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Modelling a Laboratory for Ideas as a New Tool for Fostering Engineering Creativity

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Abstract

This paper outlines the principles of modelling and designing a laboratory for ideas, an innovative solution dedicated to the development of creativity and creative problem solving skills in an engineering context. Reflecting the objectives, this paper defines the connection between creativity and engineering, adopting them as a single mindset, and describes how creativity should be taught, having in mind new education models at leading engineering schools. It highlights five factors which have a significant impact on creativity of individuals – motivation, environment, knowledge and domain skills, openness to other domains, and open ended problems in assignments. As a co-creative and supportive environment, laboratory for ideas covers these factors and encompasses different groups of actors and activities. By encouraging students' entrepreneurial intentions and practical innovativeness, it is described how it should systematically strengthen both their creativity and engineering mindset.

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Keywords: engineering creativity; laboratory for ideas; creative problem solving; students' creativity; education models

1. Introduction

To secure competitive advantage companies require continuous creation of new products, services, methods and processes. More simply, they require permanent innovation. Since most of innovations in knowledge society are based on engineering and technology, in many ways engineers are the ones who have the responsibility to create these innovations. They are expected to adapt emerging scientific principles to develop a new or advance existing technologies and materials in order to create new or satisfy existing (and constantly growing) customers' needs. In

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other words, they have to solve complex open-ended problems in today's rapidly changing environment and to do that under numerous constraints. To do this, engineers have to master mathematical and scientific knowledge, domain specific skills and tools. But it is more than just that. Engineers need to be creative to be able to offer original ideas, novel and rearranged solutions. Creativity becomes a crucial asset in the competitive and overcrowded marketplace. It is a key ingredient in producing something new and different (e.g. faster, better or cheaper), not more of the same. Therefore, the development of creative problem solving skills as a part of engineering education is essential, crucial, and indispensable.

Although many authors provide the evidence about the importance of creativity and creative problem solving skills to the engineering community [1]–[5], the most of the engineering schools fail to prepare their engineering graduates for this type of work. While industries expect engineering graduates to be creative, students learn very little about creativity on their studies. Their imagination is restricted by curricula and it is not being developed as it should be. Additionally, teaching staff sometimes cannot find the way to foster students' creativity. This is especially true for universities outside the US. Some of reasons for this could be: prejudices about creativity itself among hard-core engineering lecturers, overloaded programs without much room left for additional subjects, and the fact that it is not easy to build an effective and validated creativity training program [6]. All of these give us clear call for developing new educational tools and models which can help in equipping engineering students with creativity.

The purpose of this paper is to describe principles of modelling and designing a laboratory for ideas, an innovative solution dedicated to the development of creativity and creative problem solving skills in an engineering context. It is conceived as a co-creative and supportive environment which should systematically strengthen both students' creativity and engineering mindset by encouraging their entrepreneurial intentions and practical innovativeness.

Reflecting the objectives, the remainder of the paper is structured as follows: in Section 2 connection between creativity and engineering is defined, as an imperative for engineers as creative problem solvers in today's knowledge society; Section 3 reflects on teaching creativity and describes new education models at leading engineering schools, as examples of solutions to the existing problem; in Section 4 conceptual model of the laboratory for ideas is presented as well as actors and activities within this laboratory; while Section 5 offers concluding remarks.

2. Creativity and engineering as a single mindset

Overall perception of engineering creativity neither in public nor among engineering students is high [3]. Why? The most often engineers do not start they work form the ground, but build on existing technology and solutions incrementally improving them. Consequently, engineering results are very rarely major breakthroughs which bring public recognition. At the same time these results are achieved by teams and organizations and there is no space for single name / profession recognition in the public.

However, much of engineering is inherently creative. The word "engineering" has its roots in the Latin word "ingenium", meaning "innate quality, mental power, clever invention" [7]. It is a profession that requires knowledge of mathematics and natural sciences gained through learning, experience, and practice [8]. Engineering is defined as "the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all as respects an intended function, economics of operation or safety to life and property" [9]. Some of the most frequently used verbs to describe what engineers do are: produce, form, fabricate, construct, manufacture, build, erect, organize and develop. All these verbs are synonyms of verb create.

The origin of the word "creativity" is in the Latin word "creō", meaning "to create, to make" [10]. Creativity requires both originality and effectiveness - originality is usually described as novelty, and effectiveness may have the form of value [11]. It is the ability to deal with a problem through an intuitive process, while breaking boundaries, identifying patterns, making new connections and taking chances to come to discovery [12]. It follows that engineering tasks are creative problem solving tasks by definition. Thus, the most companies across industries would expect that engineers they hire are creative.

2.1. Engineering creativity

While there are common elements to creativity in all domains, many authors [1], [13], [14] argue that engineering creativity is different from creativity in fine arts or other fields. The main differentiator is the purpose in creation - engineering creativity results from "creativity with a purpose" [14]. Consequently, Cropley and Cropley [1] see engineering creativity through the prism of engineering results that perform the task or solve problems, including products, devices, or systems. They proposed a four-dimensional model for defining the creativity of engineering products with the following dimensions:

- relevance and effectiveness,
- novelty,
- elegance,
- generalisability,

meaning that the product solves the problem, it is original, pleasing and broadly applicable. Cropley and Cropley [1] explain that engineering creativity can be seen in a product when two of the four dimensions in their model are present, especially when these two dimensions are relevance and effectiveness and novelty.

On the other hand, some authors define engineering creativity more broadly. For example, Drabkin [15] defines engineering creativity as the ability of human intelligence to produce original ideas and solutions using imagination, while Lumsdaine et al. [16] highlight the importance of interaction with other ides, people and environment and see it as "playing with imagination and possibilities while interacting with ideas, people, and environment thus leading to new and meaningful connections and outcomes".

3. Teaching creativity

The possibility of teaching for creative problem solving gained credence in the 1960s [17]. Today results of many studies indicate that many aspects of creative thinking can be enhanced and developed by training (e.g. [18], [19]). Starting from this point, the task is to examine how to do that in the most effective way. Several factors which have significant impact on the creative process have been identified by researchers.

Motivation. Several researchers [20]–[23] identified that personal motivation is one of elements which influence creative performance. Klukken, Parsons and Columbus [20] explain that intrinsic motivation pushes creative individuals to go beyond mundane solutions, and produce something new and different. According to Amabile and Tighe [22] more interested in the problem area individuals are, more likely they will take the exploratory route when solving problems related to that area. They also argue that anything that leads a problem-solver to get deeply involved in focusing on or thinking about a task will enhance creative ability.

Environment. To express the most of its creativity an individual needs the freedom to experiment, and to fail, in order to take the risks necessary to pursue new ideas [20]. Amabile and Tighe [22] explain that constraints consistently hinder creativity and decrease task motivation. Any perception of external control (e.g. rewards, time pressure, surveillance, evaluation and even the expectation of evaluation) over those that are performing the tasks has negative influence on intrinsic motivation. Virtual and physical working space, as a part of environment also affects creativity. Standardized school furniture like wooden desks and chairs, white walls, and black boards is far from surrounding that can help in bringing out students creativity [6].

Knowledge and domain skills. Research in several domains [24] has converged on the conclusion that high-level problem solving is based on detailed and highly structured knowledge, or expertise, within the domain. Creative thinking requires a mastery of skills and knowledge within the own area. One must be well founded in math, science and a specific technical field to be able to creatively solve engineering problems [20]. So, creativity is dependent on knowledge but it goes beyond human intelligence [25], [26]. Research has repeatedly shown low correlations between IQ and creativity measures [27] as well as between academic performance and creativity.

Openness to other domains. In addition to expertise in one domain, creativity depends on ability to understand and learn many things in other domains. An openness to new ideas and information and a willingness to be

influenced by outside sources brings the capacity to connect remote (but existing) elements and produce creative links. The ability to put the LEGO bricks differently, to connect in novel and original way already existing things and technologies to solve unsolved problems is seen as one of main features of creativity by authorities like Isaak Asimov [28] and Steve Jobs [29]. Openness to other domains helps in practicing lateral thinking [30] because the search for new ideas often requires a shift in the thought process and application of what is known in one domain to a new problem in the other domain. So, strong background in a specific field is needed, but great results can be expected only if people are also capable of making connections between items which might not ordinarily seem connected [28].

Open ended problems in assignments. Although knowledge is essential to innovative solution, exposure to a problem is generally considered to be the initiator of the creative problem solving process [31]. Without a problem there is no need to be creative. Open ended and problems as close as possible to real life problems are optimal in order to force the students to explore novel approaches or applications. These types of problems provide learning experience very close to reality, offering to the students' situations which are quite similar to one engineers experience in their everyday jobs. It is suggested that the students should be given problems for which the professor knows of no solution [20].

3.1. Enhancing students' creativity through innovation and entrepreneurship labs

Students' entrepreneurship is getting more and more attention and support from policy makers and university leaders across the world [32]. Innovation and entrepreneurship labs recently established at some of the world most recognized engineering schools can serve as good practical examples how to enhance students' creativity. Three cases - KTH Stockholm, ETH Zurich and Harvard, will be presented here in brief to help us better understand the concept behind.

Student Inc. at KTH (Stockholm, Sweden) is a student run business incubator for students. It is result of partnership between Excitera, a student non-profit entrepreneurship organization, and KTH Innovation. Student Inc. supports technology based projects with promising commercial potential of students at KTH, who have developed their novel ideas together with KTH Innovation. When they make a certain progress, they can apply for a place at Student Inc. to get the necessary facility (working space) and mentorship support to commercialize their project. Mentorship includes coaching support from the experienced coaches at KTH Innovation, monthly workshops on relevant subjects, commercial support, contacts and networking [33].

Innovation and Entrepreneurship Lab (ieLab) at ETH (Zurich, Switzerland) offers an innovative environment to support the technology development and its faster commercialization, bringing together students and researchers from ETH, talented young entrepreneurs, experienced businessmen and industry partners. Talented students with an interest in entrepreneurship are offered with supervision and encouragement of experienced coaches, necessary workspace, networking with their young colleagues, successful entrepreneurs and industrial leaders. ieLab represents an ecosystem where a process for accelerated technology transfer from science to business happens [34].

Harvard Innovation Lab (i-lab) established at Harvard University (USA) helps students interested in entrepreneurship and innovation to grow their ventures, fostering creativity, cross-disciplinary and cross-university collaboration. It is student centred and faculty enabled, and operates as a start-up within the larger university environment. It combines foundational learning on innovation and entrepreneurship with expert resources for students to apply to their ideas, and offers experiential learning experiences and venture incubation program [35].

4. Laboratory for ideas

Growing number of innovation and entrepreneurship labs shows a new way for supporting and enhancing engineering creativity education models. These concepts are mostly inspired by successful examples of seed accelerators and living labs [36]. Following them as well as identified factors which have significant impact on the creative process, the concept of the laboratory for ideas is developed. The lab's purpose is to offer an environment that encourages creativity and practice of creative problem solving, and supports students to adopt creativity and engineering as a single mindset.

4.1. Conceptual model

The core idea behind a laboratory for ideas is to provoke, stimulate and motivate students and young researchers to actively use their intellectual and creative potentials to generate innovative ideas. Laboratory for ideas is conceived as open lab that welcomes students who have or are interested in developing innovative engineering and technology based ideas using own creative potentials. These ideas should be product / service oriented. Creative problem solving methods and techniques would be matched to a specific product development project type depending on the expected result – whether it is just a slight or a significant change on the product, or whether it is an improved product platform or a product that is completely new to the world [37]. To help in developing product ideas the laboratory for ideas will support students to work on their own creative ideas or on real life problems submitted by partner companies.

The basic aim is to develop a physical and virtual environment supportive for generating and developing innovative students' ideas through relevant trainings, mentoring and technology put at their disposal. However, the higher goal is to assist students in creating and developing their entrepreneurial intentions by helping them to realize their creative ideas and by providing them safe and functional environment as well as logistical, informational and operational help. Through the lab students will get the opportunity to develop and commercialize these ideas by two routes – entrepreneurial (pursuing their own creative ideas) or open innovation (working on problems submitted by existing companies).

The lab environment will provide full hardware and software, training, mentoring and networking support for the growth of student's ideas. It will bring students, researchers, experienced engineers, entrepreneurs, SMEs, solution and service providers, users into co-creative environment, cross different perspectives, provide additional expertise and information, and deepen understanding about complex interactions between technologies and market. These resources and supportive environment should substantially increase the likelihood for exploration of creative potentials and creation of innovative solutions. The lab will be physical and virtual space where innovative products and services can be conceptualized and validated, and then spun out into new venture initiatives.

4.2. Actors and activities within the laboratory for ideas

Knowing that the proposed concept is highly multi-dimensional, labs are planned to host several groups of subjects:

- students with creative ideas;
- lab staff;
- university staff;
- university students enrolled in relevant courses (subjects);
- external mentors and experienced practitioners;
- companies representatives;
- samples of end-users.

As laboratory for ideas has a goal to stimulate and develop innovative ideas and solutions by employing students' creative potentials, this lab will house various activities:

- *Educational activities that will help participants to obtain skills and knowledge necessary for goal achievement:* workshops, trainings, case studies, scientific research. These activities will aim to enable students that are lab participants to effectively use their potentials with meaningful actions, in order to bring their creative engineering ideas to the next level.
- *Educational activities for non-participating students*: problem- and work- based learning, entrepreneurial processes simulation, demonstrational teaching processes. These activities are expected to be knowledge-spill-over from the main lab projects to the university students, creating a significant impact on a bigger scale by directly influencing those that haven't taken part in main labs initiatives.

- *Mentoring activities*: guiding and helping students through joint work, consultations and meetings. These activities are expected to be an extension of educational activities suggested for the lab participants as well as the source of additional expertise. Mentoring activities will, unlike educational ones, provide assistance in specific actions of each team or individual, giving practical advice relevant to the project that is being mentored. This type of activities is expected to be of great help during each project's realization steps.
- *Idea generation activities needed for idea development or for problem solutions*: individual, group and hybrid idea generation as well as virtual idea generation with included companies and other interested parties using virtual part of the lab. This type of activities is crucial for proper usage of lab participants' creative potential. As it is expected that the participants will enter the lab with one or more good ideas, it is a priority to properly develop those ideas. Also, if a partnering company submits a problem or a challenge that needs to be solved, the lab participants are encouraged to generate creative ideas that could serve to address the issue.
- *Communication and collaboration activities*: sharing space and lab resources for ideas development, on-site inter-team collaboration, networking with other students and interested companies, communicating with mentors, university officials, market and media, preparing and disseminating relevant information and conclusions. These activities are basis for the synergy effect that is highly anticipated in the lab. Without proper communication practices, it is not possible to achieve collaboration on the proposed level. Additionally, since various teams will share the same resources, it is expected for new connections and collaborations to be created between the lab participants who would elsewhere be unaware of each other.
- *Various software- and hardware-dependent practical activities varied by idea type*: concepts development, computer simulations, simple prototype design and testing, 3D printing, project realizations, data gathering and analysis, software testing, multimedia creation, mobile technologies development, lead-user and ordinary-user testing, service providing, content analysis and many others. These activities are the core of the lab concept - to help students in pursuing their creative ideas through relevant training and technology put to their disposal and based on engineering knowledge. The lab environment is designed to provide full hardware, software, institutional and scientific support for the proper growth of any good student's initiative that fits the lab course of action.
- *Project management activities*: management tasks, team meetings, process coordination, project monitoring and control. These activities are necessary for reliable project realisation, and are result of relevant participants' education courses.

Conclusion

In today's knowledge society where technology develops faster than needs, where problems are more and more complex, and where globalization brings huge interdependencies, only good engineering knowledge, high creative ability, and capacity to communicate across domains can lead to excellent and novel solutions. While there is no common definition of creativity, it is likely that many aspects of creativity can be taught and developed if training and environment are suitable. In this paper these challenges are discussed and new concept of laboratory for ideas presented.

Engineering creativity is seen as different from creativity in fine arts and future engineers are expected to solve problems and show results through innovative products, services, or systems. It would be of great value for engineering students to get the opportunity to face real industry problems during their studies within a supportive environment. Following these ideas as well as identified creativity enablers the laboratory for ideas is modelled. It is conceived as a co-creative and supportive environment which should systematically strengthen both students' creativity and engineering mindset by encouraging their entrepreneurial intentions and practical innovativeness.

Serving as a cross-disciplinary and multi-stakeholder platform for creativity development through entrepreneurship and collaboration with industry, the lab designed and developed in described manner will offer a unique environment for problem- and work-based learning. It will significantly improve educational experience for engineering and students at large, foster their creative potentials and prepare them for active role at labour market. Through the lab students will get the right skills to enter the labour market or to create their own business. They will practice their creativity, learn how to work in a team and use their knowledge and initiative. The lab will be a new teaching resource. This will enable not only to entrepreneurially oriented students, but students at large to become

an integral part of new product and service developments, and new venture creation and thus get chance to enhance own employability.

Following developed and described model, the Tempus project "Fostering students' entrepreneurship and open innovation in university-industry collaboration - iDEA lab" (Ref. No. 544373-2013) is initiated. The project aims to develop six iDEA labs in Western Balkan countries in order to foster the collaboration between universities and enterprises, advance employment potential of graduates and enhance the companies' innovativeness. The possibility to practically develop and implement described concept opens new challenges – to measure results, compare with similar initiatives and improve model further based on achieved results.

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