CHALLENGES OF CIVIL ENGINEERING EDUCATION

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ABSTRACT: The paper discusses the present and coming challenges of civil engineering education, including leadership, creativity, computing, security, globalization, and climate changes-related challenges. In more general terms, it addresses the fundamental issue of the present focus on mostly quantitative, or numerical, aspects of civil engineering in the context of a shift from art to science in engineering education. The paper proposes a Renaissance in civil engineering education through the reinstatement of the lost balance between creativity and leadership on one side and teaching only the analytical knowledge and skills on the other side. Finding such a balance could be accomplished implementing the Da Vincian principles in civil engineering education and through the development of a modern holistic body of knowledge in civil engineering. The paper also briefly discusses both the ASCE and the European Union efforts to improve the civil engineering education. Finally, globalization of this education is proposed, which would maximize the utilization of the limited resources and would create a new era of global cooperation.

KEYWORDS: civil engineering education, challenges, balance of art and science, quantitative and qualitative knowledge and skills, leadership, creativity, computing, security, globalization, globalization of civil engineering education.

1 INTRODUCTION

Civil Engineering education is in a critical period, which may determine the future of our profession for many years to come. There is a growing global consensus that serious changes are necessary to redefine the civil engineering education in order to meet the present and coming challenges.

Only a century ago the nature of civil engineering education was entirely different than today. It was more like art than science, focused on creativity and leadership and on building a holistic, or qualitative, understanding of our profession. The available knowledge was mostly heuristic in the form of decision rules acquired through centuries of practice following the master-apprentice paradigm. Today, the focus is mostly on the analysis, on building quantitative understanding and numerical optimality, as it is in science. Our civil engineering knowledge is only partially heuristic, over the last century it has been supplemented by all kinds of mathematics- and physics-based theories, including complex mathematical models. We are all proud that civil engineering became a science, but at the same time we are becoming painfully aware that the price for this progress is the loss of our creativity and the excessive focus on the quantitative aspects of our profession. This shift from art to science has ultimately caused that civil engineers are inadequately prepared to deal with complex challenges of the 21st Century, which require novel solutions produced by out-of-the-box bold thinking (Arciszewski 2006).

To improve the present situation and to reestablish leadership of civil engineers in the modern societies we need to reassess the present nature of the civil engineering education. Most likely, the key to the future is in the balance of art and science in education, understood as proper teaching both the qualitative and quantitative aspects of civil engineering. There was a time period, the Renaissance, when it was postulated to maintain the balance between art and science, following the DaVincian principle of "art and science." That resulted in an incredible explosion of engineering creativity and in the consequential very high social position of engineers.

Unfortunately, today civil engineers are rarely perceived as proactive and creative leaders. They are usually seen as reactive technologists and followers. Subsequently, public attention moved to other areas of technology, mostly to Information Technology. As a result of that, a number of undesired phenomena occur today, including growing stagnation in our profession, deteriorating infrastructure, reduced infrastructure spending, etc. This situation has also caused that the best and brightest students choose not to study civil engineering and a lot of enthusiasm, creativity, and pride are lost in the process. Finally, we can observe a growing gap between civil engineering and other professions in terms of social position, salaries, growth opportunities, etc.

The paper proposes reinventing the civil engineering education through returning to the roots of our greatness, i.e. to the Renaissance idea of a modern man. That should help us to prepare students much better for the future and

in the process would allow our profession to rebuild our past glory and to reestablish civil engineers as leaders. The paper is intended to initiate a discussion about the past, present, and future nature of the civil engineering education, and, even more importantly, how to evolve this education in a desirable direction. We identify the present and future challenges and propose solutions, which could be implemented through international cooperation in many countries at the same time creating a momentum and reversing the present recessive trends.

2 21ST CENTURY CHALLENGES

The 21st Century civil engineer will have to cope with a number challenges, which are emerging even today, including:

- Leadership
- Creativity
- Computing
- Security
- Globalization
- Climate changes

In the past, civil engineers were the true leaders. They had a vision, a strategy, and, most importantly, they were able to initiate and implement changes to our world. They created the built infrastructure, which became a material foundation of our civilization. Unfortunately, today the leadership moved from civil engineers to politicians, who usually are not even engineers. They consider engineers as merely technologists, who are narrowly educated to use various analytical tools and who simply follow directives without any independent judgment, not to mention creative contributions. This situation must be changed and the process must be initiated through a different civil engineering education, which will clearly prepare our students to be leaders.

Creativity is understood here in a very pragmatic context of Design and Inventive Engineering (D&IE) as it is taught at George Mason University by the first author. D&IE is a body of knowledge necessary and sufficient to develop and use design processes producing both routine and non-routine (inventive) designs. In this case, routine designs are based on routine concepts, i.e. concepts known and feasible. By contrast, inventive designs are those based on unknown yet feasible and potentially patentable concepts. The focus of D&IE is on the qualitative aspects of design and problem solving in civil engineering. The teaching is concentrated on conceptual design and creative/inventive problem solving when non-routine/inventive design concepts are sought. In addition to learning about engineering creativity in general (Da Vincian principles, creative society, the Medici Effect, etc.), the students learn about such heuristic methods as Brainstorming, Synectics, Morphological Analysis, TRIZ, etc. They learn fundamentals, learn how to use various computer tools based on these methods, and apply these methods to solve inventive problems. For example, in the Spring 2007, students worked on such problems like the design of a blast resistant beam-column connection in steel skeleton structures, the design of a run-off water cleaning devise, or the design of a safe highway signpost. The response of students is always amazing when they discover that civil engineering is so much more than only the analysis of stresses or simple dimensioning. Unfortunately, the reported elective course is more an exception than a rule and it is offered only at a single university in the USA (Arciszewski 2006, Grasso and Martinelli 2007, Stouffer et al. 2004).

The present practice of teaching computing in civil engineering is highly inadequate and mostly counterproductive. Computing is often taught as computer drafting and in the context of computer simulation of various mathematical models. It is nearly entirely quantitative, it provides practical skills, but it is insufficient and even potentially dangerous. It leads to a mechanistic use of computer programs without any understanding of the computing principles implemented in the software. Ultimately, such practice may cause the incorrect use of software, for example, outside its assumed functional envelope, with obvious safety consequences. Additionally, the current practice significantly restricts engineering creativity. It forces engineers to use computer programs exactly as they were intended by the software developers, who are often without any understanding of engineering, particularly of its qualitative dimension. If we want to improve the situation, we need to teach students a conceptual understanding of computing, which will allow them to comprehend the internal workings of a computer program and to relate computing to various civil engineering activities. There have already been attempts to move civil engineering education in this direction, for example by Raphael and Smith (2003), and more details on the subject are provided in Section 6, "Globalization of Education."

Infrastructure security has been a concern in the UK for many years. After the events of September 11, 2001, it has become a major concern in the USA and is becoming important in many European countries. If we want to address this challenge, a coordinated effort has to be made to develop a good understanding of security threats and their prevention in the context of infrastructure systems. Next, this acquired knowledge must be incorporated in the academic programs as separate courses on infrastructure security or taught entirely integrated with existing courses on infrastructure systems design, construction, and maintenance.

Globalization in civil engineering, mostly in construction engineering, is simply a fact. It is a complex process of interrelated cultural, social, political and technological changes occurring at the same time and affecting its participants in often unpredictable and not necessarily desirable ways. We need to prepare our students not only how to cope with globalization, for example how to avoid outsourcing their jobs, but also how to understand globalization in order to use it to their benefit. That means teaching globalization in the context of co-evolution and of complex adaptive systems, but also teaching the globalization management.

There is a growing consensus that our planet is undergoing climate changes. No matter what is the cause of these changes, human activities, the Sun-induced warming of the entire solar system, or a combination of both, they will have tremendous impact on civil engineering. That means a strong need to prepare students to cope with all

kinds of infrastructure and environmental problems, whose nature and extend cannot be even predicted today. There is only a single alternative how to prepare our students for this challenge: to educate them how to deal with unexpected and complex problems using various "out-of-the-box," or inventive problem solving methods and tools.

3 CIVIL ENGINEERING RENAISSANCE

The restoration of the past glory of civil engineering requires bold action and significant qualitative changes in addition to mostly incremental and quantitative improvements postulated by the American Society of Civil Engineers (ASCE) Body of Knowledge (BOK) Committee, as discussed in Section 4, "ASCE Initiatives."

The authors believe that the key to our future is the reinstatement of a balance between teaching interrelated creativity and leadership versus teaching only the analytical knowledge and skills. That also means finding a balance between qualitative and quantitative aspects in civil engineering education, or ultimately finding a balance between the art and science in education.

We postulate the reestablishment of our past glory through returning to its roots: to the Renaissance concept of an educated person. This concept served engineers so well in the past and could be used again. Leonardo Da Vinci, one of the most important Renaissance figures and an artist and an engineer, has best articulated it. He was a living proof that a true greatness can be only achieved by balancing contradictory components. He has formulated seven principles, which are even more inspiring and useful today that they were in the 15th Century (Gelb 1998). We could consider these principles as a conceptual foundation of a modern Renaissance civil engineering education. They are listed here with brief explanation of their modern interpretations:

- *Curiosita*: open and curious attitude to the world and focus on constant learning
- *Dimostrazione:* constant knowledge testing and verification in the context of real world
- *Sensazione:* multi-sensual and holistic approach to knowledge acquisition
- *Sfumato:* understanding and accepting the world and knowledge in their complexity and fuzziness
- *Arte/Scienza*: balance of art and science
- *Corporalita:* balance of body and mind
- *Connessione:* holistic/systems view of the world

The da Vincian principles can be used to design a modern holistic BOK in civil engineering with the main five components (Arciszewski 2006):

- Factual knowledge
- Analytical knowledge and skills
- Creativity knowledge and skills
- Computing knowledge and skills
- Globalization knowledge and skills

When such a BOK is developed, the desired balance will be restored between:

- Leadership and discipline
- Creativity and order
- Synthesis and analysis
- Qualitative and quantitative knowledge
- Abduction and deduction
- Left and right brain hemisphere education

4 AMERICAN SOCIETY OF CIVIL ENGINEERS INITIATIVES

Fortunately, the extend and nature of the present and coming challenges have already been recognized by leaders of various engineering organizations, including the American Society of Civil Engineers (ASCE), the National Academy of Engineering in the USA, the National Society of Professional Engineers in the USA, etc. In particular, within the ASCE a Body of Knowledge (BOK) Committee has been established. BOK is understood in this case as the knowledge, skills, and attitudes necessary to enter the practice of civil engineering at the professional level. The major mission of the BOK Committee is to determine the BOK in civil engineering for the 21st Century Anderson et al. 2006, BOK 2004, 2007, Elm 1885, Hoadley 2007, Studt 2006,).

The Committee has recommended a fundamental change in the present model of a professional track leading from a university education (BS degree) through hands-on engineering experience and PE licensure exams to professional practice. It has explicitly recognized the fact that today a university education leading only to a BS degree is grossly inadequate to provide students with sufficient BOK to meet challenges of the 21st Century. Therefore, the Committee has proposed a "Tomorrow's CE Professional Track." The fundamental difference is in requiring a MS degree, or at least 20 credit hours in graduate courses, to take the PE licensure exams. This is a significant breakthrough with a potential for changing the civil engineering education and creating a spectrum of advanced courses appropriate for both regular graduate students and for practicing engineers who want to become professional engineers.

In 2004, the Committee published a book on "Civil Engineering Body of Knowledge for the 21st Century, Preparing the Civil Engineer for the Future." This book has already influenced the ongoing discussion about the future of civil engineering education. Even more importantly, the Committee has identified a list 15 outcomes of civil education and these outcomes will be gradually reflected in programs offered by the civil engineering departments in the USA. Also, the work of the Committee directly influences ABET, Inc., which is the recognized U.S. accreditor of college and university programs in applied science, computing, engineering, and technology. In this way, the changes proposed by the Committee will be gradually implemented. More extensive and far-reaching changes are coming from the BOK II Committee, operating now, which is planning to propose 26 outcomes. Unfortunately, the authors believe that the proposed improvements, although absolutely necessary and moving civil engineering in a desired direction, are still insufficient, particularly in the context of the absolutely necessary balance between art and science in civil engineering education.

5 EUROPEAN UNION INITIATIVES

In Europe not just engineering education but the university education in general seems to be in a deep (and hopefully heeling) crisis. As Hörisch writes in his book "The unloved university" (Hörisch 2006), universities tend to become knowledge factories and are badly affected by all consequences of today's laws of the open market. The pure curiosity and the joy to experiment, actually all the seven principles of Da Vinci, have vanished. Unfortunately, the Bologna process doesn't seem to bring the expected improvements. Fortunately, it has created a climate of change and does bring support for innovative approaches and projects in education.

One such project, initiated in 2001, has been focused on the joint curriculum and teaching materials development in the area of information technology in construction. It is called "ITC Euromaster" (Rebolj and Menzel 2004). The project has been funded by the European Commission in the Socrates/Erasmus framework. Nine European universities are presently active in the development and dissemination of teaching materials: (in alphabetical order): Universidade do Algarve (Portugal), Technische Universiteit Delft (Nederlands), Technische Universität Dresden (Germany), Glasgow Caledonian University (UK), Universidade nova de Lisboa (Portugal), Univerza v Ljubljani (Slovenia), Lulea University of Technology (Sweden), Univerza v Mariboru (Slovenia; coordinator of the project), and University of Salford (UK).

The main goal of the project has been to develop a curriculum on Construction IT in order to give students various possibilities to expand their understanding of research, development, and applications of computing and information science in civil and construction engineering. A result, the European Masters Curriculum in Construction IT, complements the existing portfolio of teaching programs available in the European Union. It is expected to create a new generation of computing and IT experts in civil engineering and in architecture. The need for such 21st Century professional has been recognized by various authors (e.g. Froese 2004).

The development of the content and of the teaching material for courses has been distributed among the individual partners and each is responsible for a specific course, or courses. Teaching materials have been prepared in digital form following the e-learning standards. Two universities have already accredited courses developed in the project, including the University of Maribor and the University of Ljubljana.

The only way to support collaboration of so many different universities was through the use of an effective e-learning system. According to our experience, an advanced technical infrastructure is a vital part of any such system. So far we have gathered experience regarding e-learning supported seminars (Rebolj and Menzel 2004) and in various other projects, where audio or videoconferencing (based on such tools as HorizonLive, VCON, CUSeeme, ClickToMeet) and various web-based content delivery systems have been used, including Blackboard, Fgweb, and Moodle.

The accreditation process for courses developed in several countries became a problem. There are different accreditation rules in the individual countries and at various universities. To overcome such formal obstacles and to open the ITC courses to the global community, we have decided to form an open pool of IT in Construction (ITC) related courses. The initial ITC course pool has already began accepting courses developed in the ITC Euromaster project. However, any institution with knowledge in the ITC field is welcomed to offer a course to the pool in exchange for the access to courses already in the pool. (More information is available at www.itcedu.net).

In the future, cooperation with the ASCE Global Center of Excellence in Computing is planned to share courses specifically related to computing. If successful, this cooperation may began expanded to cover all areas of civil engineering.

6 GLOBALIZATION OF EDUCATION

The proposed new civil engineering education paradigm is feasible, but its implementation is extremely difficult and expensive. It requires significant efforts to translate our present and coming challenges into the language of educational outcomes and the levels of desired competency. Next, research has to be conducted to acquire knowledge required to produce the identified outcomes. Finally, the acquired knowledge will have to be prepared for teaching purposes and most likely presented in the form of teaching modules. Considering the nature of our challenges and the difficulty and amount of studies needed to create a knowledge foundation (a body of knowledge) necessary to implement our new paradigm, it is practically impossible for a single civil engineering department to do all the required work and entirely independently to meet all challenges.

Fortunately, the globalization of civil engineering education is becoming a fact. As reported in Section 5, "European Union Initiatives," a number of international research programs focused on engineering education have already been initiated. In 2005, the American Society of Civil Engineers (ASCE) has established the ASCE Global Center of Excellence in Computing (Arciszewski et al. 2007). The Center's mission is to stimulate and organize international research projects on computing in civil engineering and to disseminate fundamental computing knowledge for worldwide use. This knowledge is presented in the form of teaching modules, which can be downloaded by potential users (academic instructors) from the Center's website (www.asceglobalcenter.org). At this time, four teaching modules are available, but during the next several weeks additional 4 modules will be added. The modules have been prepared by the computing scholars in several countries, including Switzerland, Singapore, and the USA. This is a model of global cooperation in education, which could be used if our proposed paradigm is to be implemented.

7 CONCLUSIONS

Civil Engineering education requires fundamental changes to meet the present and coming challenges. Most importantly, the issue of the today's focus on the quantitative/analytical aspects of Civil Engineering must be addressed. It is absolutely necessary if we want to meet our leadership and creativity challenges, as discuss in Section 2, "21st Century Challenges." Also, all remaining challenges require much more than only the analytical skills to deal with these challenges effectively and to produce the necessary novel solutions. For all these reasons, we postulate that a modern Renaissance educational formula is created. It should be based on a balance of art and science, or, more specifically, on a balance of teaching both qualitative and quantitative knowledge and skills with prominent focus on teaching inventive design in the context of Civil Engineering problem. That could be done through the integration of design and problem solving with a number of courses offered through the entire program.

Global challenges require global action and cooperation. Therefore, we believe that the nature and extend of our challenges simply imply global cooperation, particularly that the resources of a single country, not to mention a single university, are grossly inadequate for such an important, difficult, and huge task. How such cooperation could be organized is still an open question. However, the products most likely should be in the form of teaching modules, ultimately developed as multimedia intelligent tutoring systems.

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