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Proceedings of the International Conference on
Computing in Civil and Building Engineering
W Tizani (Editor)

Successful Education: The Key to Engineering Creativity

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Abstract

Engineering creativity can be described as all activities resulting in patentable inventions. Such activities occur mostly during the conceptual design process and usually they are not taught during traditional design courses. However, inventions are absolutely necessary to meet the challenges of our rapidly-changing world. Our ability to educate creative civil engineers is critical for the success of our profession. This paper provides an overview of a new educational paradigm, proposed by the authors, which we call "Successful Education." Successful Education is largely based on a new theory recently developed in cognitive psychology called the "Theory of Successful Intelligence." The basic assumptions of this theory are briefly discussed and the three components of Successful Intelligence are presented, including practical, analytical, and creative intelligence. The paper also discusses the use of the Medici Effect in education in order to create an appropriate environment for teaching Creative Intelligence, the key component of Successful Intelligence in engineering.

Keywords: education, successful education, successful intelligence, creative intelligence

1 Introduction

In the past, engineers were true leaders and pioneers. They created the very foundation that civilization is based upon. They were highly educated, respected and commanded high salaries. They were successful.

Engineers of the past had to be creative in order to meet the various challenges of their rapidly-expanding societies. As a result, the engineering profession attracted the best and brightest students. Today this profession is in a crisis (Arciszewski 2006; Arciszewski and Rebolj 2008). Over time, engineers have lost their ability to innovate and with it, they have lost their relevance and standing in society. These days, engineers are perceived as mere followers and technologists who focus on purely analytical matters. They have little impact on the evolution of engineering, let alone on the evolution of civilization. Engineers need to become leaders again. More importantly, they need to begin educating leaders (Akay 2003; ASCE 2008; Mohsen 2009).

Marginalization of engineers in developed countries is largely driven by globalization, the complex process of gradual cultural, social, political, and technological changes that are producing not only desired but also unpredictable and undesired results (Arciszewski 2006). For the engineering profession, globalization means the internationalization of many engineering companies, particularly in the areas of design and manufacturing. It also means the outsourcing of routine analytical engineering work. The negative impact of outsourcing can be partially offset only if new demand for engineering services is created which produces innovative solutions and products. Engineers in developed countries will have to begin utilizing state of the art knowledge and, most importantly, rely on their creativity. Innovation and creativity combined with sophisticated knowledge will be the added value that prevents non-routine work from being outsourced and for developed countries to maintain their competitive advantage in research and development.

Unfortunately, there is a problem in implementing these goals. Engineering graduates are currently not being educated, with very few exceptions, on just how to be innovators. Their education is focused mostly on routine analytical work. Thus, engineers in the West are currently at risk of losing their routine-oriented jobs to foreign competition that can easily perform these tasks at a fraction of the cost. If this scenario were to happen on a grand scale, it could lead to the decreased demand for engineers in developed countries, to the reduction of their number, and to reduced enrollment in engineering departments. Such a situation would be catastrophic at the time when there are so many present and coming challenges that may have disastrous impact on our civilization if proactive measures are not taken. Indeed, these challenges require the expansion, not the shrinking, of the profession and they cannot be met simply through the development of routine solutions representing. Engineers need qualitatively different and better solutions and inventions which address these challenges in unique and creative ways.

2 Successful Intelligence

Robert J. Sternberg, a cognitive psychologist, developed *The Theory of Successful Intelligence* (TSI) in the 1980s and 1990's (Sternberg 1996). Successful intelligence is described as the ability to achieve life success. Sternberg claims that successfully intelligent people are able to achieve their goals by leveraging their strengths, by compensating for their weaknesses, and by adapting to, shaping, and selecting environments that will facilitate their success. He also specifies that there is no absolute measure for this success. Success as defined by Sternberg is a relative concept which exists within the context of an individual's socio-cultural environment and personal desires.

TSI is based on three major assumptions:

1. Successful intelligence can be learned.
2. Successful intelligence is a combination of three abilities, which can be learned independently:
    - Analytical intelligence
    - Practical intelligence
    - Creative intelligence
3. Successful intelligence is dynamic, i.e. both the criteria of success and the approaches the individual employs (i.e. the relative mix of the three intelligences) to achieve success may change during one's lifetime.

Practical intelligence is an ability to solve simple problems occurring in everyday activities through the use of knowledge and heuristics. It may also involve adaptation to changing environments, shaping them, or selecting them. Analytical intelligence is the ability to solve routine and analytical problems, that is, problems requiring deductive skills and the use of existing knowledge (analysis of internal forces, numerical optimization, etc.). Analytical intelligence alone is what today´s traditional IQ tests measure. In addition, traditional engineering education emphasizes analytical intelligence almost entirely. Creative intelligence, on the other hand, is the ability to solve non-routine (creative) problems. This intelligence requires abductive skills and the use of existing knowledge. Solving problems using creative intelligence produces novel/unknown solutions or ideas.

Conventional theories of human intelligence describe intelligence as the ability to solve abstract problems which are entirely isolated from the real world and action. Also, it is usually assumed that human intelligence is mostly static and cannot be significantly changed through education, experience, or environment. Human intelligence, defined as such, can be tested and measured using various criteria contributing to the so-called "Intelligence Quotient," or IQ. Unfortunately, decades of intelligence research have revealed that standard measures of intelligence fail to account for the majority of variance in adult success, including professional success, where IQ accounts for only one-sixth of the differences in income (Sternberg and Williams 1997). Furthermore, IQ predicts less than 25% of variance in grades. For these reasons, conventional theories of human intelligence are simply inadequate in developing a conceptual/scientific foundation for making fundamental improvements in engineering education in order to educate more creative engineers.

The acceptance of Sternberg's *TSI* by many education theorists is important and has significant consequences for the engineering profession. Engineering educators must recognize the fact that conventional intelligence and related abilities are simply insufficient to guarantee success in engineering. Successful intelligence and its three components are needed to succeed in life as well as in engineering. Sternberg´s theory also postulates that the three intelligences can be taught and because of this, the theory provides a way forward toward modifying our educational processes in order to teach them, rather than adopting the "smart or not smart" binary model behind IQ theories. We propose that teaching all three of the intelligences set forth by the Theory of Successful Intelligence be an explicit objective of engineering education.

3 Engineering Creativity

We the authors see creativity as a necessary pragmatic skill in the context of engineering design. The objective of the design process is to find a design solution, or design solutions, usually called a "design," or "designs." In this case, a design is a description of a future civil engineering system, actual or abstract. A design can be, for example, a design of a building. We assume that a design has two major components, including a qualitative and a quantitative component. The qualitative component is called a "design concept," or simply a "concept." A concept is an abstract description of a future system usually defined in terms of symbolic attributes and their discrete values. A concept identifies, for example, a configuration of a structural system and the kind of materials used. The quantitative component of a design concept is called the "detailed design" and contains all technical details expressed in terms of numerical attributes such as dimensions, mechanical properties, and other factors.

The part of the design process producing a design concept is usually called the "conceptual design" process while the remaining phase which produce a detailed design is called the "detailed design," or "detailed designing phase." Conceptual design can be roughly divided into two categories: routine and non-routine. In the first case, the final concept, called a "routine concept," is usually selected from a class of known concepts and eventually modified. Only well-known domain knowledge is used. In this case, the process of conceptual design is simply a search of known design solution space called "exploitation." Such situations can be compared to "inside-the box" thinking.

On the other hand, a non-routine conceptual design is a process where unknown yet feasible and potentially patentable concepts are sought. Such concepts are called "non-routine concepts" or "novel concepts." They are created using the entire domain knowledge, and also knowledge from outside of the problem domain. Such a conceptual design process is like searching the entire known design solution space (called "exploitation") as well as the expanded solution space which has been created using knowledge from other domains (called "exploration"). This process can be considered as "inside-and-outside-the-box" thinking. Non-routine conceptual design cannot be conducted using traditional analytical methods and tools alone. It requires an entirely different approach, including the use of heuristic and/or sophisticated Artificial Intelligence methods and tools.

We have assumed that creativity in engineering is an activity focused on the development of unknown yet feasible and potentially patentable concepts of civil engineering systems, both actual and abstract. Obviously, this type of creativity occurs as a part of the conceptual design process. Yet engineering creativity should be clearly distinguished from engineering optimization. In optimization, deterministic algorithms and methods are used and concepts are sought in a single-domain, predetermined solution space. It is the process of exploitation of a single space and obviously it can produce results only from within this space. Optimization is ¨thinking inside a box¨ as well and requires analytical and deductive abilities alone (deduction is defined here as a form of reasoning in which existing knowledge is used to verify a hypothesis, also called a "conclusion," about it). In contrast, engineering creativity requires the use of non-deterministic, or heuristic, algorithms and methods. In this case, concepts are sought from both within the problem's domain space and outside this space using knowledge from various domains. Again, this is like thinking both inside and outside a box. Engineering creativity requires abductive abilities, sometimes called "creative abilities". Abduction is a form of logical reasoning in which existing knowledge is used to derive a new hypothesis about it, which, if verified as true by deduction or induction, can be used to expand existing knowledge.

4 The Medici Effect

Recently, Johanssen (2004) proposed a concept called the Medici Effect which describes the defining factors within a particular environment that can facilitate heightened creative and intellectual growth. The Medici family lived in Florence, Italy. In the 15^{th} Century, after accumulating much wealth through banking, the Medicis were considered one of the richest and most influential families in Europe. They became great supporters and sponsors of the arts and sciences. Many leading Italian artists and scientists of their times became members of the Medici's court. While these individuals lived on the Medici estate, they had time to focus on their work but were also forced by circumstances to constantly interact with each other. Together, they created a small community. This development was a revolutionary shift with respect to other times when artists or scientists did not interact with others from outside their own disciplines. All members of the Medici court talked and argued about their work and, in the process, they began to break down the barriers between disciplines. All kinds of ideas were generated during that time, often randomly, and these ideas were analyzed from various perspectives. Many were rejected, but those that were accepted led to new understandings of individual disciplines and to the gradual emergence of transdisciplinary knowledge. This knowledge represented a new understanding of the arts and sciences and, more importantly, a new understanding of the world. Ultimately, it became the intellectual foundation of the Renaissance.

Johansson (2004) also proposed the concept of ¨intersection.¨ This phenomenon is a result of the Medici effect and can be described as the time and place-specific integration of knowledge with components coming from various disciplines, cultures, and personalities. When a new idea is generated within a given discipline, it is usually born within the existing line of evolution and therefore can be considered ¨directional¨ (Johansson 2004). When an intersection occurs, however, the new idea represents a paradigm change, or the beginning of a new line of evolution (Zlotin and Zusman, 2006). Such an idea can be called an "intersectional idea". In this context, we can understand intersection as a phenomenon occurring when people of various backgrounds, professions, and cultures are put together and encouraged to interact. Over time, such interactions lead to dialogue, to an exchange of ideas (concepts) and ultimately to the development of new ideas reflecting integrated thinking with roots in several separate disciplines.

When intersection is considered as a knowledge-acquisition process, it can be described as a phenomenon occurring when professionals from two or more domains work together on a problem. In the process they discover that the same concepts often have entirely different meanings to different disciplines and they learn the ¨situated¨ nature of these concepts (Gero 2007), i.e. how the concepts change depending on the domain-related context. Within this context, there are at least three intersection drivers. These include globalization, the evolution of science in the direction of transdisciplinary knowledge, and the Information Technology Revolution (Johansson 2004).

The Medici Effect can be potentially used in engineering education to create an educational environment not only supporting but also stimulating teaching and learning of all three components of successful intelligence, including creative intelligence. With this stimulation, we can be able to at reconstruct an environment instrumental to to educate today´s successful engineers.

5 Successful Education

The concept of Successful Education has been recently proposed in the book, "Successful Education. How to Educate Creative Engineers" (Arciszewski 2009). In it, Arciszewski presents both the historical and social perspectives of creative engineering education. In a journal article (Arciszewski and Harrison, 2010) this concept was presented in the specific context of civil engineering education. In this article, we provide a more general overview. Much more details can be found in the mentioned publications.

We have proposed Successful Education as a new education phenomenon intended to educate successful engineers who integrate both creativity and leadership. Within this process, students learn the body of knowledge necessary to enter engineering practice but in addition to that they also learn how to become successful engineers, i.e. they acquire successful intelligence. Students learn in an active way and acquire transdisciplinary knowledge (Sage 2000) through knowledge convergence driven by knowledge synthesis and integration.

Successful Education can be best described in terms of its goals and basic assumptions. We have identified two political goals. The first one is that engineers become successful leaders in society, i.e. they initiate both political and technical changes to infrastructure systems (built and natural) in terms of new policies, projects, and activities, they develop strategies to implement proposed changes, and they are in charge of the implementation of these strategies. The second political goal is that engineers are perceived again by society as leaders and heroes of our civilization, i.e. engineering is again perceived as a prestigious profession with a high social status and salaries reflecting this status and engineering education and practice are perceived as exciting and can compete with fine arts in attracting the brightest and most creative students looking for careers as leaders and inventors.

We have identified six technical goals as well. The first one is that engineers are successful in their professional careers, i.e. they are able to achieve their professional goals, to balance in their practice the use of practical, analytical, and creative intelligence, to identify their strengths and to maximize them to compensate for their weaknesses, and are able to adapt to, shape, and/or select their professional environments. The next goal is that engineers have successful intelligence, including practical, analytical, and creative intelligence. This is followed by the goals that learning successful intelligence theory is a part of civil engineering education and that engineers graduate with a sufficient BOK to begin their practice. Finally, there are two goals related to the evolution of Successful Education in general, including the goals that Successful Engineering Education is gradually modified and expanded as needed and that this flexible knowledge system contains both technical and methodological components. There are two methodological goals, including the goal that engineers graduate with methodological knowledge of how to continue learning and how to strengthen all three types of successful intelligence and that engineers are capable of conducting practical, analytical, and creative work.

The Successful Education is based upon several educational and technical assumptions. The educational assumptions are that *TSI* is a conceptual/scientific foundation for engineering education and that the effectiveness of civil engineering education is measured by the professional success of engineers. Also, we have assumed that the existence of thinking styles is recognized and that the various styles can be and are taught in engineering classrooms. Finally, we have assumed that the learning process is a combination of traditional lectures and active and experiential learning. Our main technical assumption is that the 21^{st} century body of knowledge will represent an expansion of the present teaching paradigm through the addition of Creative Intelligence.

6 Conclusions

We need a new generation of engineers educated not only to do routine analytical work but also well prepared to become inventors. It is an ambitious goal requiring significant changes in education on the paradigmatic level. Unfortunately, incremental improvements are simply not an option. We need to make significant qualitative changes to reverse the present trend toward purely analytical education in order for engineers to become successful again.

Today, we have much more intellectual resources than those that were available at the beginning of the Renaissance. Technology and research has produced advances in cognitive psychology and progress in computing and simulation of complex systems. There is also a growing understanding that purely technical engineering education alone is not sufficient in order to be successful in the 21^{st}. Century. Therefore, we must initiate another period of qualitative changes resulting in a new wave of inventions much more powerful than those created in the Renaissance. This is the challenge that must be met with consideration to our responsibility to society and the engineering profession.

The proposed emergent educational phenomenon is obviously difficult to create. On the other hand, the pay-offs will be extremely high in the form of technology breakthroughs, inventions, patents, and building a strong competitive advantage. We have to take the risks and pursue the search for successful education in engineering reflecting our needs and progress in computing, which could help us to develop a new generation of engineering creativity teaching tools.

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