Summary

To be able to tackle real life problems students need more than basic education. Problems that are under defined and have more than one solution require engineers that are skilled in creative problem solving. Basic education normally doesn’t cover exercises used to encourage creativity in students so in this essay definition of creativity and phases of creative process for problem solving are presented together with examples and possibilities for incorporating creative problem solving in regular curriculum. Also, importance of teacher, course preparation and atmosphere that supports creative process are stressed out.

Key words: creativity; problem solving; education; creative process

1. Introduction

As an engineering student, in future one must be ready to face challenges of engineering practice that are waiting to be solved. Through academic education student gets familiar with different tools and problems that are specific for area of study. Tools include mathematical expressions, algorithms, technical codes and all kind of software packages together with measuring and acquisition equipment. Those tools and acquired knowledge are mainly used to solve problems with single correct answer, therefore making academic excellence synonymous with convergent thinking skills. With real life problems, multiple solutions are possible, as multiple ways of finding them also, in addition problems can be over defined or more commonly under defined. Biggest problems of our society are not going to be solved by using known tools in common way, that way they would have been solved already. Situations like this, which are to some extent technological, cannot put to use adopted and learned algorithms but require creative engineers. In order to have one, engineering schools must not rely only on lecture-homework-exam format with single solution problems. Incorporating methods and courses for improving problem solving in regular curriculum can encourage creativity in engineering students and give them skills to tackle wide range of problems in their engineering area.

2. Creativity

In past creativity has been thoroughly studied but unanimous definition doesn’t exist. Many would agree that creativity involves ability to put things together in a new way. When concerned with problem solving definition goes as ability to challenge assumptions, break boundaries, recognise patterns, see in new ways, make new connections, take risks and seize upon chance when dealing with a problem [1]. This definition, as many similar found in dictionaries, stresses that creation of something new, different and helpful, with or without
previous knowledge, is regarded as creative. It is important to note that creativity is more heuristic than algorithmic process that is completely rational and has mechanical rule to solve problem. Creativity is skill incorporated to some extent in all individuals and includes three components: expertise (knowledge in many forms, for example technical), creative thinking skills (how flexible and imaginative is approach to problem) and motivation (inner passion to solve problem) [1]. Also, creativity of an individual can be driven further by supporting environment and working group. Therefore, creative engineer is one that is motivated and able to use existing data and knowledge to explore and create novel solution to specific engineering problem. Solution of a problem in the end is result of convergent process, but to be creative engineer must in different stages of problem solving process incorporate skills of divergent thinking also.

3. Divergent vs. convergent thinking

Difference between convergent and divergent thinking can be seen in ending result. When converging, solution and ideas tend to move towards single and only possible solution, which is common with well defined problems in traditional way of education. This format is most efficient by means of presented amount of information in limited time but fails to motivate students to think outside of the box. Divergent thinking, when applied to a problem, results in multiple solutions. How many solutions will be produced depends on definition of the problem. Less defined problem gives more options when trying to solve it. Quality of divergent thinking process can be measured by its fluency (ability to generate as much ideas as possible), flexibility (ability to modify information and look from different perspective), originality (ability to generate novel and unusual ideas) and elaboration (ability to elaborate novel idea, to put idea to practice) [2]. Divergent process can be stimulated further by employing work in small groups due to diversity of knowledge and expertise.

Although one might think that divergent thinking is crucial for creative process, without skills in both schools of thinking engineer cannot come up and materialize creative solution. Convergent thinking relies on experience and previous knowledge and is vital in early stages of creative process when ideas are formed, as much as in the late stages of the process where results of divergent thinking are analyzed and rejected or further evaluated. Each phase of creative problem solving process is characterized with interaction of convergent and divergent thinking making creative engineer to be skilled in both.

4. Creative process

Creative process and adoption of it’s rules are essential for development of creative skills. Result of problem solving process is not the only measure of creativity level, problem definition, fact finding and preparation for problem also require demonstration of creativity skills. Therefore, creative process can be in general divided in four phases.

The preparation phase contains critical approach to the problem. Open ended or under defined problems must be further analyzed. Raising new questions, new possibilities, filling missing information and figuring out how to get them help to formulate a problem, as sometimes formulation is more essential than solution [2]. The way problem is framed often reflects the purpose and can cause paradigm shift by reformatting question (going from how do we dispose plastics? to how do we make disposable plastics?) [3]

The phase of generation is used to create as many ideas as possible to address formulated problem. Ideas should be diverse as much as possible and should be generated without criticism and interrupting the creative process. Divergent thinking and its quality are
essential for this phase and different methods and exercises are used to encourage thinking skills, such as brainstorming, mind mapping, forced connection, etc.

*The incubation phase* is period in which active process is not used, lasts during course break, lunch, overnight and allows subconscious intelligence to suggest solution. Certain time of incubation helps restart creative process, this time more directed at the formulated problem, thus possibly generating solutions for difficult challenges in *heuristic* moment.

*The verification phase* includes analyzing, clustering and evaluating all solutions generated in previous two phases. Few of the most possible solutions are examined in different ways, combined or improved while knowing implications and consequences of each proposed solution to formulated problem. This phase also includes planning of further actions and implementation of the solution.

As the idea behind creative process is not just problem solution but improving problem solving skills in engineering students, additional phase can be introduced, *evaluation phase*. In this phase students can reflect and evaluate whole creative process and effectiveness with which students were able to implement solution. This evaluative reflection provides further learning for improving solving problems based on past experiences [2].

It is recommendable that creative process at each phase starts with divergent thinking to produce as many ideas and information possible and then to switch to convergent thinking to select most usable and promising ones. Interaction between convergent and divergent process is crucial to drive the process from problem formulation to problem solution. In order to support the creative process role of facilitator must be introduced (teacher) who will make sure that action plan of the process is well known, elaborated and implemented. How to introduce creative process through course and exercises is crucial when trying to create creative engineer.

5. Engaging creativity in classroom

Practicing the use of creative process to solve problems is natural way of gaining creativity for engineering students. It is important to show students how to use and apply such process on certain problem and what are the benefits of it. Creative learning model proposed by Treffinger et al. [4], meant to stimulate and develop creativity in engineering students, consists of three levels: *learning and using thinking tools, learning and practicing process of problem solving and working with real problems.*

First level assumes presentation and teaching of different tools for convergent and divergent thinking. Students are given tools to create, modify and combine their ideas or solutions and are introduced with the rules of each tool. Methods to do so include *brainstorming, mental maps, attribute listing, idea checklists, analogical thinking* and many more. Details about exact tools can be found in literature but their common goal is to open up student’s efficient divergent thinking [2].

Second level deals with application methodology of those tools in solving problems. In this phase is vital for teacher to ensure that students adopt systematic problem-solving pathways. Problems can be presented as part of case studies, simulations, role playing, team work and so on. Forcing team work and work in groups develops skills needed for interactive collaboration and uses most of the group’s knowledge and experience.

In final level students are challenged with real life problems that require use of learned skills in previous two phases and successfully adapt creative process in problem solving.

Exercises used as a part of level one and level two encourage and reward creative thinking as they force students to look at the subjects they are studying from different perspective, also they make it easy to include large number of students to be active during class [5]. Regardless
of what tools are used, goal of these exercises is to force students to accept novel way of looking at problems. Role of facilitator was already mentioned and one has to be careful not to let students consider exercises to be trivial or consider them childish and explain how these methods are used in industry to create products, cut costs and give new solutions. Also, the facilitator is responsible for introducing the problem and driving the group between divergent and convergent phases of process. Following application of theses methods in real courses two factors are stressed out as crucial: preparation and repetition [5]. Class should be given some info about what exercises are supposed to accomplish. Repetition makes the learning process effective so all new exercises should be repeated at least two times. When doing things for first time students tend to misunderstand the rules and convert exercise to something they are familiar with. In order to accelerate learning process application of fifth phase of creative process is advised by means of collecting several student works and discussing them in class [5].

When and where to apply such exercises depends on teacher. Creating elective courses won’t have impact on larger amount of students as only small groups could attend this kind of course per semester. These methods should be integrated as much as possible in regular curriculum. Open ended and divergent problems can be assigned to small groups as a part of in class or home exercise and supplement traditional method of teaching with single correct answer problems.

One example of such exercise is reported in [5] and [6] where students were asked to make and solve a final exam for the course. Making exam as a conventional single solution problem would earn minimum passing grade, and more credit could be achieved if the exam requires demonstration of abilities for analysis of course material, synthesis of knowledge from other subjects and evaluation of multiple solutions. The students found exercise to be extremely useful and interesting and test generated excellent exam questions that contained synthesis of knowledge from related subjects.

Example of encouraging creativity in elective course and organization of one can be found in [1] and [6]. In [1] idea of whole course is to demonstrate creative problem solving as a useful tool for engineers. First third of course is used for guest lecturers who talk about use of these tools in industry and for introduction to the tools of creative process. Rest of the semester is aimed at work in small groups with practical project with support of teacher. Problems addressed range from development of products, solving real life problems to design of topics for Master thesis.

Application of active learning as tool for improving creativity is reported in [6]. Difference from [1] lies in role of a teacher and previous knowledge about problem to be solved. Problem addressed was same for each group of students and was chosen so that students don’t have experience or knowledge to solve the problem individually or easily. To solve it, students had to develop new skills and cooperate with teachers and assistants. Also, to pass the exam product had to be built, idea alone was not enough (virtual hand that will mimic movement of hand on computer). Teacher had to take a role of a coach of each team. During meetings with each team coach had to discuss problems and participate in devising solution together with students while taking care to involve all team members to think and shape their ideas about final product. As a coach, teacher also developed his own problem solution. In both occasions, students reacted positively about their problems and had to adopt new skills to tackle the problem and find solution. No matter what form of course or exercise is used to encourage creativity, role of a teacher is crucial as he is the one who prepares and executes process of improving creative skills in engineering students.
6. Creating creative atmosphere

Important factor in generating new creative skills is working environment and possible situational factors. Besides good preparation and analysis of creative process, teacher must make sure that students feel free to act creatively. In first place teacher must start the creative process, give directions or present case histories of problem solutions so students get to know what is expected from them. Also, one can offer leading questions as focal points for brainstorming or some other tool. When asked a question, students need some time to think about it and the answers shouldn’t be criticized as good one or bad one. Creative process shouldn’t be interrupted and stopped if someone gives good solutions early on, divergent phase is all about quantity and diversity. Students should be thought information gathering skill to break their fear of unknown and informed that sometimes failure can lead to new ideas. Questioning and cooperation must be encouraged and applaud. Former can be further motivated by breaking class in smaller groups where those who are shy can present their ideas through group leader. In the end, evaluation of the ideas can improve creative skills even more and motivate students to participate in future problem based exercises.

7. Responsible creativity in engineering

During learning procedure of creative problem solving, as during basic education, importance of good engineering practice must be stressed out. In the end, responsibility of an engineer is not just to give the most efficient and economic solution but to ensure safety of users, environment and infrastructure. 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 [8]. Therefore, creativity in engineer can be utilized only when student has enough professional knowledge and expertise which is achieved mostly through basic education and serves as foundation for adoption and responsible use of creativity.

8. Conclusion

Main goal of high degree education is to prepare engineering students for real life situations. Traditional methods of teaching with single solution problems give basic knowledge needed to start a career and begin process of further learning and specialization. But, industry also needs engineers that are creative and that can create new products, technologies and cut costs. Therefore, curriculum should incorporate exercises or elective courses that will encourage creativity and creative problem solving in students. Several examples of courses were mentioned in the text and importance of the teacher as a facilitator or coach is stressed out, where teacher is not just supposed to prepare exercises but to create atmosphere that will allow development of creative skills in engineering students. High degree education should recognize creative spark in individual and motivate him to further develop new skills as in the end, university’s responsibility and its interest is creation of creative engineers.
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