to do so than with the sporadic activities from the universities, an optimization of the processes on the *push* side is in the long run more effective.

The following text describes a possibility how this can concretely and successfully be done. Dr. Christian Ferrari from the Liceo di Locarno describes his approach to modernize physics at secondary schools. His method may be also attractive with regard to the EPS problem mentioned at the beginning. C. Ferrari graduated in physics at the EPFL in 1999 and received his PhD in mathematical physics at the EPFL in 2003. Since then he is teaching physics at the Liceo di Locarno.

Modern Physics at the Liceo di Locarno

Christian Ferrari, Liceo Cantonale di Locarno

My primary goal in teaching is to cover physics from Galilei up to the end of the 20th century, thus adding a century of discoveries to the traditional program. The motivation is twofold: Firstly, all students at secondary schools should be confronted with modern physical ideas (like genetics is presented in biology classes) as a part of the general culture, the mandate of every educational institution. Secondly, we need to convince the best of the students that physics is an intriguing option for a professional career.

Modern physics is taught at Locarno in two ways: In one-year projects, and in the specialization classes "Physics and applications of mathematics" (PAM) or in the optional classes "Physics". PAM is a course where physics and mathematics are coordinated so that the students reach a stronger mathematical background.

One-year Projects: In the one-year projects the students have been so far mainly involved in topics of quantum physics or relativity theory (see Box 1). My main motivation is that with the choice of cutting-edge topics the fascination of physics is best transmitted, and the students can gain enough selfconfidence to take up studies in natural sciences and in particular in physics. Mandatory for these projects is an intense coaching, allowing the students to achieve a thorough understanding.

Classes: During classes I teach the following selection of modern physics:

(a) Special relativity, where I start from the Galilean re-

Box 1: One-year projects (since 2004)

Quantum physics

From delocalisation to teleportation using nonlocality, Nicola Ghiringhelli

Delocalisation and quantum cryptography, Tiziano Zamaroni

Einstein-Podolsky-Rosen argument and nonlocality, Sacha Gianini

Atomic Models from Thompson to quantum physics, Marco Tognetti (supervised together with Gianni Boffa)

The black body and the beginning of quantum physics, Simone Colombo (with Gianni Boffa)

Cryptography, Anna Rapp

Tunneling effect and nuclear phenomena, Thomas Pferdekämper

Quantum Computer, Dorian Hautlé and Gionata Genazzi

Relativity theory and applications

From Relativity to the Black Holes, Enea Di Dio

Global Positioning System, Sandro Mani

Cosmology: Evolution and Model of the Universe, Vanessa Mordasini

Gravitational waves, Matteo Tomasini

General Relativity and Macrococosmos, Dalibor Drzajic (with Stefano Russo)

The project by Nicola Ghiringhelli won the award for the best "diploma project" of the secondary schools of the Sopraceneri (Ticino) issued by the ETH Zurich at the occasion of its 150th anniversary.

Almost all these projects can be found on [1].

lativity principle and develop the historical path up to the Einstein's axioms, pointing out the epistemological breakdown with Newtonian mechanics. I then discuss the concepts of special relativity and their modern experimental tests (e.g. the speed of light experiment at CERN).

(b) Quantum physics, which is exposed in more detail in Box 2.

(c) An introduction to subatomic particles, where I present some aspects of nuclear fusion and fission (also in relation with the mass-energy equivalence of special relativity). Moreover, I give a descriptive introduction to the Standard Model of elementary particles.

In my teaching I base myself on the threefold unifying concept of observable, system state, and time evolution for both classical and quantum physics. With this concept I could achieve a seamless, natural transition from classical to quantum that is very well perceived by the students.

Very much to my pleasure this approach has been proved successful. Out of 15 students having followed PAM, and having finished school, 9 started studies in Physics, Mathematics, Engineering or Biology with success (see

also Box 3). In view of these "statistics" I think I could improve on Process A in the aforementioned water mill model. The further motivation to study physics, Process B, is harder to judge at the present time. It seems to me, however, that a step in the good direction is taken with the one-year projects.

During my experience in teaching quantum physics I could benefit from a vivid exchange of opinions with Prof. Valerio Scarani (University of Singapore, previously University of Geneva). This collaboration gave good results, in particular for the one-year projects. I also interact with two colleagues in Ticino, Dr. Matteo Nota and Dr. Saverio Prinz. With the former I proposed a course of advanced training for teachers, and with the latter I made an institute project realizing the PAM course, which is strongly supported also by the direction of the Liceo, and I wish to acknowledge Dir. Fulvio Cavallini for this.

The exchange of knowledge between university researchers and secondary school teachers is, in my opinion, a great chance and a necessity for the continuing education and for improving the quality of the classes. Modern physics calls for that!

Box 2: Didactics of quantum physics

I start with an overview of classical physics with its epistemological foundation. Determinism, compatibility, the measurement process, and the system state are discussed. Those are later compared with quantum phenomena to show their failure or need for change in status. After a short historical development of quantum theory, I present the Stern-Gerlach experiment as an example of a system that cannot be explained classically. This allows me to introduce the structure of modern quantum physics: Observables, states, and time evolution, and so to integrate the threefold unifying concept, with which the students are already familiar from classical physics. The study of spin-1/2 and particle interferences with the help of a Mach-Zehnder interferometer (MZI) shows the main ideas of one-particle quantum physics (incompatibility, delocalization, and superposition states). The mathematical tools are from basic linear algebra for the PAM class. In the optional "Physics" course I use the approach of [2], which avoids the matrix formalism. Spin-1/2 and MZI can be used to explain quantum correlations (e.g., with a Franson-type interferometer), the Bell theorem, Aspect experiments, and the key concepts of entanglement and nonlocality.

[1] http://www.liceolocarno.ch/Liceo_di_Locarno/Internetutti/ferrari/LAM.html

[2] V. Scarani, *Initiation à la physique quantique*, Vuibert, 2003 (3e éd. 2006); available also in English and German.

Box 3: Feedback by a former student

"What convinced me to study physics is the bizarre behavior of Nature when we look at relativistic or quantum phenomena. For example I was most impressed by the counterintuitive results of incompatibility of some observables. Moreover, the learning of modern physics as we had it at the Liceo has numerous didactical advantages, because it shows the close relation between physics and mathematics. During the first year at EPFL I could profit, in contrast to most of my colleagues, of this teaching and see why and how the mathematical theory is useful for interpreting Nature." (*Alba Grassi, Physics EPFL, 2nd year*).