

Long-term Interactive Methodology in Science Education

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Abstract

An integrated long-term interactive approach is proposed for combining academic science education with additional methodology for enhancement of personal skills. It aims at making students more efficient both in their studies and further career development. The scope of communication skills includes both teamwork interaction and effective presentation of ideas. Internal motivation covers knowledge and mastery of constructive reasoning and emotional intelligence. Creativity is considered as a life-long progressing mindset and corresponding practical methods are provided. Along these lines, a new format for teaching of modern physics for students of engineering and other fields of science is described. It is based on constant interaction which provides them with an overview of developing trends and their meaning rather than with a system of established facts and their formal mathematical description. Formation of adequate basic concepts of reality in tune with modern fundamental science as early as possible during secondary education is suggested as a key area of future development.

Keywords

Academic; Communication; Creativity; Engineering; Innovation; Motivation; Physics

Introduction

Modern times are challenging in many ways to politics, business and academic education. Although the first two provide most of the requirements and funding to the third in this row, exactly the third is supposed to guarantee an adequate inflow of human resources to the first two.

What is happening now with the interaction between these areas? Overwhelmed with crisis scenarios and emergency actions with predominantly short-term effects, EU (European Union) politician and businessman pay much less attention to the "Europe 2020" growth strategy and its implications for academic education. Of course, this strategy needs to

be reworked according to the new realities. But the overall situation is so turbulent that tested approaches in decision making and funding are more and more discarded by self-organization and emergent behaviour.

In this paper, we describe our own steps and guidelines towards efficient emergent behaviour which utilizes fundamental skills and best practices from both academic education and business. This combination is meant to provide students not only with the necessary level of applicable technical training but also with a solid set of communication skills, internal motivation and creativity. Such an approach will enable program participants to shape a favourable career path according to their individual features, to establish efficient contacts with potential employees as well as integrate quickly into working teams and company cultures. Moreover, they can become more flexible in overcoming negative trends in youth unemployment in developed and developing economies.

Modern Physics is the physics of the XXth century and represents a crucial area of contemporary science education. This "time" definition is actually based on two milestones of the early twentieth century: Einstein's relativity and quantum mechanics. Physics of earlier times (Newton's laws, Maxwell's equations, thermodynamics, etc.) is called "classical".

For many years, Modern Physics has been extensively taught mainly in faculties of physics and chemistry as well as at chemical technology, technical, computer and information technology universities throughout the world. Lecturing on Modern Physics started in the USA during the 1980s as a result of extremely active and sharp debates about such a necessity. Since then, there exist lots of excellent textbooks and manuals

mainly in English, some of them translated into Russian. Most of these textbooks have been titled “Modern Physics for Scientists and Engineers” and have very similar contents (Thornton & Rex, 2006; Serway, Moses & Moyer-Thomson, 2005; Taylor, Zafiratos & Dubson, 2004; Tipler, 2007; Serway & Jewett, 2009; Fowler, 2007). They have been written in a modern style with many examples and solved problems. Therefore, they are popular among students of other sciences (chemistry, biology, engineering, etc.) because they can find there well-explained fundamental physics knowledge of modern relativism and gravity, quantum mechanics, statistical physics, solid-state physics, charge carriers in semiconductors, atomic and nuclear physics, elementary particle physics, etc. These courses usually follow in details how such new ideas have been developing. It is important to note, that there exist many written teaching materials on Modern Physics that are freely available in the Internet: particularly Facebook and YouTube with excellent video lectures, which is very helpful for students and corresponds to their new style to quickly “absorb” information.

In the academic year 2010-2011, a “Modern Physics for Engineers” course was started for the first time within the “Wireless Networks and Devices” Master’s Program in the Faculty of Physics at “St. Kliment Ohridski” University of Sofia (Dankov, Nesheva, Neshev & Gachev, 2011). Its goal was to cover the fundamentals of the twentieth century physics fairly rigorously, but on an adequate level for future engineers in the area of wireless communications.

We present here our idea for a new step forward: interactive teaching of Modern Physics where curriculum is shaped according to students’ individual background, preferences and challenging topics.

Structure of the Host M.Sc. Program in the Area of Wireless Communication as a Basis of the Combined Approach

An interdisciplinary Master’s program in microwave communication focused on innovation (Dankov et al., 2011) is the tested basis of the proposed combination of academic science education and development of communication skills, internal motivation and creativity. It includes three interconnected axes: 1) networks, software, channels; 2) devices, systems,

signals and 3) networks and innovation management program has achieved steady and sustainable growth over the last ten years (FIG. 1). It has been attractive to high-scoring students also with availability of training on the basics of personal and team innovation management. The growth tendency after 2008 shows significant stability in respect to crisis influences.

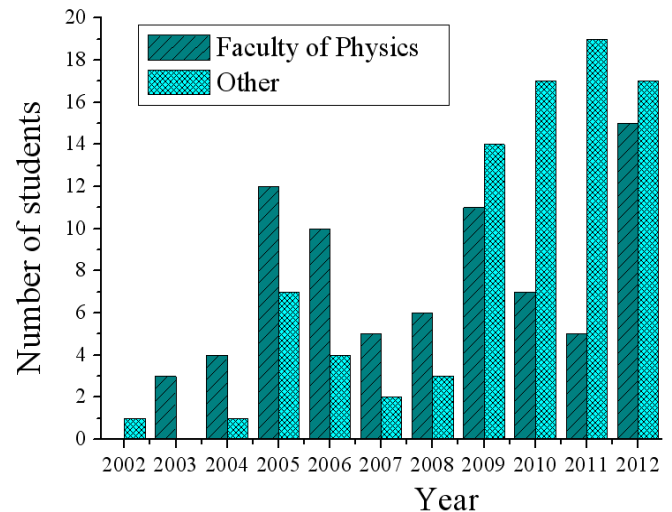


FIG. 1 NUMBER OF THE STUDENTS PARTICIPATING IN THE PROGRAM WITH DIFFERENT BACHELOR DEGREES – FROM THE FACULTY OF PHYSICS AND ELSEWHERE

Higher education in the area of microwaves: wave propagation, RF components and devices, antennas, wireless communication, etc. is among the most sophisticated and costly educational processes for many reasons. First of all, electromagnetic modelling of microwave structures is based on pure circuit approximation as well as on pure wave approximation, combined to a specific extent in each particular case. Therefore, students have to acquire sound knowledge both in the areas of electronics and electrodynamics on sufficient scientific and engineering levels. In addition, practice-orientated education in microwave physics and technology requires well-selected measurement equipment, components and devices which are generally expensive and not easy to operate. Moreover, modern RF design is based on utilization of circuit and structural (2-D and 3-D) electrodynamics simulators, which needs additional efforts for provision (licenses, upgrading) and training (computer classes, student seminars). Incessant development of research and modernization of key facilities, technical solutions and applied approximations in the microwave range also urges lecturers to continuously upgrade their own knowledge and skills.

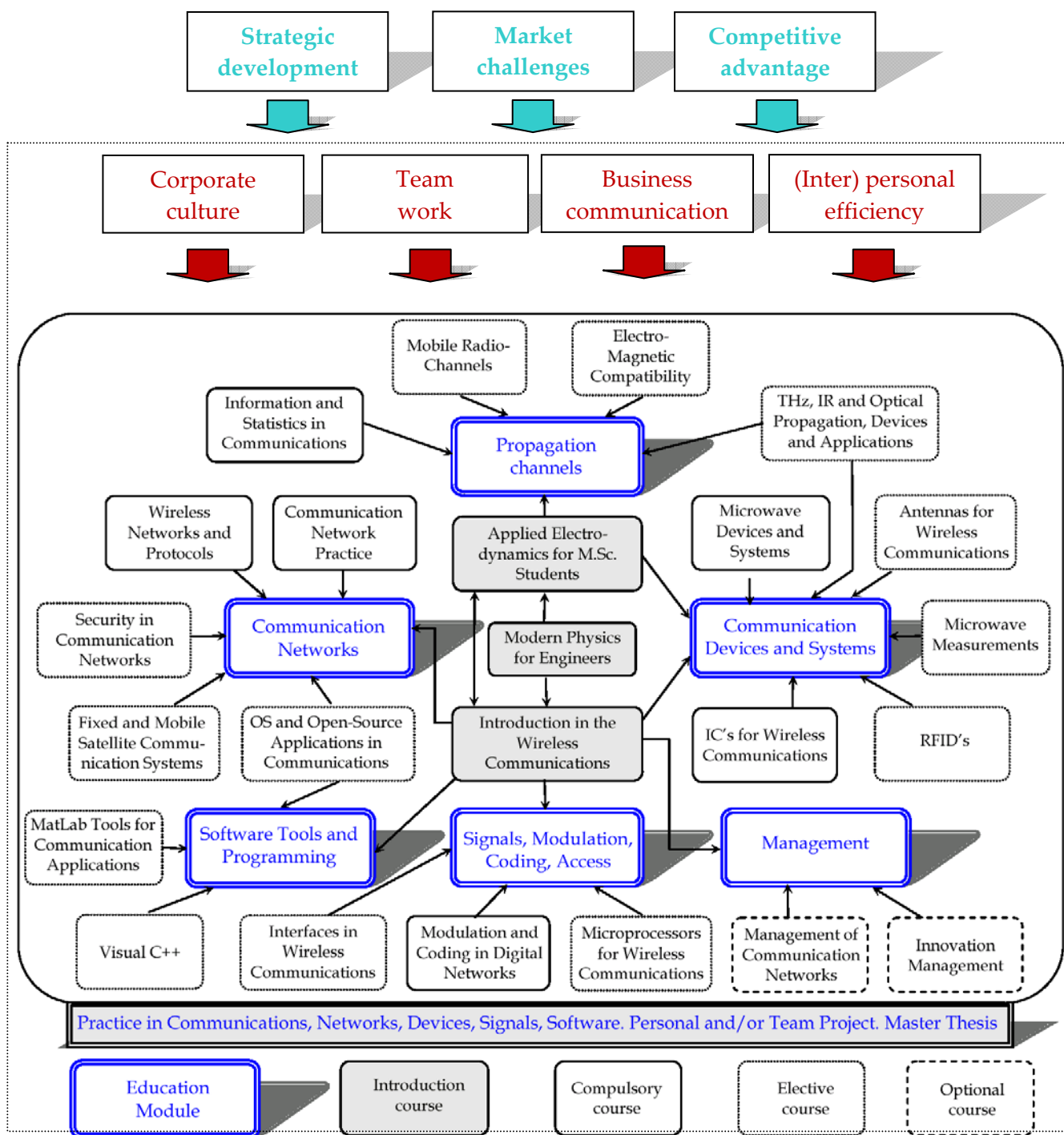


FIG. 2 SCHEMATIC STRUCTURE OF THE M.SC. PROGRAM AND ITS ADDITIONAL SKILLS DEVELOPMENT CONTEXT

The schematic structure of the M.Sc. program is presented in FIG. 2. The 1.5-year education is divided into 3 stages – introduction (1.5 month), education in 5 modules (1 year) and final practice, individual tasks and Master thesis (1/2 year). Three introductory courses (Introduction to Wireless Communication (Dankov, 2006), Applied Electrodynamics for M. Sc. Students and Modern Physics for Engineers) are

essential for the launch of the education process. Students usually come from different higher education institutions (see FIG. 1) and therefore having received different B.Sc. specialties and levels of training. A main goal of these courses is to align preliminary student knowledge in the area of physics, electro-dynamics, technology and communications before starting the next stage of core professional education.

It includes 7 compulsory and 7 elective courses (from 13 courses) distributed in 5 modules. These modules virtually reflect the necessary balance between the most important and inter-dependent directions of practice-oriented education in wireless communication: signals, channels, networks, software tools, communication devices and systems. One or two compulsory courses in a given module present the main concepts, ideas, basis and applications. The other elective courses (usually with state-of-the-art upgrade within 3-5 year intervals) provide additional knowledge and experience in the corresponding module (see the presented course titles in FIG. 2). Single course/lectures (delivered by leading specialists on single occasions) on particular advanced communication topics is also implemented (2 times yearly). The final stage of student education is trainee practice (in companies and/or university labs), work on an individual task and a final project – Master thesis (usually connected with the individual task). The presented M.Sc. program structure is optimized for 15-25 students per year. Our experience has shown that students easily accept this structure, and do not lose their interest during the whole period of education and continuously update their professional orientation after each taken course.

Apart from staff of the Faculty of Physics at "St. Kliment Ohridski" University of Sofia, the program includes lecturers from other faculties and higher education institutions as well as leading specialists from cooperating companies. Thus, being quite interdisciplinary, the lecturers' team has been capable of providing an efficiently balanced mixture of theoretical knowledge, practical skills and access to state-of-the-art information and technology.

In addition, constant exchange of information has been maintained between academic staff and companies about students with particular interests and skills and, on the other hand, about needs for professionals with special qualification in certain special areas. Right candidates have been directed towards initial contacts with corresponding companies and facilitation has been provided for reaching mutual agreements on future professional realization.

Within this process, we have been observing steady formation of a broader context for development of additional skills, predominantly originating from and relevant to the area of business.

Proposed New Combination and Interpretation of Academic Science Education with Methodology for Development of Communication Skills, Internal Motivation and Creativity

The core of our idea is to induce formation of efficient business skills and attitude in students as early as during their studies through:

- Adaptation of academic teaching to state-of-the-art business training and development methodologies;
- Constant interaction and work with specialists from leading companies (preferably with management experience) according to best business practices and standards;
- Reinterpreting lecturers'-students' relationship as joint work with shared goals, commitment and responsibilities.

The advantages of such an approach would be acceleration of professional maturity, greater motivation to study and much greater chances for finding adequate jobs.

Current state of affairs is depicted in FIG. 3. Academic educational institutions receive funding from students and/or other sources to serve them as clients by giving the desired type and level of higher education including knowledge and skills according to present standards. Of course, this is not the standard provider-client relationship because here the client is not always right. However, being in a position of clients during present worldwide economic turbulences certainly diminishes students' chances of making efficient and far-reaching decisions concerning the direction and content of their studies.

Our suggested modification is depicted in FIG. 4. Such a way of functioning would make possible immediate application of soft skills training, coaching and mentoring in an academic setting. This is because students will feel and be regarded as co-workers who also invest their time, effort (and money) in the final product: their own qualification and development. We intend to initiate such interaction in the form of very short modules during standard courses, extra-curricular activities and individual meetings. But what should these activities be focused on with top priority?

The first area would be business communication in its whole variety: interpersonal, writing and presentation

skills. In general, such a set has always been regarded in business as a key to personal and corporate success (see for example NACE’s Job Outlook Survey, 2012).

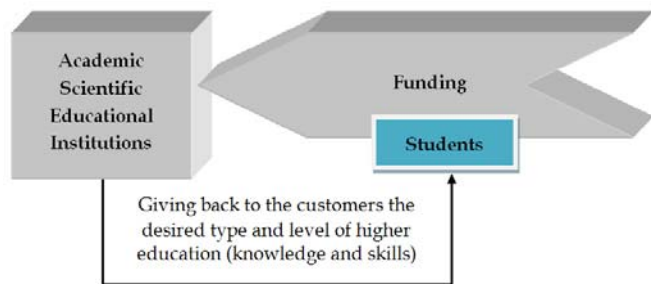


FIG. 3 CURRENT PROVIDER-CLIENT RELATIONSHIPS BETWEEN ACADEMIC EDUCATIONAL INSTITUTIONS AND STUDENTS

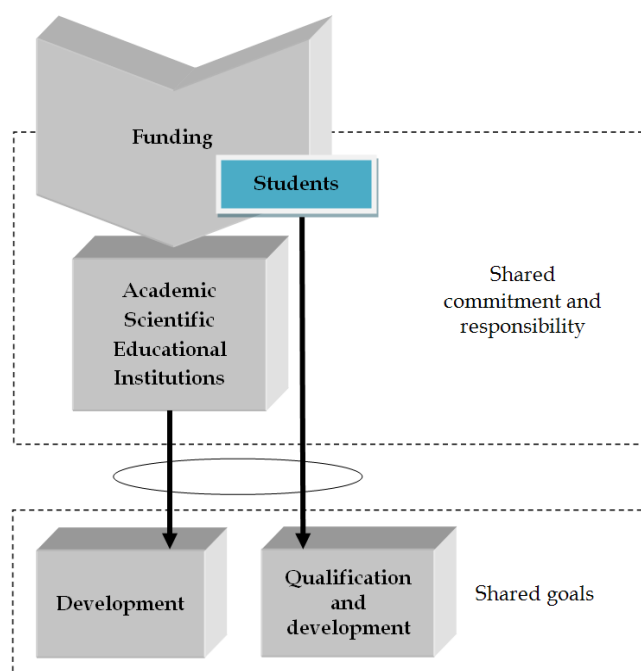


FIG. 4 JOINT WORK RELATIONSHIPS BETWEEN ACADEMIC EDUCATIONAL INSTITUTIONS AND STUDENTS

The second area would be internal motivation. Apart from the different motivation theories known in the literature, our observations are that high personal awareness and practical skills for enhancement of internal motivation are needed nowadays to study natural sciences and pursue a related career path. In our opinion, a key concept here would be Emotional Intelligence and its corresponding pool of knowledge and methods (Goleman, 1995). Based on that, students can learn to apply constructive reasoning with all available (intellectual and emotional) information regardless of circumstances.

The third area would be creativity as the basis of discoveries, inventions and steering of one’s personal life. On the one hand, it is connected with recent

discoveries of neurogenesis in adult brains which is enhanced by learning Gould, Beylin, Tanapat, Reeves & Shors, 1999), which gives even deeper meaning of lifelong learning as an attitude to be developed during academic studies. On the other hand, the scientifically verified Breakout Principle (Benson & Proctor, 2003) provides a wide range of practical methods and approaches to this goal.

So far, the main testing ground for this approach has been the “Innovation Management” course within the above-mentioned “Wireless Networks and Devices” Master’s Program. Steady growth of students’ interest, involvement and networking, including cases of successful internship and professional placements at leading companies are convincing performance indications.

Modern Physics in a Microwave Engineering Master’s Program

At first sight, the course Modern Physics for Engineers (FIG. 2) does not have direct relations with the other courses in the program (Dankov, Nesheva, Neshev & Gachev, 2011). For example, there exist specific education modules, of which fundamentals can be learned with basic knowledge of physics. But the main achievements of Modern Physics have important place in many other areas: technology, devices, signals, wave propagation, measurements, etc.

The strength of this particular course is significant not only due to the step-by-step accumulation of basic knowledge of modern physics; and it becomes valuable mainly due to the mastery of this knowledge in its completeness, while being presented with interactive methodology.

Inretactive Teaching Approach

A recent study has shown significant advantages of interactive teaching compared to traditional lecturing during the first-year physics sequence taken by all undergraduate engineering students at the University of British Columbia (Deslauriers, Schelew & Wieman, 2011). The authors’ instructional design for the experimental section was based on “deliberate practice” methodology in the form of a series of challenging questions and tasks that are required by students physicist-like reasoning and problem solving during class time, directed by frequent feedback. The distribution of student test scores is shown in Figure 5.

The average scores were $41 \pm 1\%$ in the control section and $74 \pm 1\%$ in the experimental section. Random

guessing would produce a score of 23%, which means that the students in the experimental section performed almost twice better on the test than those in the control section.

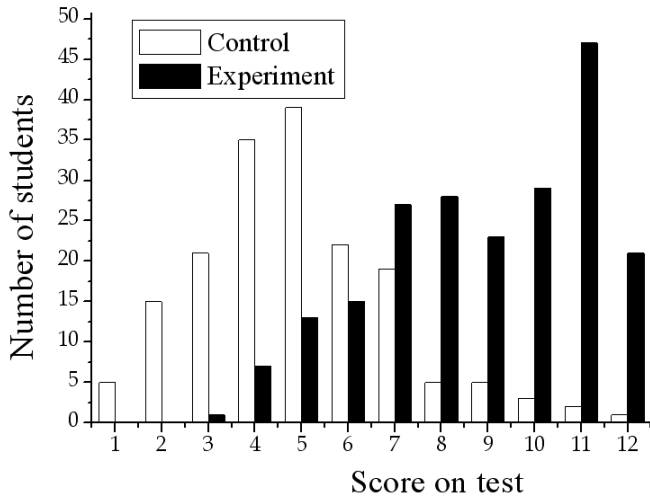


FIG. 5 HISTOGRAM OF STUDENTS TEST SCORES FOR THE CONTROL AND EXPERIMENT SECTIONS (DESLAURIERS, SCHELEW AND WIEMAN, 2011)

Learning content in the above work covered the area of electricity and magnetism which are more or less familiar to students from their secondary school studies. So, how can a similar teaching style be applied concerning relativity theory and quantum mechanics that are virtually “terra incognita” for them?

Our proposed modification of interactive learning consists of the following additional components:

- Flexible curriculum design according to preliminary and continuous interest

assessment;

- Finding proper combinations of physical meaning, philosophical background and mathematical description.

This modification has produced positive preliminary results while being tested within the Erasmus student exchange program in terms of increased interest and self-confidence in the area of modern physics that were qualitatively observed during the teaching process and were also assessed by means of introductory and follow-up structured interviews.

Flexible Curriculum Design

Proposed stages of curriculum design are shown in FIG. 6. The preparation phase is based on self-rating by the students of the following areas: previous knowledge of physics, interest in modern physics and disinterest in physics. Topics from these areas are first enumerated and then rated on separate sheet of paper in the same sequence.

Collected information from the whole group is analysed for shaping the introduction phase with common philosophical background for understanding of Modern Physics, elaboration of physical meaning related concepts and magnitudes as well as setting the efficient common level of mathematical description. The completion phase then includes dealing with advanced challenges beyond students’ “comfort zone”, exploration of former areas of disinterest for gaining useful knowledge and individual consulting for future development on the basis of observed skills, qualities and tendencies.

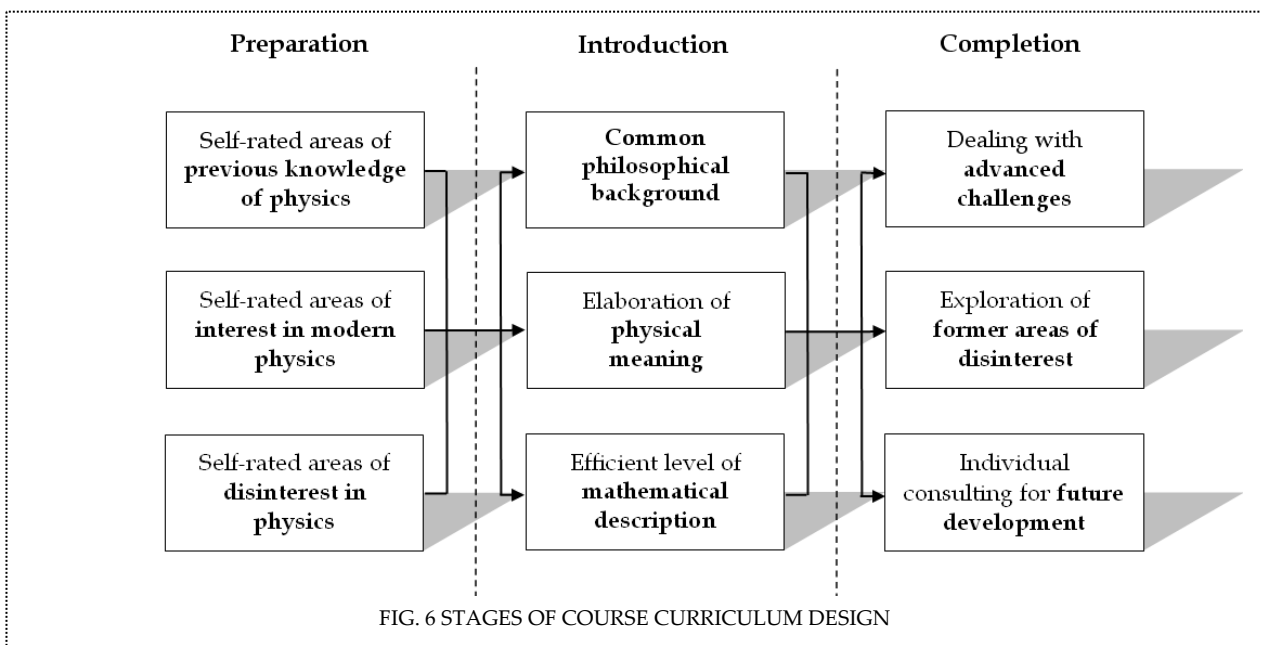


FIG. 6 STAGES OF COURSE CURRICULUM DESIGN

Proper Combinations of Physical Meaning, Philosophical Background and Mathematical Description

In general, wide-spread academic teaching approach in physics can be represented in FIG. 7. It implies start with a foundation of the laws of physics and their mathematical formulation, followed by clarification of their physical meaning. Later on, it might be possible to include consideration of the relevant philosophical background which, concerning courses for engineers and students of other sciences happens only rarely.

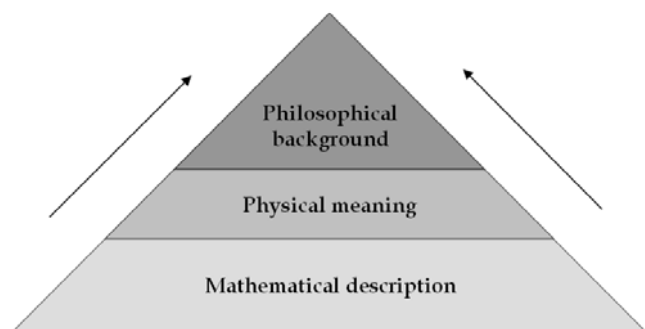


FIG. 7 WIDE-SPREAD ACADEMIC TEACHING APPROACH IN PHYSICS

Taking this into account, our approach can be represented in FIG. 8. In order to introduce students more smoothly into the subject, we propose to start with the essentials of the philosophical background of Modern Physics, continuing with the physical meaning of related phenomena and only afterwards setting the adequate level of mathematical description.

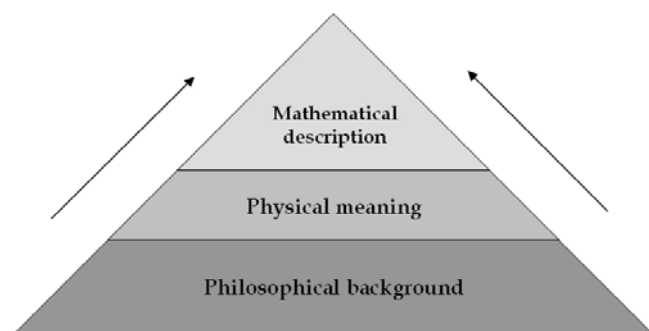


FIG. 8 PROPOSED INTERACTIVE ACADEMIC TEACHING APPROACH IN MODERN PHYSICS

Along these lines, our overall strategy is to give a logically coherent and sequential account of the basic principles of relativity and quantum theories of atomic and nuclear structure as well as some topics in elementary particles, molecular and solid-state physics.

The course starts with basic treatment of special relativity, because it is the foundation of the content of almost all later chapters in which the photons are completely relativistic particles. Quantum effects are

then introduced through the basis photon-electron interaction, and wave properties of material particles are considered. On the foundation of the basic principles of relativity and quantum physics, the curriculum advances into atomic, nuclear, elementary particle and solid-state physics. After clarification of the fundamental principles of wave mechanics, de Broglie's hypothesis, wave functions, the Superposition and the Uncertainty principles, students are introduced into the Schrödinger theory of quantum physics. This theory is applied to the examples of an infinite potential well, step potential and potential barrier, quantum harmonic oscillator, hydrogen atom, two-atomic molecule and interaction of magnetic field with electrons in atoms. An outline of the solution of the Schrödinger equation both for one-electron and multi-electron atoms (i.e. with three quantum numbers n, l, m) as well as some general features of wave functions is considered.

After a short presentation of physical statistics, students are ready for study of the electrical properties of the solids. A brief discussion of crystal structure precedes coverage of classical and quantum free electron models. In order to explain the big differences in electrical properties of solids as well as special properties of semiconductors, existence of allowed and forbidden energy bands is described. We also introduce the concepts of electron effective mass and "holes". Intrinsic and dope semiconductors as well as movement of their electrons and holes and their electrical properties are discussed. This helps students to understand the behaviour and characteristics of semiconductor devices: diodes, bipolar transistors, field effect transistors, etc. The content in nuclear physics includes nuclear models, decay and reactions. At the end we provide a general exposition on a basic level of elementary particle physics.

Thus, in summary, the course curriculum practically includes all main topics of Modern Physics: relativity, quantum mechanics, atomic physics, statistical mechanics, solid-state physics, nuclear physics, and elementary particles. Statistical mechanics is normally not included in lectures on Modern Physics. However, we have been observing that for proper understanding of many topics in contemporary physics – such as applications of quantum mechanics – this content is essential. In our opinion, engineering students nowadays should be able to work quantitatively with the concepts of Modern Physics. Therefore, our goal is to present these in a manner, which is logical, attractive and adequately rigorous. Special attention

should be given throughout the course to the physical meaning of all related phenomena.

Future Challenges: Suggestions to Modify High-School Teaching of Modern Physics

There have been consistent efforts worldwide to introduce deeper knowledge of Modern Physics during high school education (see for example: Oni-Grinberg, Nevo, Haisraeli, Karliner & Yankielowicz, 2011; Topics in Modern Physics, Teacher Resource Materials, 2006; Physics for the 21st Century, 2012). It could be assumed that such approaches are capable of attracting more talent by showing state-of-the-art achievements, interesting recent discoveries and attractive career opportunities. Their common features are adapted to teaching content (without too much simplification) and/or hi-tech multimedia presentation.

Nevertheless, exploring the attitude of our university students, we have generally observed that their difficulties in Modern Physics studies are not so much because of mathematical formulations but reflect the common "cognitive dissonance" between ideas and perceptions derived from surrounding "classical" world on the one hand and, on the other hand, ideas and descriptions of quantum world and the Universe as a whole. Moreover, recent work by Aage Bohr, Mottelson & Ulfbeck, 2008, implies that such a dissonance even in professional physicists could be overcome by replacing the "atomic worldview", the notion that matter is built of elementary constituents, with a "geometric" one, based on probabilistic occurrence of uncaused events.

Although transformation of worldview is definitely not a trivial task, we suggest a possible solution starting at high school level. Its goal is to prevent students from developing concepts of surrounding world that would already be too stiff at the time of their academic studies, thus becoming obstacles to grasp the fundamentals of Modern Physics. In essence, corresponding methodology should be based on giving rise to awareness of phenomena as having no distinct boundaries both in space and time, correspondingly overcoming dualistic distinction between existence and non-existence. This could be achieved by demonstrating as early as possible for example fuzziness of boundaries of material objects by exploring their images at different magnification, ranging from macroscopic to atomic scale. After establishment of such ideas, understanding could naturally be extended to fuzziness of temporal

boundaries of phenomena, illustrated by (thought) experiments in time measurement. That is how the basic layer of the proposed interactive teaching approach (FIG. 8) can start to build up at earlier age providing a more flexible set of concepts to develop the rest of the structure during academic education.

Such a course of action could be able to provide proper balance between high-school time spent both on the classical "fundamentals" and modern physics along the lines of a recent letter by Hamish Johnston, Editor of Physics World Magazine to the US President Barack Obama titled *The awesome lack of modern physics in US schools* which, according to its author, is relevant to many other countries around the world. (Johnston, 2012).

Conclusions

Our challenging times need new approaches to attraction and education of students in the field of natural sciences. We are convinced that utilization of best practices for personal and professional development in academic education and business as early as possible in a well-balanced combination can overcome negative influences and give rise to many new opportunities. In addition, introduction of long-term interactivity starting at high-school level can effectively upgrade and extend teaching of Modern Physics towards students of other fields of science which are essential for modern development of science and technology. We are convinced that such a teaching approach will enhance formation of unique physics-thinking style which is attractive and useful to creative and motivated students.

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