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ENGINEERING THEORY AND PRACTICE: WISDOM OF THINKING

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This paper considers the mutual relationship and cooperation between engineering theory and practice in the development of the professional performance of engineers. In this paper, theory is understood as the ability of creative thinking - the spiritus movens (moving spirit) of any reasonable human activity, and that of the engineer's in particular. Therefore, high standards of general education preceding the university schooling, and at the university itself, should be of much concern for the engineering students, educators, and practitioners - in order to develop intellectually mature humans-engineers. The non-technical demands placed upon the engineer require more than pure technical capabilities. The author wishes to present the development and the state-of-the-art of his own judgment in that matter.

1. IMPULSE

After many years of a comparative drought in the discussion of the basic importance of theory in the engineering profession, recently a paper has been published (Lawson 2002) that addresses the meaning of theory in the holistic formation of civil engineers. In general, the paper states clearly that "theory promotes understanding, and understanding enables engineers to develop the practical expression of judgment and intuition vital to the engineering profession."

According to Lawson (2002), "most early knowledge was empirical" and "engineers stood on the shoulders of those who went before them." In the mid-nineteenth century, it has been found that learning should precede doing and, thus, professional competence began to be based on systematic, scientific knowledge. Science has been recognized as a key foundation for practicing true

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engineering profession. A shift from the rule of thumb to the rule of science became a reality.

But soon the school culture clashed with the shop culture
and science had to be combined with experiment. Engineering became a practical art. However, skilled judgment and experience remained still important foundations of engineering decisions.

Together with the powerful development of the computer in the 20th century, many engineers have been convinced that there emerged an era of a total mechanization of their work. As Lawson (2002) reports, the world appeared to be "a wonderfully complex but essentially deterministic machine." It appeared possible "to be able to compute and predict almost everything." But later it has been documented that the intuitive understanding of the problem was still of substantial importance. Nevertheless, many students acknowledged the omnipotence of the computer, believing that "theory is impractical; even useless" (Lawson 2002). Such a stand is dangerous because – as Lawson (2002) adds - "today's engineer may generate analytical solutions of unparalleled rigor and precision, but have neither the intuitive experience nor the theoretical understanding to explain their meaning." Thus understanding became the crucial factor of the engineering professionalism.

The idea of understanding eliminates both the extremes:
* that of the pure empiricist (focus on phenomena) – who is limited due to the lack of sensitivity regarding possible insights from the theory;
* that of the pure analyst (focus on theoretical output from computer) - who is limited due to the belief as having all the answers.

Finally, Lawson (2002) states: "Both extremes represent logical outcomes of choosing not to learn and apply theory." In that situation, the only remedy is the theory "to provide a meaningful link to the real world, not to overly abstract it ... This then becomes the focus of engineering education and practice." Accordingly, today each educator should recognize the right amount of theory, particularly - the linkage between theory and practice, such that understanding be increased.

2. GENESIS

The author has published previously on the topic of theory and engineering practice several times. In his first contribution (Cywinski 1993), he wrote:

"I have forty years of experience in conducting the c.e. teaching, training, and practical work - as Professor of the Universities of Gdansk (Poland), Mosul (Iraq), and Tokyo (Japan), as well as Consultant Engineer of the University of Baghdad (Iraq) and UNESCO Expert in Technical Teacher Training in Mogadishu (Somalia). I have got the opportunity to observe the c.e. students and engineers of different nations within various systems of education and conditions of professional life.

Throughout all those years I always had to face the problems of mutual relations of theory and practice, or general and particular contents, in c.e. education. One fact was interesting to notice that graduates from the general secondary schools were, usually, better university students than those from the technical secondary schools - although the latter, originally, showed a superiority in the understanding of the c.e. profession. (Note: The then Polish educational system contained 8 years of primary and 4 years of general secondary, or 5 years of technical secondary schools). Farther, looking at the output of graduated civil engineers, I was able to find that those with high theoretical background were better prepared to cope with various professional issues, even when the last ones were visibly practical in nature. Was the opinion of Gustav R. Kirchhoff and Wilhelm Ostwald (Nobel 1909), that there is nothing more practical than a good theory, correct?

The word 'engineer' comes from the Latin 'ingenium', i.e. - spirit, genius, ingenious power, or sagacity. Thus, engineer should be understood to be endowed with an outstanding intellectual potential, as the primary source of his practical disposition. The application of purely practice oriented c.e. education runs the danger not to develop properly this potential, generating rather a narrow shaped personality. Simultaneously, education tuned merely on the practice of today is not able to meet, competently, the needs of future. Thus, present education should primarily concentrate on the general sense of civil engineering and less aimed on its particulars, bringing up not only technical information, but teaching to utilize it, creatively, within the overall requirements of the society. The student's real practical c.e. formation should be shifted to the time after his graduation. Having developed an appropriate intellectual ability, he will be able to adjust smoothly to any practical demand of the specific professional area met.

The above mentioned general principles of education have been followed, with small fluctuations, at my maternal Faculty of Civil Engineering of the Technical University of Gdansk during the total period after W.W. II (MSc system of studies). They have shown their advantages through the successful professional performance of its many graduates, especially those who went abroad and had to practise the c.e. profession in terms often very much uncommon at home.

According to the Austrian novelist Marie v. Ebner-Eschenbach, theory and practice form a unity as human spirit and body, and therefore they remain mainly in a mutual conflict. In my opinion, it is the task of the spirit to train the body, or - the objective of the theory to construct the practice. But simultaneously, within a feed-back relation, practice stimulates evidently the development of the theory - as experiences of the body become processing material for the spirit”.

This text exposes the main ideas on the considered subject, backed by the author already ten years ago.

3. SURVEY

After the above mentioned paper, the author’s conference report (Cywinski 1995) was published. In order to investigate the problem of theory and practice in civil engineering education, the author concentrated first on the profession of engineering itself. He referred to the corresponding definition of the ASCE that - in its general form - stated the profession to be "... a calling in which special knowledge and skill are used in a distinctly intellectual plane in the service of mankind, and in which the successful expression of creative ability and application of professional knowledge are the primary rewards ..." In this definition, such notions as the intellectual plane and creative ability appeared important for the proper execution of the engineering profession.

Next, author referred to the U.S. Educate Act of 1994 - that stressed the necessity to improve, by the year 2000, the theory related education, as follows: "The U.S. will be first in the world in math and science achievement."

At that time, specialists agreed to recognize - within the past 100 years - two specific periods: the "practice oriented" (1890-1960) and the "research oriented" (1960-date). For the future, they recommended a "professional education" that should enable students of technology to execute their engineering profession in full from the very beginning after their graduation. The author disagreed because engineers should be prepared to answer not only the material question of how but also be able to cope with the spiritual challenges of why. The author referred to the statements of some adequate Polish research of the 1930s: "Technical sciences, ... advancing rapidly, soon are becoming old-fashioned", "Only fundamentals and thinking should be taught","A didactically rational teaching program eliminates specialization, by the conviction that life will make it better, faster, and more efficient than school", etc.

Then author focused on some U.S. research that concluded that engineering education needed to provide the capability of ”thinking”; for example: "Creativity depends on the information base and the capacity for unrestricted thinking". On the other hand, many others claimed that "engineering graduates ... are not prepared for the jobs they face in the present world." To address this problem, the remedy was that the engineer of the future should be a leader and, therefore, his educational experience should continue for all his life.

Later, the author continued his work at that problem. Always, he strongly backed his stand that only an intellectually highly developed personality of the civil engineer was the right precondition for his or her successful professional performance.

Reference to several former classic research on the mutual links of theory and practice was supplemented by a specific one that introduced the idea of "design" which - as a third type of knowledge - was assumed to bridge the gap between "theory" and "practice"; it was not the application of theory in practice but the application of scientific principles arising from the understanding of harmony between theory and practice. Creation became here a very significant factor.

In general, author spoke for the "theory" as reflecting the spirit, and "practice" - the matter of the engineer's any professional handling; hereby spirit was acknowledged to be primary.

In 1997, the author published a study advocating the broad influence of humanities and arts in the education of engineers, civil - in particular (Cywinski 1997). According to that study, a new engineer was needed who - having a broad education and presenting creative thinking attributes - would have no blind trust to the computer but would be able to rely on intuition. The author mentioned that although, at that time, there was a wide tendency to make the educational model conform with only the actual demands of the industry, the growing consumption needs of society required in that respect much more. The university was said to be responsible for the spiritual disposition of man, largely in charge for any development also in the material sphere of humanity.

Creative spiritual disposition was found to be based upon several particular aspects, being elements of the society's given cultural landscape (a place that has been created, shaped, and maintained by the links and interactions between people and their environment) - to mention alone ethics, aesthetics, environment, heritage, and sustainability. All of those elements could be promoted only by properly developed engineers. In that case, the intellectual foundation of civil engineers should be broad, well-rounded, and multidisciplinary. They should be able to synthesize from engineering, architecture, and the fine art. Several practical examples of bridge engineering have been given as relevant proofs of author's theses.

A summary of author's research made so far, was presented in Cywinski (1998). The author, discussed the viewpoint that "any technical university or college education should be, primarily, the stimulant for the development of the students' high intellectual potential, and that the true professional experience can not be taught and gained at school. Therefore, basic and engineering sciences should be still the main core of education, with due reference to the needs of the society accentuated by economy, humanities, and arts." The author added that the industrial model of economy became obsolete. Therefore it should be changed - "to meet the requirements of the research and information network economy" largely basing upon the advanced intellect of the engineer.

On other occasions, author has shown clearly what were the pitfalls and crossroads of the purely industry oriented engineering education. In his opinion, students should be given a professional education sufficient to get job - in order to be rooted in the nature of competition, according to the needs of the society. However, nobody was ever able to foresee the details of those needs, due to the constantly changing world. Therefore, the development of the students' ability to synthesize, on grounds of many different parts of particular information, remained top goal of any engineering education.

In author's opinion, there appeared the necessity to follow a broad, creativity oriented education of civil engineers, surely being superior to the model advocated by many others that was based solely on the satisfaction of the actual demands of the industry. The many challenges of the 21st century required the civil engineer to be an open-minded, original individual - having, besides a high technical and economical capability, also a rational understanding of the humanistic background of the profession.

The author referred particularly to his experiences as Professor of the University of Tokyo. He was able to find that the Japanese model of engineering education based upon much sophisticated theory, was leaving the development of the practical skills of students to the time of their professional life after graduation. He stated: "It appears that this model of engineering education had a very decisive influence on the success of the Japanese post-war recovering and development, on the actual leading position of Japan concerning the high-tech standards of engineering and the life of the nation, as a whole."

But the author saw the necessity to quote little more: "Our precursors in the engineering profession were familiar with the Ten Commandments, felt their positives and were able to apply them properly in performing their professional duties. They were no strangers to the broad humanistic background of technology and were aware of the positive effect of heritage on the professional output of the civil engineer. Suggestions for the present teaching program indicate that today all that, and much more in addition (e.g. oral and written communication), must be taught at the university - as a conditio sine qua non (indispensable condition) to safeguard a proper conduct of the profession after graduation. This is the result of the consumptional way of life advocated by TV and other media, and of the defeat of ambitious literature by the comics styled; it caused a severe decline of educational standards at the secondary school level."

Philosophical reflections on selected problems having impact on the shape of the engineer, have been discussed in Cywinski (1999). Cultural factors of engineering education were here of top interest. Special attention was paid to creativity. Citing outside research (Peters 1998), he wrote: "Creative engineers apply the model of technological thought which is a hybrid of scientific thinking and of that called matrix thinking; the latter is similar to that of the artists ... Scientific method is linear and hierarchical and aims to be independent of the thinker's personal and cultural value system so that results can be repeated by anyone. Matrix thinking is nonlinear. It moves from track to track, from level to level through associate leaps in logic. Matrix thinking is subjective and always depends on the thinker's own value system." Is that view not an additional confirmation of author's primary conviction about the principal importance of humanities and arts in engineering education and practice?

In Cywinski (2001) author approached the issue of sustainability, as depending largely upon the engineer's personality. He underlined that "true development cannot be limited to purely technical problems; human ecology should be taken into account." Spiritual motivation of engineering professionals can be here of fundamental value for their material handling. "This means that true development, referred to as the dignity of man, must be based on the priority of spirit versus matter, of person versus object, of ethics versus technology."

4. THEORY

In this chapter the author tries to shape the main argument for his theses and to summarize the contents around that argument.

According to the common definition, ”theory” means an idea formulated from known facts to explain something. A lexical definition (Lawson 2002) says that it is a "systematically organized knowledge applicable in a relatively wide variety of circumstances." It means that scientific theory "sets out ideas in a systematic way." Thus, theory is mainly deductive; it allows "to deduce logically quite specific expressions about the nature and behavior of the phenomenon of interest." Theory is said to increase our understanding of things. But Lawson (2002) stresses the necessity to join theory integrally with the real-world materialization.

Today, engineering should be treated as applied social science (Vesilind 2001) and, therefore, must have a broad philosophical foundation; theory related treatment is its important element.

Because "modern world is a complex, interwoven, dynamic of technology and humanity" (Bonasso 2001), present civil engineers - presumed to be leaders of the society - must think systematically, visualize complex technical and human interactions, and resolve conflicting viewpoints. Accordingly, they need "a more inclusive philosophical framework." (Bonasso 2001) continues: "The integral philosophy offers such a framework. This philosophy includes the individual and community as both physical elements - the outer world we see, and the psychospiritual elements in the culture - the inner world of meaning." Rather than a philosophy of parts, integral philosophy is meant to be a philosophy of the whole. He adds: "Engineers and scientists require an expanded philosophical foundation."

From all the above mentioned papers it is evident that present engineering is largely associated with philosophy and the spiritual elements of culture. In author's opinion they are deeply rooted in the nature of theory which, being responsible for setting out ideas, is considered to be the offspring of wisdom – the mother of thinking and understanding.

Author regards theory, as the primary source, to be representative for the philosophical framework of engineering as a whole – thus determining crucially any analysis and synthesis in engineering design, construction, and maintenance. The philosophy reflects the absolute constitution of wisdom.

In Darton (Darton et al. 1990), one can read:

* "I Wisdom, share house with Discretion, I am mistress of the art of thought." (Pr 8:12).
* "Blessed are those who have discovered wisdom, those who have acquired understanding!" (Pr 3:13).
* "Wisdom's treasures contain the maxims of knowledge, ..." (Si 1:25).
* "Meditating on her is understanding in its perfect form, ..." (Ws 6:15).
* "For Wisdom begins with the sincere desire for instruction, ..." (Ws 6:17).

In Darton (Darton et al. 1990), there are also many other statements identifying *wisdom* and *understanding*. In author's opinion they all together are reflections of *theory* that is considered in this paper.

Until now, engineers were usually regarded as "Sons of Martha" (Fredrich 1989). They make it possible for the rest of the society to "choose the better part." However, it may happen that sometimes they must be able to show another stand

- that of the "Sons of Mary". They should listen to the more general excellence of wisdom. As Shakespeare says: "There are more things in heaven and earth that are dreamt of in your philosophy, Horatio."

It means that engineers will confront situations which cannot be defined by an analytical framework - they must be able to think "irrationally". Therefore, in some cases "engineers of dreams" (Petroski 1995) must become, paradoxically, "dreaming engineers". In such situations reference to the universal wisdom attributes could help them to find the appropriate solutions.

5. PRACTICAL THEORY EDUCATION

Although "wisdom is brilliant, she never fades" (Ws 6:12)- (Darton et al. 1990), everyday engineering practice requires a theory that could be easily recognized and implemented. It seems that several thoughts of Schneck (2002) can be here adequately instructive.

So, in order to develop practical thinking capabilities of students, the 21st century of education should be:

"(1) more deductively oriented than inductive;
(2) more process oriented than product oriented; and
(3) more generically practice oriented than skills oriented."

It means that students should be aware of common denominators keeping various courses together - by perceiving "the multidimensional nature of human experience." Education must be "more holistic". Students should be thought "how to use unified, deductive approaches to the creative formulation and solution of engineering problems." Holistic training means the teaching of students not what to do as engineers, but what to be as engineers. The deductive approach should cause the students immediately to think in general, global terms.

Schneck (2002) distinguishes seven elements of knowledge: frame-of-reference, scale-of-observation, resolution, structure, order, relation, and synthesis. All of them show our particular limitations in the true recognition of reality but, simultaneously, in practical applications they can bring us closer to the understanding and to an authentic solution of problems.

Author's thoughts are here more general. He wishes to underline the process of the mutual influence of theory and practice and vice versa. That process has an iterative character – bringing up, step-by-step, a continuous progress in technology and human civilization as whole.

6. CLOSURE

In conclusion, the author wishes to stress, specially, the general question of human development – considered as closely connected with technology. As it is stated in Chalasinski (1957) - when speaking of the culture of technology, one meets also, directly or indirectly, various humanistic aspects. Hereby, the intellectual progress generates, quite naturally, the technical progress, and vice versa - the latter accelerates certainly the development of the former. The problem of the mutual connection and correlative influence of the spiritual and material cultures becomes interesting for both the humanists and the technicians. This is especially important when analysing engineering sustainability (Cywinski 2001).

Therefore, engineering education which addresses the development of *creativity* and *understanding* is always very much needed. *Wisdom of thinking* furnishes its necessary general basis. May the contemporary young generation accept it as its own. "Human beings live not on bread alone ..." (Mt 4:5) - (Darton et al. 1990). That motto, if implemented, could largely improve the condition of the present 21st century, so tragically imprinted at its very beginning.

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