

Creativity and Engineering Education

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Abstract

The paper reviews the experiences in implementation of methods for enhancing creativity in engineering education. At the beginning it discusses the public perception of engineering work and recapitulates the general views on creativity. Next it reminds on the common aspects of creativity and innovativeness in engineering. Then it summarizes the basics of creative processes and some of the often mentioned methods for provoking and stimulating creativity such as brain storming, brain writing 6-3-5 methods, lateral thinking, TRIZ, methods like the Walt Disney creativity strategy, design for six sigma, synectics and ideation in general. The paper in the continuation compiles some reported experiences in teaching creatively and learning creativity in engineering education such as active learning and problem based learning. At the end it presents some examples of student involvements in creative problem solving projects at the Department of Naval Architecture and Ocean Engineering in Zagreb.

Key words: engineering education, creativity, learning methods, TRIZ, Brainstorming, Lateral thinking, Creative Thinking Skills, Active Learning AL, Problem-Based Learning PBL, Problem Solving, sinectics, six sigma

Introduction

Scientific discovery and innovative engineering design are complex cognitive, social, and sociological acts and have been studied at many different levels. Engineers are not commonly perceived as creative professionals (Stouffer, Russel, Oliva 2004). A Harris Poll sponsored by the American Association of Engineering Societies and IEEE-USA found that “only 2 percent of the public associate the word ‘invents’ with engineering; [and] only 3 percent associate the word ‘creative’ with engineering” (Bellinger 1998; Wulf 1998). This observation deserves reaction of engineering community and reaffirmation of the engineering creative work which is of tremendous impact on overall wellbeing. Most engineering projects demand creative or innovative approaches in the design of equipment, systems, and facilities. With the complexity surrounding every engineering project mounting as natural resources dwindle, the world population increases, and the global infrastructure and economy grow ever more intertwined, the creativity and innovation necessary to address the big issues facing civilization— maintaining the infrastructure; providing food, water, shelter, and power to the population; and growing sustainably and safely—will only increase in importance (Stouffer, Russel&Oliva 2004).

Creativity and innovation are increasingly important categories in national and global industry and play strategic role in numerous aspects of practicing engineering as well as in engineering education. The high need for a deeper and careful understanding of creativity and innovation in all fields inspired a great deal of studies into the nature creativity.

Traditionally, engineering education emphasizes problem solving ability through professional knowledge. There is a strong connection and the distance at the same time between professional knowledge and creativity. The lack of expertise can hardly produce creative ideas or enable engineer to recognize a creative solution among all alternatives. On the other hand, too-extensive expertise resulting in tendency to jump to first found solution that can solve the imposed problem in a conventional manner, doesn't promise any inventive ideas in tackling new problems.

In common parlance, a problem is an unwonted situation, complicatedness or a question for an investigation, consideration or solution. Therefore, a problem is any situation which offers an opportunity to make a difference, to improve things in their present appearance. Problem solving as an activity is converting an actual current situation (the NOW-state) into a desired future situation (the GOAL-state). The increase of the quality of life (or avoidance of a decrease in quality) imposes active involvement in improvement of problem solving particularly in creative approach to problem solving. Creative or innovative thinking in broader sense is the kind of thinking that leads to new insights, novel approaches, new ways of understanding and conceiving of things as well as of problem solving. There are also some not so obvious examples as well, such as ways of putting a question that expand the horizons of possible solutions, or ways of conceiving of relationships that challenge presuppositions and lead one to see the world in imaginative and different ways.

Creativity and inventiveness

Creativity is frequently associated with notions such as talent, spontaneity and coincidence, i.e. factors that cannot be influenced or determined but ultimately are left to chance. However, the modern literature on creativity reveals that, although factors such as luck or chance certainly play a role, creativity in higher education may be enhanced (or hindered) by specific institutional and environmental situations as well as cultural factors. Favourable conditions include team work, cross cultural exchange grounded in socio-cultural diversity, trans- and interdisciplinarity, time and resources and a risktaking culture that tolerates and even encourages failure (e.g. Landry 2000, Tepper 2005). This has led to the hypothesis that higher education institutions and their external stakeholders may influence their level of creativity by enhancing these conditions through specific processes and structures at different levels and in different spheres.

Torrance, the “Father of Creativity”, defined creativity as “the process of sensing problems or gaps in information, forming ideas of hypotheses, testing, and modifying these hypotheses, and communicating the results. This process may lead to any one of many kinds of products—verbal and nonverbal, concrete and abstract” (Torrance 1963). Groundbreaking research in educational psychology (Torrance 1977) led to a benchmark method for quantifying creativity. “Torrance Tests of Creative Thinking” effectively demystified the common assumption that IQ alone determined creativity. It also led to the now accepted belief that creative levels can be increased through practice (Childs 2003).

Several other educators have offered definitions for creativity as it applies to engineering. It has been described as “the awareness, observation, imagination, conceptualization, and rearrangement of existing elements to generate new ideas” (Farid et al. 1993).

Goldsmith described creativity as “The production and disclosure of a new fact, law, relationship, device or product, process, or system based generally on available knowledge but not following directly, easily, simply, or even by usual logical processes from the guiding information at hand” (Santamarina and Akhoundi 1991). Pereira (1999) defined creativity as “the capacity to perform mental work that leads to an outcome both novel and applicable.”

The creative thought, then, is something that leads to the creative act or the creation of something new—an idea, theory, or physical product. When approaching technical matters, the term “innovation” is often used instead of creativity to describe the process that leads to insight or progress in a field, with a technique, or with a physical product. While innovation connotes a sense of inventing a thing as opposed to an idea or a theory, it is essentially a synonym for the creative process. Perhaps technical people prefer to be “innovative” rather than “creative” (Stouffer, Russel&Oliva 2004).

The Creative Process

Creativity techniques serve to encourage and provoke thoughts, different thinking or new ideas in a creativity process. Some techniques require groups of two or more people while other techniques can be accomplished alone. Most creativity techniques use associations between the goal (or the problem), the current state (which may be an imperfect solution to the problem), and some stimulus (possibly by improvisation or random selection).

The notions of an instantaneous inspiration or of a lone genius thinking up something brilliant and changing the world is a myth that has been debunked (Bogen 1991; Richards 1998; Weisberg 1986). Most people who study creativity now accept the notion that creativity is not something that happens in a vacuum. The definitions presented above articulate the notion that creativity is a process rooted in the real world.

The creative process must go through a series of four stages, beginning with 1) a notion or need (sensing, problem definition, and orientation); 2) an investigation of that notion or need (testing, preparation, incubation, analysis, and ideation); 3) an articulation of a new idea or solution (modifying, illumination, and synthesis); and 4) a validation process of that idea or solution resulting in an idea, theory, process, or physical product (communicating, verification, and evaluation) (Stouffer, Russel&Oliva 2004).

These four stages should be familiar to engineers, as they more or less mirror the design process itself, which never forget is (or should be) a creative endeavor (Santamarina 2002).

The creative side of design, especially regarding shipbuilding is commonly thought to lie with shipbuilding routine in shipyards and more artistic discipline—naval architecture. Many groundbreaking design concepts stem from simple, often sublime reformulations of current thinking and practice, and that these creative breakthroughs are often fed by study and observation outside of engineering paradigms (Peters 1998).

What engineers do is inherently creative, as comparisons between the creative process and the design process demonstrate. Yet while “creativity is an essential component in engineering design,” focused interviews with leading creative engineers has found that “engineering schools do not adequately prepare students for creative endeavors or for the realities of modern industry” (Richards 1998). This observation needs further investigation and some of the commonly known views on methods for enhancing creative processes and ways of their implementation in engineering education are resumed in the sequel.

Brainstorming method

Brainstorming is a group creativity technique designed to generate a large number of ideas for the solution of a problem (Osborn 1953). Brainstorming with a group of students is a technique provided for problem-solving, team-building and creative process. The impact of brainstorming on the productivity in generating ideas is not fully certified. However, there are some heuristic benefits when the brainstorming creates a large number of ideas quickly and motivates participants. Brainstorming in a group situation should be used for determining possible causes/solutions to problems and planning out the methods and steps of a problem solving. There are four basic rules in brainstorming:

- Focus on quantity of ideas
- Withhold criticism

- Welcome unusual ideas.
- Combine and improve ideas.
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Most brainstorming sessions follow this procedure:

1. Introduce a question, problem, or topic both orally and in writing on chart paper;
2. Invite participants to respond with as many ideas or suggestions as possible, ideally in single words or short phrases. Encourage everyone to participate but do not proceed in any set order;
3. Explain that until the brainstorm is complete, no one may repeat or comment on any response;
4. Record every response on chart paper. Often, the most creative or outrageous suggestions are the most useful and interesting;
5. Afterward, prioritize, analyze, or use the list to generate discussion or problem solving.

There are a number of variations on the conventional face-to-face meetings used in brainstorming. Electronic brainstorming uses email instead of face-to-face meetings. A facilitator sends participants the subject question and they respond directly back to the facilitator. The facilitator then compiles the ideas and resends to the group for more feedback. Aside from the obvious convenience factor, this technique overcomes the "production blocking" problem where one or two team members dominate a session and it frees participants from the social shyness factor of expressing themselves in a group setting.

Brain writing 6-3-5 method

Method 635 also known as the 6-3-5 Method is a group creativity technique used in marketing, advertising, design, writing and product development (Rohrbach 1968). Based on the concept of Brainstorming, the aim of 6-3-5 Brain writing is to generate 108 new ideas in half an hour. In a similar way to brainstorming, it is not the quality of ideas that matters but the quantity. The technique involves 6 participants who sit in a group and are supervised by a moderator. Each participant thinks up 3 ideas every 5 minutes. Participants are encouraged to draw on others' ideas for inspiration, thus stimulating the creative process. After 6 rounds in 30 minutes the group has thought up a total of 108 ideas.

Lateral thinking

Lateral thinking is a term coined by Edward de Bono, for the solution of problems through an indirect and creative approach (de Bono 1970). Lateral thinking is about reasoning that is not immediately obvious and about ideas that may not be obtainable by using only traditional step-by-step logic. Edward de Bono has written extensively about the process of lateral thinking - the generation of novel solutions to problems. The point of lateral thinking is that many problems require a different perspective to solve successfully.

De Bono identifies four critical factors associated with lateral thinking: (1) recognize dominant ideas that polarize perception of a problem, (2) searching for different ways of looking at things, (3) relaxation of rigid control of thinking, and (4) use of chance to encourage other ideas. This last factor has to do with the fact that lateral thinking involves low-probability ideas which are unlikely to occur in the normal course of events.

The TRIZ methodology

TRIZ is a Russian acronym for ‘The Theory of Inventive Problem Solving’, which was originally developed by Genrich Altshuller, (Altshuller, 1956, 1979). The research continued, eventually resulting in the screening of more than 2 million patents and from which numerous analytical and knowledge based tools for solving inventive problems were developed. Screening of more than 2 million patents resulted in classifying inventive solutions into five levels:

Levels of Solution (Altshuller, 1979)

- Level 1: Standardization: 32%
 - Solutions by methods well known within specialty
- Level 2: Improvement: 45%
 - Improvement of an existing system, in same field.
- Level 3: Invention inside technology: 18%
 - Improvement in existing system, usually from other fields
- Level 4: Invention outside Technology: 4%
 - New generation of a system, using science not technology.
- Level 5: Discovery: 1%
 - New system usually based on major discovery.

Through this work is discovered that inventive solutions centered on eliminating contradictions, where contradictions are performance trade-offs. Examples of which could be strength vs. weight, speed vs. efficiency, etc. are called technical contradictions. It was identified that level 2 solutions partially eliminated the contradiction and levels 3 and 4 would completely eliminate the contradiction using existing technology. It is believed that TRIZ approach could help anyone develop their capability to innovate at levels 2, 3 & 4.

The most effective solutions are denoted - the breakthroughs. A problem requires creativity when attempts to improve some system attributes lead to deterioration of other system attributes. Collisions, such as weight versus strength or power versus fuel consumption, lead to first axiom of System Conflict. Creatively solving such a problem requires overcoming the conflict by satisfying all colliding requirements. A second fundamental axiom of TRIZ is the Ideality Principle, which is that technological systems evolve toward increasing ideality. No system is a goal in itself, but only a "fee" for realizing the function desired of the system. The lower is the fee the more ideal the system. At the ultimate, an Ideal System needs no energy to operate, costs nothing to produce, occupies no space, has no failure modes, etc. The Ideal System is no longer a physical entity, but the required functions are performed. In real systems, the "degree of ideality" can be characterized by costs compared with the aggregate of the useful functions performed by the system. And finally, the conclusion of all the examination was the third axiom that the inventive process can be codified, structured and solved methodically. Contemporary TRIZ is both a theory of technology evolution and a methodology for the effective development of new technological systems. It has two major subsystems based on the laws (prevailing trends) of technological system evolution: a set of methods for developing conceptual system designs and a set of tools for the identification and development of next-generation technologies and products.

Walt Disney strategy

The Disney Creative Strategy was observed, modeled and developed by Robert Dilts based on his observations of the process Walt Disney used while creating (Dilts 1991, 1994). Creativity as a total process involves the movement between small and large bits of information, conscious and unconscious process and varied representational systems. The Disney creativity process involves the distinction and coordination of three stages or sub-processes:

- Dreamer - the person for whom all things are possible
- Realist - the person who sorts things out
- Critic - the person who picks up on the bits that don't fit

The participant activates all three roles, in the indicated sequence.

The three stages require distinct approaches:

Dreamer “*Want to*”

- Why are you doing this?
- What is the purpose?
- What are the payoffs?
- How will you know you have them?
- Where do you want to be in the future?
- Who do you want to be or be like?
- What range of topics do you want to consider?
- What elements of those topics do you want to explore?

Realist “*How to*”

- Establish time frames and milestones for progress with evidence and test procedures
- What will I be doing?
- How specifically will the idea be implemented?
- How will I know if the goal has been achieved?
- Who besides me is involved (time constraints)?
- When will each phase be implemented?
- When will the overall goal be completed?
- Where will each phase be carried out?

Critic “*Chance to*”

- How do all the elements fit together?
- What elements appear unbalanced?
- What parts do not fit with the overall objective of the project?
- What parts of the project are underdeveloped?
- How possible is this within the time frame?
- Why is each step necessary?

Design for Six Sigma

Design for Six Sigma (DFSS) also known as DMADV—(Define, Measure, Analyze and Verify) is a systematic approach for manufacturing companies to address product and process issues at the early development stage (Yang&Basem 2003). Through inventive thought processes, early error elimination, and robust design, DFSS has impacted product quality and performance and increased profit. The DFSS methodology embraces four-phase IDOV — Identify-Design-Optimize-Verify. The various practices from inventive design methodologies, deterministic and stochastic numerical methods, and the use of CAE simulation techniques, are often mapped to the DFSS procedure. DFSS is relevant to the complex system/product synthesis phase, especially in the context of unprecedented system development. It is process *generation* in contrast with process *improvement*.

Six Sigma finds its roots in the fact that all product development processes are inherently unpredictable (Cooper, 1994). The outcome of any product development process produces products that fall within a band, or range, of performance. Six Sigma provides a way to measure this variability. The methodology known as DMAIC (Define, Measure, Analyze, Improve, Control) closely describes the Six Sigma approach. The DMAIC methodology, instead of the DMADV methodology, should be used when existing product or process is not meeting customer specification or is not performing adequately. DFSS is more of an approach than a defined methodology. However the common theme is that DFSS is used to design or re-design a product or service from the ground up in an effort to more predictably manage product development and manufacturing variability.

Synectics

Synectics is a creative problem solving method that stimulates thought processes of which the subject may be unaware (Gordon 1961, Prince 1970) that is closely related to brainstorming (Osborne, 1953). The main difference is that Synectics is more formalized and more rigorous than brainstorming. It might seem strange to formalize a creative process, however many people feel the open-ended nature of free-form brainstorming overwhelming. Synectics helps by giving a guide for generating new ideas. It is often summarized as "making the strange familiar and making the familiar strange". Although normally considered as a creativity technique or process, synectics can also be considered a state of mind or even a philosophy.

Synectics applies the principles: looking at familiar things in unfamiliar ways and combining the previously discrete. One distinguishing factor of synectics is its emphasis on metaphor and fantasy. Perhaps the best known synectic technique is the use of *trigger questions* based on physical aspects, processes, emotional connotations, anything. Creative output increases when people become aware of the psychological processes that control their behaviour and has three fundamental precepts of synectic theory:

- The emotional component of creative behaviour is more important than the intellectual component
- The irrational is more important than the intellectual component
- The emotional and irrational components must be understood and used as "precision" tools in order to increase creative output

Synectics believes that success in problem solving is improved by using non-rational thought to lead to rational solutions. The process involves making the strange familiar and the familiar strange and uses analogical and metaphorical thinking.

Ideation (idea generation)

Ideation is an emerging buzzword (c. 2007) representing the creative process of generating, developing, and communicating new ideas, where an idea is understood as a basic element of thought that can be either visual, concrete, or abstract. As such, it is an essential part of the design process, both in education and practice (From Wikipedia, the free encyclopaedia).

Teaching creatively and learning creativity

Engineering students must learn to approach problems with an open mind, unconstrained—though certainly influenced—by textbook solutions. They must learn to see the familiar as strange, and the strange as familiar on a regular basis, and not rush to spit back a single “correct” solution. Torrance encourages instructors to develop constructive—as opposed to critical—attitudes in themselves and in their classrooms. In a series of experiments “students who assumed a constructive rather than a critical attitude toward available information were able to produce a larger number of creative solutions as well as more original ones” (Torrance 1977).

Creative teaching may be defined in two ways: firstly, teaching creatively and secondly, teaching for creativity. Teaching creatively might be described as teachers using imaginative approaches to make learning more interesting, engaging, exciting and effective. Teaching for creativity might best be described as using forms of teaching that are intended to develop students own creative thinking and behaviour. However it would be fair to say that teaching for creativity must involve creative teaching. Most any process can be improved, and since creativity is essentially a process, it too can be studied, tracked, and improved. There are tests and metrics that can help measure and gauge creativity, but the experts agree that to develop creativity you must learn to flex and reflex your creativity power (Klein and Shragai 2001; Plucker and Runco 1998; Torrance 1977). This process is often enhanced through the use of creativity tools such as brainstorming and idea notebooks (Feldhusen and Treffinger 1986; Navin 1993).

Brainstorm training

Brainstorming is a two-step process where ideas are first generated without constraint, and then critiqued using criteria such as practicality or applicability to the problem domain. Brainstorming is an excellent teaching strategy to generate ideas on a given topic. Brainstorming helps promote thinking skills. When students are asked to think of all things related to a concept, they are really being asked to stretch their thinking skills. Brainstorming taps into prior knowledge, offers all students a chance to express their ideas, eliminate fear of failures, show respect for each other, try something without fear, tap into individuality and creativity and eliminate the fear of risk taking.

Richards (1998) recommends a series of activities to incite creativity when faced with an engineering problem:

- Immerse yourself in a domain or problem;
- Be prolific—generate lots of ideas;
- Use tools for representations and thoughts (e.g., brainstorming, notebooks, and sketches);
- Play with ideas;
- Avoid premature closure;
- Don't be afraid to be different;
- Be open and receptive to new ideas;
- Do it—practice your craft;
- Maintain a product orientation;
- Relax—indulge your diversions;
- Reflect—review what you have done;
- Have fun!

This list can be viewed as steps in an on-going process, as individual milestones in creative development or as inspiration for a professor or team leader. Many variations of brainstorming

techniques exist, including using computer programs such as Ideafisher (Santamarina and Akhoundi 1991; www.ideafisher.com).

There are many ways to design classroom assignments or teamwork activities to develop creativity. Torrance (1977) recommends several guidelines to promote creativity:

Before a Lesson

1. Confrontation with ambiguities and uncertainties
2. Heightened anticipation and expectation
3. Familiar made strange and strange made familiar
4. Looking at something from several different psychological, sociological, physical, or emotional points of view
5. Provocative questions to establish set for examining information in new ways
6. Predictions from limited information required
7. Tasks structured only enough to give clues and direction
8. Encouragement to take next step beyond what is known.

After a Lesson

1. Ambiguities and uncertainties played with
2. Constructive responses encouraged
3. Going beyond the obvious encouraged
4. Elaborating some element through drawings, dramatics, imaginative stories, etc.
5. Search for elegant (better) solutions
6. Experimentation and testing of ideas encouraged
7. Future projection encouraged
8. Improbabilities encouraged
9. Multiple hypotheses encouraged
10. Reorganization or reconceptualization of the information that is required.

Problem-Based Learning

Problem-based learning (PBL) is one of the student centered approaches and has been considered by a number of higher educational institutions in many parts of the world as a method of delivery (Awang&Ramly 2008). PBL is a total pedagogical approach to education that focuses on helping students develop selfdirected learning skills. It derives from the theory that learning is a process in which the learner actively constructs new knowledge on the basis of current knowledge. PBL provides students with the opportunity to gain theory and content knowledge and comprehension. PBL helps students develop advanced cognitive abilities such as creative thinking, problem solving and communication skills (Major 2001).

Santamarina (2002) warns that “teaching creativity has limited impact if it is not immersed in problem solving exercises.” He recommends assigning daily time in the classroom for creative thinking and the “simple, yet far reaching modification” of incorporating additional, open-ended questions to every assignment. These questions should challenge students to make connections and move beyond the technical aspects of a given problem. Examples could include defining alternative solutions, critiquing other students’ solutions, or changing the project parameters for a third-world nation.

Project-based learning (PBL) forces students to creatively grapple with real-world-style projects. PBL can force engineering students to make connections between courses and also “to seek out and solve problems at the boundaries of the engineering disciplines” (Ghosh 1993). Used regularly, PBL can also result in:

- Increased critical thinking
- Increased self direction
- Higher comprehension and better skill development
- Self-motivated attitudes
- Enhanced awareness of the benefits of teamwork
- A more active and enjoyable learning process (Johnson 1999).

Evaluations of courses designed around PBL indicate that “students are very positively motivated by projects which put what they have learned in a course into as real a perspective as possible.” In addition, many faculty members will be pleased to learn that “students spend more time on these projects than they do for exams and other work but do not complain” (Sener 1998).

Case studies in engineering education

Case studies are a particular form of PBL, and modelling classroom lessons and assignments around actual, real-world projects can be an effective bridge to industry. Case study problems are the perfect vehicles to invite project participants into the classroom to engage students, as well as to address current or even cutting-edge practice and techniques. Case studies can also be a venue to encourage creativity. Through case study assignments students can begin to see that there can be multiple solutions to a problem—even one that was completed in the real world. Case-study-based learning has been shown to encourage:

- Creativity
- Interaction among students
- Feedback from students to instructor
- Instructor’s learning opportunity from students
- Connection of education to “real-life” problems
- Student’s understanding and retention of knowledge (Angelides et al. 2000).

Teaching lateral thinking through case studies proved to be fruitful and insightful. Engineering students became more exposed to real-world and unstructured problems. They were able to provide solutions that are sound and feasible economically, socially and politically. Combination of both ‘vertical’ and ‘lateral’ modes of thinking is likely to offer new solutions to engineering problems (Al-Jayyousi 1999).

TRIZ implementaton in engineering education

TRIZ has stood the test of time in Russia and is rapidly being acknowledged as an contributor to the development of innovation skills within industry and academia. Fully understanding synergistic potential of this approach is in its early stages, but is showing significant potential. The need to develop innovative thinking skills in both business and engineering is a stimulus to exploring TRIZ, but also investigating the underlying principles. The teaching of TRIZ on engineering curricula is expanding rapidly, and the educational results of its introduction on undergraduate programmes appear very promising.

TRIZ helps in some significant ways. It details how to define a problem and how to generate ideas. It solves technical conflicts (contradictions) by applying inventive principles. Once the class of conflict is identified, TRIZ directs the problem solver to the class of principles leading to solutions while avoiding compromises. It leads to scientific effects that can be used to conceive solutions, inventions and next-generation designs.

Active Learning

Active learning is anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes (Felder&Brent 2003). *Student-centered teaching methods* shift the focus of activity from the teacher to the learners. These methods include **active learning**, in which students solve problems, answer questions, formulate questions of their own, discuss, explain, debate, or brainstorm during class; **cooperative learning**, in which students work in teams on problems and projects under conditions that assure both positive interdependence and individual accountability; and **inductive teaching and learning**, in which students are first presented with challenges (questions or problems) and learn the course material in the context of addressing the challenges. Inductive methods include *inquiry-based learning, case-based instruction, problem-based learning, project-based learning, discovery learning, and just-in-time teaching*. Essentially Active Learning refers to our belief that an engineer often learns best by taking part in an activity- working in a team, building products, and finding out how his or her ideas and designs work. Student-centered methods have repeatedly been shown to be superior to the traditional teacher-centered approach to instruction, a conclusion that applies whether the assessed outcome is short-term mastery, long-term retention, or depth of understanding of course material, acquisition of critical thinking or creative problem-solving skills, formation of positive attitudes toward the subject being taught, or level of confidence in knowledge or skills.

Examples of stimulating student creativity

This section presents some of the student activities on the Department of Naval Architecture that stimulated creativity and inventions out of the regular student's involvement in educational process. Of particular interests were the projects that the students through the Croatian Association of Students of Naval Architecture have selected and executed as their own initiatives.

The International Waterbike Regatta IWR

Since IWR activities appear in our academic life, about 15 years ago, they have substantially changed the atmosphere in study of naval architecture on the Faculty for mechanical Engineering and Naval Architecture in Zagreb. The education in shipbuilding becomes an exciting study in broader sense. And it is not only education, the study is now, thanks to waterbiking, also an efficient and entertaining way for interchange of versatile experiences in communication among colleagues from many universities. The design and construction of vessels is an outstanding method to check student's creativity, engineering and managing capabilities. There is no better way for application of the theoretical background on practical problems. The practice of organising IWR on different places offers opportunities to acquaint new people and new countries. Moreover, by preparation for IWR, precious skills and useful practice have been gained by looking for sponsors, searching for support and solving organisational problems. IWR activities promote engineering studies and attract young people to join technical schools and faculties. The contacts among the teachers and students contribute to better co-operation among universities. There are so many benefits of waterbiking and not any disadvantage that IWR make all the enthusiasts very happy. The University of Zagreb, The Faculty for Mechanical Engineering and Naval Architecture and the Department for Naval Architecture and Ocean Engineering accompanied by the Croatian Association of Students of Naval Architecture strongly supports the waterbike activities. Students have been awarded since now for two innovations. The first was the buoyant rotating stabilizers on power wheels by the International Jury of the Professors involved in IWR organization. The second was the hydraulically powered water bike awarded by the German Engineering Association, Fig. 1.

The Visions project

VISIONS-OLYMPICS action aims to increase the European competitive advantage by tapping into the unspoiled/unbiased creative minds of the young generation. It will:

- Offer out of the box concepts and ideas for the future of European maritime transport,
- Develop these ideas within an environment where purpose driven innovation is cultivated and performed in a risk free environment,
- Build bridges between universities and industry,
- Enhance the skills of future employees in a highly competitive environment,
- Offer targeted dissemination to industry.

Students participated in the Visions Competition with three projects:

- Device for handling bunches of containers for faster loading/unloading operations,
- Hybrid vessel for shallow waters for urban traffic on small rivers,
- Floating Olympic Stadium, Fig. 2.



Figure 1. Hydraulically propelled waterbike

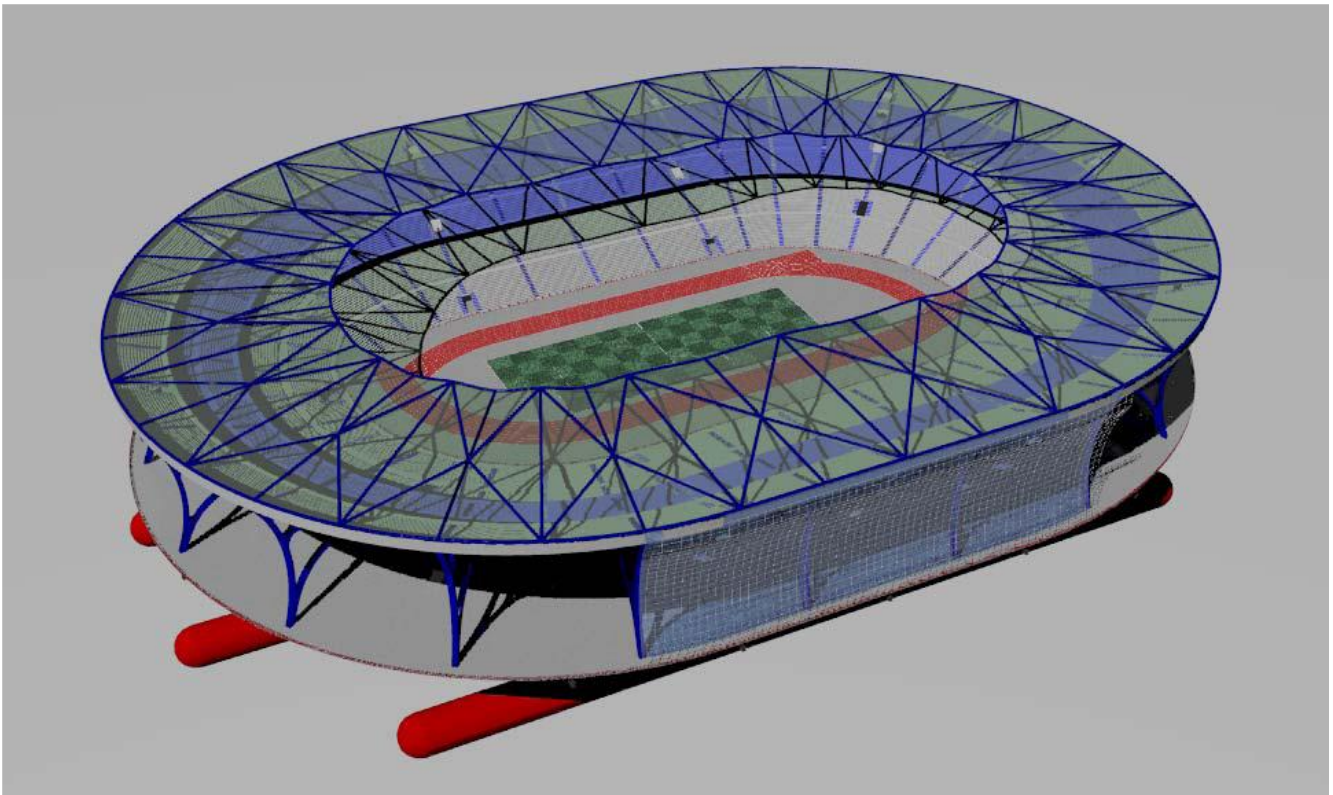


Figure 2. Floating Olympic Stadium

Conclusion

Creativity helps to see the world in a new way. Creativity also helps to consider multiple angles instead of just one, and it helps create bridges between different fields of knowledge and between innovation and the tried-and-true. There is no right way to approach creativity, but an atmosphere encouraging divergent thinking (what people in creativity studies call innovative thinking) and uncensored thought generation is conducive to deriving novel solutions. This period of free play, no matter how long or short, must eventually be constrained in order to derive tangible, practical solutions (Pereira 1999).

However, if one concentrates on practicality at the outset, it is likely that ordinary, tried-and-true solutions will result. And in the world confronting the profession, the same-old will make engineers has-beens. For productive PROBLEM SOLVING is important both creatively GENERATE ideas and critically EVALUATE ideas. Usually, innovative and creative ideation is the most exciting and appreciated part of the problem solving process. However, critical evaluation is a necessity, because if ideas are immediately and without hesitation converted into action (without being wisely evaluated) that can lead to unsatisfactory results. Asking the right questions are also an important part of a creative solution emergence, therefore by itself, the unsupervised solution generation is not sufficient.

Creativity can be a powerful tool to enhance technical efforts to solve engineering problems of all kinds. Educators are responsible for stimulating creative thinking among students. Taking a creative look at engineering education does not mean ignoring or choosing to disregard the normal project parameters or technical constraints that must be imparted to the next generation of professionals. Instead, using creativity can mean generating excitement in students as they approach engineering problems in original ways (Raskin 2003).

An important goal of education is helping students to learn how to think more productively by combining creative thinking (to generate ideas) and critical thinking (to evaluate ideas). Both modes of thinking and knowledge of methodologies for creative and inventive problem solving are essential for a well-rounded productive engineer.

The Report "Creativity in Higher Education" of the European University Association (EUA) -creativity projects 2006-2007 (Socrates, Education and Culture) provided ten key recommendations and invited its partners in higher education, government and society to join in a dialogue on how to foster creativity in European higher education. The complex questions of the future will not be solved "by the book", but by creative, forwardlooking individuals and groups who are not afraid to question established ideas and are able to cope with the insecurity and uncertainty this entails. If Europe should not succeed in strengthening creativity in higher education, the very goal of a European knowledge society would be at stake.

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