

## FACING REALITY IN MEASUREMENT-ORIENTED COURSES - POLISH EXPERIENCE -

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*Abstract: Measurement is assumed to be the most reliable means of acquiring information on physical reality. What are the logical foundation of this conviction, and how they should be integrated in the syllabi of measurement-related courses? Abstract thinking has been considered a cornerstone of Latin civilisation. Are we facing the crisis of this paradigm in higher engineering education? These are only two among several aspects of facing reality that are analysed in this paper.*

*Keywords: measurement, experimentation, abstract thinking, communication*

### 1. INTRODUCTION

Measurement science is of fundamental importance for all the branches of engineering which have to deal with real-world objects and phenomena. The same applies to experimentation methodology and techniques since the ability to carry out real-world experiments is of critical importance for the future engineers. Unfortunately, this ability seems to be seriously endangered, *inter alia*, by omnipresence of computer-related topics in engineering curricula. Paradoxically, it is also endangered by some cultural changes that undermine the historically established role of abstract thinking in the development of Latin civilisation. The educators cannot avoid the question: *what kind of remedial measures should be undertaken?* The paper aim is to partially contribute to better understanding of various aspects of *facing reality* in measurement-related courses.

### 2. EPISTEMOLOGICAL ASPECT OF FACING REALITY ...

We have used to think about measurement as the most reliable source of information on physical reality. We have used to teach our students that no mathematical model of a physical object may be designed neither verified without measurement. This pragmatic view is a very convenient starting point for teaching applications of measurement in engineering. On the other hand, it cannot withstand criticism following thorough logical analysis of epistemological status of measurement. The following conclusions drawn from another author's paper<sup>1</sup> seem to well explain the source of difficulties:

- ◆ Any procedure of mathematical model identification may be decomposed into two qualitatively different stages: identification of the structure of the model and identification (estimation) of its parameters. The interpretation of the concept of measurement in terms of homomorphism implies the conclusion that the measurement may be considered as a special case of parameter identification.
- ◆ The credibility of a mathematical model depends on the credibility of measurements used for validation of this model. On the other hand, the credibility of those measurements depends on the credibility of mathematical models used for designing measurement instruments.
- ◆ Consequently, epistemological status of measurement and mathematical modelling must be considered comparable. The answer to the question about the relation of measurement results and mathematical models to physical *reality* remains open until fundamental axioms of gnoseology are introduced into play.

The above-sketched way of reasoning seems to complicate a naive picture of measurement-based sciences, but at the same time it may ease the tension between so-called theoreticians and so-called practitioners that for ages has disturbed their co-operation in metrology. It may also contribute to better understanding of virtual measurements and accelerate their integration with traditional measurement science and instrumentation technology.

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<sup>1</sup> R. Z. Morawski: "Modelowanie matematyczne a pomiar", *Metrologia i systemy pomiarowe*. Tom II, zeszyt 1, 1995, pp. 25–35.

### 3. TECHNOLOGICAL ASPECT OF FACING REALITY ...

Preoccupation with information and knowledge as an individual, organisational, and societal resource is stronger today than at any other time in history. The volume of books printed in 16th-century Europe is estimated to have doubled approximately every seven years. Interestingly, the same growth rate has been calculated for global scientific and technical literature in the 20th century and for business documents in the United States in the 1980s<sup>2</sup>. The growth of recorded information is a historical phenomenon, not peculiar to modern times; the present, however, has several new dimensions relative to the information resource: modern information systems collect and generate information automatically; they provide rapid, high-resolution access to information; and they manipulate information with previously unattainable versatility and efficiency. In general, information systems applications are motivated by a desire to augment the mental information-processing functions of humans or to find adequate substitutes for them. Their effects have already been felt in various domains of every-day life, especially in the economy, in the governance of society, and in the milieu of individual existence.

Information systems have a strong impact on the individual's standard and style of living. They affect the scope and quality of health care, make social services more equitable, enhance personal comfort, provide a greater measure of safety and mobility, and extend the variety of leisure forms at one's disposal. More subtly, they also affect the content and style of an individual's work and in – consequently – perturb the social and legal practices and conventions to which one is accustomed. Moreover, massive data-collecting systems bring into focus the fuzzy borderline between the common good and personal privacy, calling for the need to safeguard stored data against accidental or illegal access, disclosure, or misuse. Individuals cannot ignore the impact of information systems on their skills and jobs. Information technology makes obsolete, at least partially, many human functions: first mechanical and repetitive tasks were affected; now clerical and paraprofessional tasks are being automated; and eventually highly skilled and some professional functions will be made unnecessary. Individuals performing these functions face the probability of shorter periods of employment and the need to adapt or to change their skills. As technologies, including information technology, grow more sophisticated, their learning curves stretch or the required skills become narrower; continuing training and education are likely to become a way of life for both employee and employer. Unlike the slow, gradual evolution of human labour in the past, present-day changes are occurring rapidly. Unless society members anticipate these effects and prepare to cope with them mentally and in practice, job dislocations and forced geographic relocations may prove traumatic for employees and their families.

The most fundamental issue of information society is the well-being of the human spirit in an increasingly knowledge-intensive environment. In such an environment, knowledge is the principal and perhaps most valuable currency. The growing volume and the rate of obsolescence of knowledge compel the individual to live in the continuous interaction with information resources.

### 4. INSTITUTIONAL ASPECT OF FACING REALITY ...

The modern university evolved from the medieval schools known as *studia generalia* – places of study open to students from all parts of Europe. Until the end of the XVIIIth century, most universities offered a core curriculum based on the seven liberal arts: grammar, logic, rhetoric, geometry, arithmetic, astronomy, and music. Students then proceeded to study under one of the professional faculties of medicine, law, and theology. In the later XVIIIth and XIXth European universities were secularised in their curriculum and administration, and the German model of the university as a complex of graduate schools performing advanced research and experimentation proved to have a world-wide influence. Meanwhile, universities' curricula also continued to evolve: the study of modern languages and literatures was added to, and such sciences as physics, chemistry, biology, and engineering achieved a recognised place in curricula, and by the early XXth century – the newer disciplines of economics, psychology, and sociology were also taught. The typical today's university may educate both undergraduates and graduate students in the entire range of the arts and humanities, mathematics, the social sciences, the physical, biological, and earth sciences, and various fields of technology. Universities are also the main source of graduate-level training in such fields as medicine, law, business administration, and veterinary medicine. This overview of the history of universities<sup>3</sup> clearly demonstrates a process of continual specialisation, *i.e.* of disintegration of knowledge. The Spanish existentialist, José Ortega y Gasset, was among the first thinkers who noticed the dangers of overspecialisation or – as he put it – *barbarity of specialisation*. In his book *The Revolt of the Masses*, published in 1929, he developed a systematic critics of the cognitive approaches characteristic of the beginning of this century. The awareness of the dangers implied by the atomisation of knowledge matured during the fifties and the

<sup>2</sup> Encyclopaedia Britannica CD99 – multimedia edition.

<sup>3</sup> based on Encyclopaedia Britannica CD99 – multimedia edition.

sixties. Consequently, some attempts have been made to practically overcome its negative side effects at the university level; in particular: interdisciplinary studies have been launched; meta-sciences (information theory, systems theory, ...) have been introduced into the curricula, and a matrix organisation has been implemented in many academic institutions.

The tendency towards specialisation particularly pronounced in engineering by the early XXth century – has been recently quite effectively balanced by a counter-tendency towards reintegration of traditionally separated domains of engineering education. A conspicuous product of this counter-tendency is a new domain of technology called *microsystems*. In the early 90s a fusion of microelectronics, optoelectronics and fine mechanics resulted in micro-electro-opto-mechanical systems (MEOMS). Those systems, enhanced with some biochemical elements, have been recently getting a quite universal means for solving problems of several traditional domains of engineering. But reintegration of engineering is only one premise of the reintegration of engineering education that has some other aspects related to knowledge, skills and attitudes to be taught at an institution of higher engineering education.

## 5. ANTROPOLOGICAL ASPECT OF FACING REALITY ...

The next aspect of *facing reality* in measurement-related courses refers to human factor in higher engineering education, *viz.* to the evolution of the attitudes and skills of our students. There are many causes contributing to the acceleration of this evolution by the end of the XXth century:

- ◆ rapid development of information technology and its implications in every-day life;
- ◆ increase of the age groups entering the institutions of higher education;
- ◆ rapid expansion of image-based pop-culture.

These are only the most important ones – common to the countries historically related to the sources of Latin civilisation. The long-term success of this civilisation has been explained by historians and philosophers in many ways, but all they have seem to agree that abstract thinking was an important cornerstone of this civilisation that supported this success. The idea of *classification* underlying abstract thinking enables us to grasp infinite reality using a finite set of concepts and rules. It makes us also capable of getting control over exponentially growing quantity of information. It enables us to communicate verbally – to speak and understand speech, to write and to read with understanding. A particular feature of this type of communication is its selectiveness – both communicating persons are able intellectually control the majority of transmitted information. This is not a case in image-based communication, established – for example – by means of television, where only small part of information stream is subject to such a control, while its majority is “absorbed” unconsciously by the receiving person. The image-based communication is a distinctive feature of the information age, with all its positive and negative consequences. The latter ones have recently reflected on the decreasing students’ ability to really understand and correctly use abstract notions; to fully understand traditional handbooks of mathematics or physics; to draw logical conclusions from the results of computation or results of a physical experiment. And this is another aspect of *facing reality* by an institution of higher education, and – in particular – by professors responsible for measurement-related courses.

## 6. PEDAGOGICAL DILEMMAS

New technologies become out of date after *ca.* 3 years while the cycle of reaching full professional efficiency by a graduate is 6–8 years (4–6 years of study and 2 years of initial professional experience). Consequently, it seems to be useless to base the education of the future engineers on the ideas that will become obsolete at the beginning of their professional careers. The rapid advancement of technologies is accompanied by an exponential growth of the volume of engineering knowledge that cannot be unlimitedly added to the engineering curricula. This is the reason for more synthetic and methodical teaching of the fundamentals.

Generally speaking, the main competence of an engineer is to solve technical problems, or – more precisely – to design solutions to those problems, to supervise the implementation of those solutions and to use them in practice. Therefore, the *skill* of creative thinking seems to be of primary importance for an engineer’s professional success, and – consequently should be taught at the university. This fundamental skill may be developed by appropriately designed laboratories and projects associated with more advanced courses. However, it seems reasonable to enhance their productivity in this respect by the classes devoted to the techniques of creative thinking and to the organisation of processes of inventive thinking – to the inventics and praxeology. The graduates should be also prepared to solve problems formulated outside of their main domain of study, and – consequently – co-operate effectively with other engineers, with experts in medicine, biology, management or marketing. They should be open to new ideas coming from both technical and scientific sources in various languages; they should be prepared to join interdisciplinary design and/or research teams.

The professional success of an engineer is determined not only by his/her knowledge and skills, but also in the same degree by his/ her personality and *attitudes*. The following features of an engineer's personality count among the most desirable:

- ◆ creative imagination, being an inexhaustible source of original ideas and a tool for predicting consequences of technical developments;
- ◆ readiness to analyse new ideas, even those contradicting the established views and opinions;
- ◆ initiative which stimulates creativity when the situation requires a new solution of a technical problem;
- ◆ ability to associate abstract and concrete facts, which determines the effectiveness of applying theoretical knowledge in engineering practice and which conditions an engineer's professional development by generalisation of accumulated experience;
- ◆ ability to objectively evaluate the results of work, which influences the quality of team work.

The extension of the engineers' responsibility for human life and happiness implies increased requirements concerning their moral standards. It is a moral duty of engineers to take into account ecological, cultural and ergonomic aspects in designing technical objects and actions. Consequently, providing the graduates with opportunities for developing ethical views and attitudes becomes an obligation for the university. This is an objective of humanities and social sciences introduced in the curriculum, but it is also a role of the system of study to increase the students' responsibility for the effects of their professional activity and develop the culture of quality.

The above-outlined positive methodology of engineering education is in every day academic life confronted with hard reality characterised in Sections 2-5. The intellectual distance to physical reality -- objectively justified up to certain measure by epistemological premises mentioned in Section 2 -- has been growing enormously in the experience of the new generation of students due to the omnipresence of virtual-reality technology. Their experimental capabilities and skills have been severely handicapped by the withdrawal of the majority of secondary schools from offering laboratory exercises supporting lectures in physics, chemistry or biology. On the other hand, their potential for abstract thinking has been considerably reduced by the lack of appropriate training, implied by several factors:

- ◆ predominant role of image culture in their early formation;
- ◆ predominant orientation of secondary schools on the preparation of candidates for the most fashionable (after 1989) studies, *viz.*: business, management, law and public relations;
- ◆ predominant orientation of young people on quick financial success requiring concentration on a narrow specialisation rather than on broad fundamentals;
- ◆ post-modernist way of thinking, promoted by media and some post-Marxist academic milieus, undermining traditional systems of values -- including such values as wisdom, logic and systematic philosophy.

The limited ability of abstract thinking disables the students to understand fundamental ideas and concepts that inevitably appear in academic lectures<sup>4</sup>. The negative effects of incomplete understanding are amplified by the inability to concentrate on a line of logical reasoning. Consequently, an average student is unable to benefit from an average academic lecture. He/she is rather inclined to browse in the *Internet* or in the books -- preferably, in the books providing detailed explanations without room for personal deduction and reflection. On the other hand, the lack of elementary practical skills, concerning the use of simple tools and instruments, is deterring students from courses supported by laboratory exercises -- other than software games -- and prevents them from learning by hands-on experience. The avoidance attitude towards experimental work is reinforced by the signals coming from the job markets for our graduates: the most desirable profile of professional qualifications seems to be that of a software engineer able to arrange and maintain a computer network in a bank or in a telecommunication company. Taking into account that salaries offered by those institutions are up to 10 times higher than a standard Ph.D. scholarship, one may easily imagine that it is practically impossible for our students to be seduced by the beauty of abstract thinking or experimental work in a measurement laboratory.

A discrete charm of virtual reality, offered by information technologies, support by the post-modernist way of thinking, is ravaging the mentality of young people:

- ◆ they loose the sense of the borderlines between the world of images and reality;
- ◆ they loose the interest in managing physical objects -- manipulation of images seems to be more attractive for them;

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<sup>4</sup> Two groups of students, each composed of *ca.* 100 students of the 5<sup>th</sup> semester, have been tested at the Faculty of Electronics and Information Technology (Warsaw University of Technology) in such a way that they were asked to give a one-sentence definition or description of four concepts: *theory*, *model*, *measurement* and *logical induction*. Only a few of them were able to correctly interpret all the concepts; the concept of *logical induction* turned out to be the most difficult.

- ◆ they lose the reflex of verifying results of operations performed on the models by means of appropriate experiments;
- ◆ they lose criticism towards results of computation.

The disintegration of knowledge, reflected in the structure of contemporary universities, is strongly supported by the students demand for specific knowledge and skills preparing them to the best-paid jobs. No room is left in practice for the real academic studies aimed at the development of personalities and at other long-term objectives, such as moral or intellectual leadership.

The teachers of measurement-oriented courses are in particularly difficult positions because measurement science and engineering:

- ◆ is an interdiscipline related to all fields of engineering, science, medicine, *etc.*;
- ◆ requires profound preparation in mathematics, physics, and – recently – in chemistry and/or biology;
- ◆ requires extensive use of experimental techniques.

That's why the teachers of measurement-oriented courses, together with the teachers of control engineering, have been particularly sensitive to a cultural shock that happened during academic transformation in Poland after 1989.

## 7. QUESTIONS INSTEAD OF CONCLUSIONS

What can be done under circumstances described in this paper ? There have been made some attempts at the Faculty of Electronics and Information Technology (Warsaw University of Technology) to remedy the difficulties, *viz.*:

- ◆ The traditional five-year studies leading up to the M.Sc. degree have been replaced with two-level studies comprising the four-year studies leading up to the B.Sc. degree and two-year studies leading up to the M.Sc. degree. In this way an additional threshold of selection has been introduced for those who aspire to the M.Sc degree.
- ◆ The share of design and laboratory classes in the programme requirements has been increased from 35 % to *ca.* 50 % in order to broaden the students' contact with physical experimentation.
- ◆ More than 30 advanced, accredited, courses – related to the fundamental issues of electronics and information technology – have been offered to the graduate students to enable them compensation of the lack of such courses at the undergraduate level.

All those remedies seem to partially solve existing problems, but not eradicate their causes. The roots of the problems remain untouched, and no clear strategy for fighting them has been put forward up to now. Some basic questions to be answered are the following:

- ◆ Who should act in this respect at the primary and secondary level of education ?
- ◆ Who should act, if at all, in the world of media to counterbalance the destructive tendencies observed there ?
- ◆ What is the role and responsibility of the academic institutions for both fields of action ?

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