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Technology, Science, Physics and Culture: Scientific View of the World as a Non-technical Subject in Engineering Education

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SUMMARY *Technology stems from science. Science represents important and specific values in the whole of human culture. The history of scientific and philosophical ideas is an exciting and thrilling story with an open end. Such topics can contribute to educating the whole and balanced engineer.*

1. Introduction

The life of contemporary human society is deeply imbued with modern technology. It influences the life of all people with all the things it brings and offers to them. Let us imagine a life without planes, cars, telephones, radios, TV, computers, lasers and, in general, without electricity, lights, machines, etc. Modern technology brings comfort and enriches life. However, it is also a potential source of many dangers. Even wars are conducted with the means of the most sophisticated technology. Growing industrial production is exhausting raw materials and energy sources. It seriously threatens the environment and the life possibilities of future generations.

Engineers, protagonists of this trend, are usually educated at technical universities and colleges of engineering. Their preparation should not rest only in studying professional courses that prepare them to become experts in certain selected specializations, and train them for direct employment in industrial plants, where they are expected to provide growth and an improvement in production. Their responsibilities are much broader than this. When one considers the full role of technology in a modern society, it is evident that engineers should also participate in and contribute to the spiritual life of humankind.

Engineers are human beings first of all. They have a specific place in the social structure, and they should not let decisions concerning technological achievements remain in the hands of the others, e.g. politicians and economists. In view of the way technology enters the life of society, engineers must also study economics, management, sociology, law, psychology, languages, etc. and supplementary topics according to their personal wishes, perhaps literature, history, arts, etc. Engineers should be 'whole engineers', i.e. 'whole people'. They must not lose their human identity and abandon responsibility in influencing how the technology created by them is penetrating the lives of all people.

Modern technology is a considerable part of the whole culture of our society. When historians or archaeologists speak about a certain culture, say Acheulean, Ancient Egypt, Renaissance, etc. they have in their minds the whole way of life, the production of material goods and the ways people thought in each epoch.

Contemporary technology is connected with the life of society by two bonds. It gives life to its products. However, it is also attached to the opposite side; it also takes something. Modern technology stems from science. It is its product. Fruits which are borne on the tree of knowledge and which ripen into technological achievements in the care of engineers, can be sweet or bitter, according to the way they are used.

2. Science as a Part of Human Spiritual Culture

Science has arisen out of the traditions and the sources of the Western way of thinking, i.e. from classical antiquity, Judaism and Christianity. However, the science of our time involves the whole world.

Modern natural science represents an intentional and systematic search for connections between natural events. It formulates suitable concepts and quantities and tries to express relations among them in a mathematical quantitative form, as exactly as possible. The aim is not to know but to be able to predict which effects will appear under deliberately prepared conditions. Its method contains observations and experiments, the creation of notions, the construction of an exactly formulated theory, the calculation of predicted results in specified experiments and a verification of them. If the predictions agree, the theory is good. It adequately describes the studied domain of effects. When future observations and experiments find a disagreement, perhaps under conditions previously unstudied, the theory must be modified, corrected, or even completely reformulated using new concepts. The old theory, which under specified conditions gave satisfactory results, remains useful as a simplified approximation applicable under restricted conditions. In particular, many such changes and revolutions have occurred in the 300-year-old history of physics. The new, enlarged and reformulated theory is able to embrace a more extended sphere of effects in a unifying universal view. The scientific idealization proved its worth; it is successfully revealing the laws which control the natural events.

Biology ranks man into the world of animals. He is put on the top place in the gradual evolutionary changes of nature and life, which are assumed to be explainable in this framework. The success of science in the eighteenth and nineteenth centuries, with deterministic mechanical laws as its core, was so impressive and fascinating that it led up to an exaggerated haughtiness and immodesty. Many assumed that the knowledge of that time was not only an important stage but the last and definite level of human understanding of nature.

The base of contemporary science is represented by physics, which penetrates to the deepest level, and which introduces universally applicable general concepts (such as space, time, energy, particle, field, charge, etc.) and formulates the most fundamental laws. No part of nature is excluded from its domain. Since the beginning of the twentieth century it has dealt with the fundamental structural elements of the world (molecules, atoms, particles as quanta of fields, etc.). Its laws form the basis for an understanding of the laws in other natural sciences, e.g. in chemistry and in biology on the molecular and cellular levels. When we speak febout science in this article, we usually have physics in mind.

What are the values which science represents in the human spiritual culture? Certainly, it is not only the fact that its development has created modern technologies and that it entered into practice as a decisive productive power.

A considerable part of human nature is thirst for knowledge and understanding. Science is just the best tool that humankind has when penetrating the mysteries of the world he/she lives in.

A majority of engineers, and probably most scientists belong to the so-called 'realists' when doing some concrete experimental research work. They accept the idea that there is a real world which exists independently of our cognition and our wishes. This world is gradually being recognized. 'Empiricists' stress the fact that the only knowledge that we actually have is our experience. Our theories do nothing more than organize the pieces of this experience into logically consistent relations. I think that we can let philosophers quarrel about advantages and subtleties of both these approaches. For our purposes it is not important now.

For the method of science the only relevant requirements are the logical consistency, coherence and compatibility, and the strict and persuasive experimental verification. The applicability of science in technology originates only from here. Inherently, scientific models are not inviolable and never definitive. However, these models comprise a gradually enlarging domain of our experience. So, with a certain caution, it is possible to say that it is a process of improving and enhancing the recognition of nature.

Of course, the time is coming when it will be necessary to try to 'place' better the recognizing subject, i.e. man himself, into this picture. With new means, scientists (e.g. in quantum physics) begin to speculate about the essence of consciousness and about the so-called mind-body problem.

Science is not a discipline contradictory to and incompatible with the moral, artistic and religious feelings of human beings. If properly interpreted, it even offers numerous points of contact with these fields.

Certainly, scientists know that they do not know everything. They know that the scientific method has certain intrinsic limitations. They know that human spiritual life and the scale of human values are richer than contemporary science can embrace and comprehend. However, in the name of any philosophy, any life-attitude, it is not possible to refuse science. It is, indeed, the best, most honest and most faithful source that people have for the answers to their questions. Science and technology bear no responsibility for the problems they seemingly bring to people. The responsibility belongs to people themselves. Everything depends on how they use the technological achievements. For this reason, it is necessary to include the humanities and the arts in engineering curricula.

The scientific method needs imagination and intuition. It originates in them. But its statements are firmly rational, diligent and reserved. Science is open to any ideas and suggestions presented for solutions of problems. Nothing is forbidden *a priori.* It cultivates a modesty and toleration. Of course, it also cultivates a criticism and 'responsibility' in the way of thinking. Every word has to have its content, every sentence must represent a thought. In science, one is not allowed to babble and prattle. It is of great value to the world, where irrationality, superficiality, recklessness and thoughtlessness, together with natural human inclination to mysteries and arcana, lead to superstitious beliefs in various poltergeists, clairvoyance, astrology, sects, etc. In political life, an uncritical way of thinking leads to the success of populism. Together with a tendency toward a certainty and an 'ownership of truth', it leads to fundamentalisms, nationalisms and intolerant attitudes of all kinds. Both approaches do not exclude each other, and in the epoch of modern technology, which engineers help develop, they represent a serious danger. I think that the tolerant but critical way of thinking is to be considered an important moral and democratic value.

3. Physics as an 'Adventure of Knowledge'

All engineering students have to study physics to a certain extent according to the needs of their specializations. They must also study mathematics as an inevitable language of science and technology. Why not make use of this fact? Why not use physics also outside their specialized professional preparation? The development in physics is suitable for an excellent illustration of the character of science generally. It can also demonstrate the changing position of science in the whole of human culture.

Discussions of the method of science, particularly when given attractive and intriguing problems, can valuably motivate students to an interest in the deeper connections of technology and its origin in human spiritual life. It would be unwise, foolish and even harmful not to employ mathematics when convenient. Some problems can properly be formulated only with the mathematical language.

Physics can be considered the heart of natural science. It is not a dehumanized, dryasdust and tedious set of formulae to be learnt by students. It is a living and growing body of knowledge dealing with the deepest and most fundamental level of nature. The history of physics is an exciting and thrilling story. It is actually 'an adventure of knowledge' (Einstein, Infeld). Its interests are universal. It deals with the largest that we can examine (the whole universe) as well as with the smallest that we know (subnuclear particles). Physics studies the structures of matter in the world. Now it is even trying to grasp the ways in which they evolve in time and how they work together.

Physics has been profoundly instructed in several revolutionary jumps where new concepts and approaches have been formulated and where quite new theories have been born. Revolutionary processes and changes in scientific thinking as studied in sociology, methodology and philosophy of science (K. Popper, T. Kuhn) are usually demonstrated in physics.

No physical statement can be proven for ever. It is accepted if it works, until some limits of the model in which it has its place are found. However, that does not mean that different approaches are equally valuable as 'postmodernists' sometimes declare. In a certain sense the so-called modern physics has been 'postmodern' for a long time. But its changes are not directed against science; quite the opposite, they follow from the scientific method itself. Physicists are open-minded fellows.

What, from the rich and fascinating history of new physics and from its contemporary open problems, can be fruitfully discussed with students? Let us mention some of many suitable topics.

First, the great physical theories and their main ideas can be gone through and examined. Classical mechanics showed that the laws of nature are universal; the motions of planets and mechanical devices on the earth can be described with the same equations. Mechanics enabled us to grasp and to understand elastic, acoustic, hydrodynamic, heat and many other phenomena. For some time it seemed that mechanical models could explain nearly everything. The electromagnetic field theory revealed the limits of such hopes. The idea of ether fell down and the relativity theory appeared. It combined space and time. The relativistic theory of gravitation brought cosmological models of the universe as a whole. The genuine twentieth century physics is represented by quantum mechanics. Despite its enormous success in practical calculations in atomic physics, its philosophical interpretation is still controversial. Its extension to quantum fields is the physics of subnuclear particles. New trends in physics and other natural sciences are connected with the cognitive sciences. A theory of quantum gravitation is still missing. The forward outlook is open.

The very valuable topics for discussions are the numerous 'paradoxes' in the relativity theory. They follow from the inseparability of space and time. One of the most interesting of them is the so-called twin paradox or paradox of time, which states the fact that a travelling cosmonaut will return to earth younger than his brother who remained on earth. The relativistic relation between mass and energy, and the 'creation' and 'annihilation' of particles, can also be fruitfully discussed.

The influence of gravitation on relativistic geometry leads to its non-Euclideanity and the facts that the sum of the angles in a triangle is not equal to 180°, the circumference of a circle is not a 2π multiple of its radius, etc. Models of the universe may be infinite or finite. Many interesting astrophysical items can also be discussed on this occasion: relict radiation, quasars, evolution of galaxies and stars, black holes, etc.

A considerably more difficult task is to analyze the quantum theory. Students know that quantum effects are responsible for the structure of atoms, molecules, condensed matter, etc. They know the Schrödinger equation and Heisenberg relations. However, for philosophically relevant discussions about the interpretation of quantum mechanics, something must be added. The famous paradoxes such as the Einstein-Podolski-Rosen paradox, the Schrödinger's cat paradox, etc. need some additional explanation. But as a result, the questions of non-locality, entangled states, quantum computation, quantum cryptography and similar hot topics can also be included. The quantum approach to reality is quite different when compared with the classical one. Quantum theories of 'elementary particles' tend to combine all types of physical interactions into a unified general 'theory of everything'.

An attractive theory from the classical realm is the deterministic chaos theory. It reveals the source of unpredictability in some natural processes. Students are usually keen on creating fractal pictures using computers. The 'strange attractors' of dissipative dynamical systems have a fractal nature.

The mathematical concepts used here, such as non-integer metric dimensions, are a good starting point for further interesting discussions about the role of mathematics in science in general. The set theory, many different infinities in mathematics, the character of real numbers (bearing actually an infinite amount of information), the continuum problem, etc. can be talked about.

Gödel's results in mathematical logic reveal the limits of the axiomatic methods. The incompleteness theorem can be considered as one of the most important results in the twentieth century. Some problems from computer science (the Turing's halting problem, the concept of algorithmic information content, etc.) are closely connected.

One of the most exciting problems in contemporary science is to understand the difference between the past and the future. The 'time's arrow' and irreversibility of natural events on the macroscopic level is obvious. The physical origins of this time asymmetry on the microscopic level is not so clear.

Discussions about the second law of thermodynamics and about Maxwell's famous demon can naturally be extended to talks about an inevitable degree of energy dissipation when computing and about information processing generally. Flows of information and flows of energy in complex systems are interconnected.

Through computer simulations and cybernetic approaches it is possible to pass to discussions about the synergetic processes of self-organization, formation of structures and information processing in complex biological systems.

Scientific speculations about the so-called 'theories of everything', the strange quantum notion of 'reality', the great phenomenon of life and the mysterious mind-body problem can close our list of possible topics for discussion with students.

It must be stressed again that the aim of such talks is not to teach physics but to profit from the students' knowledge in it and to take advantage of using their interests in concrete open problems at the frontiers between science and philosophy. These philosophical discussions should lead to the finding of cultural connections and to a search for the place of man in the world.

In these talks, it is possible to use any of a number of books on these and similar topics, e.g. [1-14]. Also, in some journals such as *Scientific American,* suitable inspiring articles can be found.

4. The Course 'A Scientist's Understanding of the World'

In the sense already explained, at the Physics Department in the Faculty of Electrical Engineering of the Czech Technical University in Prague, we are trying to bring our students towards a better understanding of the role of technology in human culture by, means of an optional course of the above name. This course is offered to senior students having some knowledge of mathematics and physics. However, the course is not a technical and professional one. It does not explain physics and its applications in technology but shows its philosophical and methodological aspects, and it stresses the position of science, particularly physics, as an important part of human culture.

The first part of the course content deals with philosophical connections of the well-known themes from the theory of relativity and from quantum physics, which are, to some extent, included in the usual courses of general and modern physics. The second part is aimed more towards the students of some relatively new specializations, such as: computer science, informatics, cybernetics, robotics, etc.; courses that attract many excellent students.

The main topics of the course are:

- The position of 'man' in the world; human problems and questions.
- The rational way of understanding, as elaborated in science and particularly in physics; its limitations.
- The formation of theoretical models and their verification, or falsification.Revolutions in concepts and approaches.

- The epoch of mechanical models and their universal success. Laplace determinism. Development of electrodynamics and its applications. The concept of fields.
- Interconnections of space and time in the theory of relativity, mass and energy; relativistic paradoxes.
- Gravitation and space-time geometry, cosmology, the evolution of the universe.
- The quantum character of the microworld, structure of matter and atoms. The world of subnuclear particles, types of interactions, unification process.
- Philosophical aspects of quantum mechanics, its interpretations, Heisenberg's relationships, the process of measurement, the notion of reality in microworld, quantum paradoxes, non-locality.
- Dynamic systems, deterministic chaos, determinism and randomness. Fractals and non-integer dimensions.
- Mathematics as a language of science, its methods and possibilities, set theory, different infinities, real numbers, problem of continuum. The provable and the unprovable, Gödel's theorems.
- The irreversibility in natural events, the asymmetry of time, past and future, creativity of time.
- Entropy and information, Maxwell's demon. Flows of information and flows of energy, dissipation of energy in computation. Relationships of physics to cybernetics, computation and biology.
- Complexity, chaos and order, self-organization. Synergetics, creation of structures, evolution. Possibility of life in the expanding universe. Problem of consciousness.
- Science as a source of all achievements in modern technology. Science as a part of human culture, its methods and values.
- Science and philosophy, human connections, perspectives, open questions.

The course includes lectures and discussions on the afore-mentioned topics. Students can also bring other problems into discussions, if they are connected with the general intention of the course.

5. Conclusions

To teach such a course is not easy and some of the problems are still open. However, the author's experience with this one-semester course with the extent 2 + 2, which has been offered for several years, is undoubtedly positive. Usually, many senior students of all specializations register for the course. This course motivates excellent students towards further reading and deeper thinking. In order to pass the course and obtain a positive evaluation, students are required to participate actively in discussions and to prepare a short essay on a theme chosen individually, according to their interests and additional reading. We hope that the course represents a positive and significant contribution to the education of the whole and balanced engineer.

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