Engineering creativity support for future research and development

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ABSTRACT

The human abilities to use nature’s materials and force to their benefit, by means of engineering applications has made the human development possible. Multiple factors have influenced the human development, sometimes accelerating it, other times slowing it down to annulation. Although it is known and accepted that creativity’s role is essential in engineering performances, the neglecting of creativity in engineering education is not understood. The graduates from Anglo-Saxon countries and Europe reduced creative potential and the lack of necessary abilities concerning the solving of the companies’ problems have been emphasized by specialists in education and governmental reports reinforces the need to creativity in engineering education. The diagram of engineering education presented in the paper defines in conceptual terms the way engineering study programs can be developed with an adequate creative composition.

The evaluation of the students’ creativity level at the master and doctoral levels of engineering programs belonging to two European universities has shown the need for improving creativity solutions.

The development of creative abilities can be realized by formulating creative objectives which are specific to learning: creative evaluating topics, open projects, answering topics, originality of solutions and the use of projects method.

Keywords: creativity, engineering, design, education.

INTRODUCTION

In the course of human history, a decisive factor in human development was the existence of the human abilities to solve different situations, aspects of life, encountered situations. All these adaptations have had different forms but the most critical moments were those having technical connotations, as in their essence the material usage and of nature force with reservations of human communities have necessitated creativity and inventiveness.

The protection of humans against nature’s hostility have imposed the development of wooden and stone constructions and the daily meals of people, especially those of large communities of people have necessitated tools and irrigations. Afterwards, maintaining good health conditions imposed the development of good travel, housing and waste processing systems. Solving these problems by means of engineering applications has made possible the human development, but solving one problem has been the appearance ferment of a new one, of other problems, more difficult than the previous ones, as officially recognized and significant historically shown in the industrial revolution.

At the beginning there appeared the moving and power source produced by man using the
engineering creation and coal combustion that is the steam engine. Afterwards there appeared the
internal combustion engine as a solution for weak points of the steam engine (large amount of coal,
the output, the large size of the machine) but, on the other hand, there also appeared new concepts
such as power, the insurance level and most of all, the pollution. The change of the climate and
pollution are today stimulating factors for the need to change the old technologies with new ones, by
means of which the secondary unfortunate results of the past are diminishing.

As to these, we legitimately ask ourselves: which are the origins and the roots of creativity and what
role do they play in developing the engineering solutions, or do they give an answer to human
needs? An easy answer is offered by the cycle “problem-solution-problem-solution…” which
explains the engineers’ need in being creative with solutions to the problem which society
generates.

There are always new problems that appear, that have never been encountered before, so the
solutions for them are not to be found in the past experiences but in future discoveries.
An exploratory example is the Diesel engine, which today excessively pollutes the environment and
for which VW has given an immoral solution or the British solution of interdicting of Diesel
engines in the industrial production, situations that emphasize the need for creative solutions, for
example adding the engine’s new components which are to reduce the polluting emissions. The
ability of rendering the materials and forces of nature profitable in human communities’ benefit
indicates the engineers’ capability to solve problems and emphasizes the permanent-present role of
creativity (Amabile, 1996; Charyton & Merrill, 2009; Howard, 2008; Mumford & Gustafson, 1988).
Engineering can be considered therefore an attitude, a state which in future will attempt to develop
new solutions to the problems that appeared along society’s development. Thus, we understand
better that the engineering essence is the competition accompanied by the ability of discovering and
developing new solutions (Amabile, 1996; Copley, 2006; Nickerson, 1999; Sternberg, 1998;
Treffinger, Young, Selby, & Shepardson, 2002). This is why creativity has to be carefully and
deliberately developed in the engineering education.

Over time, the chance of developing and discovering creativity has not been the same. Multiple
factors have influenced the development decision, sometimes stressing it, accelerating it on other
occasions or slowing it down until annulment. Human development has always been a stimulating
factor of discovery and creativity, these two being inhibited or accelerated by social, political or
natural events that have influenced the human communities.

The pyramids of Egypt, along with the other wonders of the ancient world have always been a good
example of creativity and discovery presence in the human components and qualities. But also the
mystical depth of the Middle Ages with its religious excesses represents an enlightening example of
stopped time; the witch hunts or the punishment of Galileo Galilei do not represent but an
annulment of the discovering and creative spirit. The military conflicts brought about the need of
discoveries, followed by the birth of competitive spirit in almost all the domains.

The shock of launching in 1957 of the first artificial satellite by the former USSR has brought about
the connection of creativity, inventiveness and engineering to a systemic and scientific mode of
participating to the competition. The American government’s reaction wasn’t delayed too long and
comprised all strategic zones of the federal state. The critical analyses done by American specialists
on the Soviet success have shown the existence of a superior creative spirit (A.J. Copley and
Copley, 2009), sustained by institutional strategies, politics and programs. In other words, the
American analysts have discovered the existence of ex-soviet orientation towards “creative
research”.
It is an easily outlined conviction that engineers who worked for the spatial program were not at all strangers concerning the two components of creativity, analysis and synthesis. Adding to this, in 2002 the American researcher Horestein is recalling that the projection required both elements: “...if more than one solution exists, and if deciding upon a suitable path demands ... making choices, performing tests, iterating, and evaluating, then the activity is most certainly design. Design can include analysis, but it also must involve at least one of these latter elements.” In fact the creativity relation with engineering is more profound (D.H. Cropley, 2015). If creativity generates new solving problems solutions, engineering perfects solving of assumed technology. It is no wonder that during these years research has progressed bringing to our attention new conceptual important clarifications. Thus, Brockman, in 2009 states that successful engineering solutions are those that have both components of creation, the one analytical, of convergent thinking and the other, synthetical, of divergent thinking, for the conception of technological solutions. Referring to this, the author’s conclusion is convincing: engineering is a fundamental creative process of solving human problems.

ENGINEERING CREATIVITY

It is a certainty that in our century creativity has become an essential element of development. Specher (1959) and Mokyr (1990), researchers of the previous century, have clearly underlined the importance of creativity and innovation in developing the human communities, putting the emphasis on the prosperity of nations. Thus, the vital role of creativity in obtaining human success is understandable. The challenges of the 21st century are major, as well - health, individual and collective security, climate, pollution, food etc., so that discovering new technological solutions has become a strategic grievance of human kind. Although it is a known and accepted fact that creativity’s role is essential in engineering performances, the neglecting of creativity in the engineering education is not understandable. Moreover, at the beginning of the century, in 2002, the researcher Florida, underlines the aspects of creativity: “... involves the production of meaningful new forms”, specifying that these forms are referring to:

- physical objects that can be made, sold and used;
- theorems or strategies that can be applied in many situations;
- systems for understanding the world that are adopted by many people;
- music that can be performed again and again. “

The senses concerning the products’ fulfillment that must have public utility and duration are for sure connected by the applicable character of engineering, the one that is used for obtaining the products. In different scientific publications, there appeared constantly signs of the lack of competences concerning the existence of creativity. In the UK, Altman and Garner, in 2002 claimed that the British educational system doesn’t encourage the innovation, and Bateman (2013) suggested that in the IT domain the difficulties in finding a job have their explanation in the graduates’ lack of creativity.

A similar picture is to be seen in the USA, where different sources describe the companies’ dissatisfaction towards new university graduates. They have less creative potential and do not show the necessary abilities for solving the company’s problems. In 1999 and in 2013, in Australia there have been published reports concerning the quality of university graduates that indicate that (D.H. Cropley, 2015): “Critical reasoning and analytical skills/Problem solving/Lateral thinking/ Technical skills” is high on the list of selection criteria for employers, and yet, when asked to rate the employability skills of graduates actually hired in 2013, employers indicated that only 57.3% exceeded average expectations in problem solving. Tilbury, Reid and Podger (2003) also reported on an employer survey in Australia which concluded that Australian graduates lack creativity.”

In Europe the research done on students belonging to engineering programs (Duse, 2017) have shown abilities that need improvements.
Turning back to the engineering education as a study subject of creativity existence, we discover the report of the Royal Academy of Engineering from UK entitled “Creating Systems that Work: Principles of Engineering Systems for the 21st Century” in which the researchers Elliot & Deasly, in 2007 criticize the way in which the provocations of the new century are understood by means of the engineering education. This report binds firmly creativity to engineering processes, considering it “the ability of elaborating new solutions for real problems”. Another possible answer could be discovered in the prevailing development of the left hemisphere of candidates for the teacher’s profession. It is known that in the forms of admission - the admission examinations for the engineering studies (especially in Europe), the logic-math disciplines (mathematics, physics, logics etc.) occupy a central role, exclusively. In addition, there is also the engineering professional culture, by means of which students are educated to accept and develop technical solutions of maximum security, without risks, very often leading to the suppression of creativity and innovation. There arises the question: if creativity is so important for engineers, why isn’t it present in every curriculum of the engineering study program? Why is engineering creativity ignored? A possible answer is to be found with the Australian researcher Cropley (2015), who indicated three causes: the engineering way of study is too much concentrated on a certain specialization, the educational process is concentrated on the acquisition of knowledge and the teachers aren’t sufficiently prepared for understanding, teaching and sustaining creativity. The solutions for this de facto situation require changes of behavior, of teaching content and of curriculum content. A starting point has been represented in 2007, by Sternberg’s publication of research results, referring to “the creativity’s cover” and to strategies which can develop a favorable area to creativity, that is an incubator of creativity. Thus, the development of creativity was aimed as an ability, a professional component. We are adding here the fact that the enriching of teachers’ knowledge who teach engineering study programs could offer a true chance for sustaining creativity in the engineering education, with the last 7 decades of psychology discoveries.

**CREATIVITY VS. ENGINEERING EDUCATION**

These considerations allow us to settle the engineering education formation on two perpendicular axes, the vertical one representing knowledge and profile ability and the horizontal one representing complementary knowledge (figure 1).

![Diagram of engineering education](image)

**Figure 1: Diagram of engineering education**
Judging and analyzing engineering creativity within these coordinates, one can observe that in the case of profile education we deal with declarative knowledge (the objectives of learning), with procedural knowledge (the strategy of learning – how?) and conditional knowledge (evaluation – when and why?). The horizontal axis comprises the complementary knowledge and abilities beginning with those which are predominantly native (painting, music), then reaching those of communication and creativity. The answer given by specialists referring to the lack of engineering creativity contours is in fact the lack of balance in the engineering education: the graduates’ specialization, the pseudo-expertize of programs’ content and the lack of the teachers’ knowledge concerning creativity, are reasons for which it is important and show how it can be developed with engineers. The representation of these causes on the diagram of engineering education has the form of a vertical narrow area around a vertical axis. The vertical axis’ shifting to the left or to the right offers us the chance of engineering programs’ development with the cultural complement dominant (on the left) or with the creative complement dominant (on the right). The higher they are positioned on the vertical axis, the closer they are and reach the conditional knowledge of superior order. In this judgment on creativity within the engineering education, essential is the conclusion that we do not solve the problem of graduates’ creative abilities adding creativity to the engineering curricula or enriching the evaluation of conditional knowledge. The specialists’ statements indicate that we deal with a structural problem that can be solved with the intervention of educators, psychologists and engineer professors on realizing the engineering education concepts. To this opinion, we can also add a number of aspects on the presented creative process, presented in figure 1 and philosophically but also psychologically proven by other authors.

The essential problem that blocks the changing of engineering education curricula by comprising creativity is complex, as it comes from the reductionist tradition of the educational system (Cropley, 2015).

Thus, the engineering approach tries to understand the objectives and phenomenon by means of decomposition in simple parts, easy to understand. The analysis applies the reductionist way of detaching one object in order to find out its functionality (what are its characteristics and how it works). In this sense, classical mechanics is a good example and the analysis is a valuable instrument and means for gaining engineering knowledge. The same analysis is of no help in knowing and understanding the functioning of complex entities, with more objects that interfere, as in the case of systems. Cropley illustrates his explanation using the example of the piano whose individual sounds we cannot find out, we can hear them only be disassembling the piano. This is the mentalist, mechanic, reductionist mode that is infused in the engineering thinking by an ancient influence, coming to us from Descartes and others’ scientific methods. The reductionist mode is dominating even today the engineering education. Connecting the analytical reductive mentality in the diagram of engineering education, to the vertical axis of profile knowledge and abilities and doing the final products’ analogy “the engineers’ piano”, as case study, the reductionist educator breaks down the final product, the engineer in many pedagogical pieces and thus obtains knowledge on what future engineers should learn. Unfortunately, looking upwards, creativity is getting lost as the pedagogical parts resulting from the breakdown have only a declarative character (Cropley, 2015).

Sternberg & Lubart (1995) and afterwards, in 1996 Sternberg & Williams proposed that another motive is that of synthetic abilities concerning the idea generation. Unfortunately, the reductionist and analytical mentality removes the synthesis capability which is the key element of creativity.

In engineering education, the final products’ breakdown means more components, different components like the calculation and the Laplace transformations, Ohms’ law, the thermodynamic laws and the Boolean algebra etc. The down – up approach on the profile axis of knowledge and abilities is favoring them and they are very well assimilated by hard studying students to the detriment of the components on the horizontal axis referring to complementary knowledge and
abilities. This is why the evaluation of students in the engineering domain (Duse, 2017), on the paper’s stated reasons could help to investigate the level of gained (/existing) creativity. Continuing, the research objective is that of discussing the evaluation questionnaires applied to students for establishing the level of creativity. The resulted conclusions will better direct the development of engineering education by means of modifying the curricula and the teaching models and methods.

CREATIVITY RESEARCH – METHODS AND RESULTS

Creativity tests have always been a study subject, regardless where they were used – at the workplace or in education, especially in universities. Therefore, there arises the question: “how to assess or measure a creative educational culture?” The correct answer comes on two ways:

- by means of key performance indicators, regarding the innovations or the cultivation of ideas that the university develops (referring to qualitative ideas);
- by means of creativity tests.

Creativity tests were used by many researchers, educators and psychologists to measure the creative coefficient (CQ) of people. Beneath the individual and collective information on student creativity, a test can be useful in offering the university a clear vision on the creative education culture landscape.

In this regard, there can be mentioned some of the types of creativity tests taken into account for this paper:

- Guilford’s test regarding divergent thinking;
- Remote associates - “the one-right answer”;
- The Torrance test regarding critical thinking;
- Self-assessment tests;
- How creative are you? (Kellogg Northwestern University).

Taking into account the strong points and the weak points of the five creativity testing systems, the authors opted for an online system, http://www.testmycreativity.com, a free creativity test which combines different features of the above-mentioned tests and gives a global score.

In order to answer the main question of this paper regarding the “role of creativity in engineering education”, the creativity test http://mycreativitytest.com was applied to two groups of students from the Drilling Oil and Gas Faculty (AGH) in Cracow, Poland and from the Engineering Faculty of Sibiu (LBUS), respectively, from the master and the doctoral school programs.

The first ones were at the end of their training program (master), while the ones from the doctoral school were at the beginning of their training. The selection was done in this manner because after graduating the master study programs, most engineers start working in companies while a part of them, interested in specialization, opt for the doctoral school.

After completing the 40 items of the test, each student received the result as a circular diagram (figure 2) which comprised the obtained general score, the specific area and the creativity dimensions specific to the engineering job. Also, explanations for understanding the eight dimensions are added.

At the Drilling, Oil and Gas Faculty, 45 students, from the 2nd study year of the master program (19% women and 81% men) and 6 students from the doctoral school (5 men and 1 woman) have taken the online creativity test. The results obtained for master program students are shown in table 1, while table 2 presents the results for the students in the doctoral school. At the doctoral school, the area of creativity specific to the engineering job has surpassed 83 %, while for the master programs the value obtained was 40.5%.
Figure 2: Circular diagram of creativity

Table 1: Results for master students, AGH Cracow

| Number of accomplished dimensions of creativity | Number of students | %  |
|-----------------------------------------------|--------------------|----|
| all accomplished                               | 8                  | 17.7|
| -1                                            | 6                  | 13.3|
| -2                                            | 5                  | 11.1|
| -3                                            | 1                  | 2.2 |
| -4                                            | 3                  | 6.6 |
| < (-4)                                        | 22                 | 48.8|
| Total                                         | 45                 | 100%|

Creative students
Limited creativity: 26.6%
Low creativity: 55.4%
(below average in more than 50% of the dimensions)

Table 2: Results for doctoral students, AGH Cracow

| Number of accomplished dimensions of creativity | Number of students | %  |
|-----------------------------------------------|--------------------|----|
| all accomplished                               | 1                  | 16.6|
| -1                                            | 2                  | 33.3|
| -2                                            | 1                  | 16.6|
| -3                                            | -                  | -   |
| -4                                            | 1                  | 16.6|
| < (-4)                                        | 1                  | 16.6|
| Total                                         | 6                  | 100%|

Creative students
Limited creativity: 50%
Low creativity: 33.5% (below average in more than 50% of the dimensions)

The 40.5% percentage of the creativity area specific to the engineering profession is more vulnerable at a detailed look, as only 43.7% of students have fulfilled all dimensions. Limited creativity on different levels is present for more than a quarter of all students and more than half of them present low creativity (under 50% of the satisfied dimensions).
The Polish students, with their percentage of 83% exceeding the area of creativity specific to the engineering profession, seem to be well taught/trained for a creative and innovative work. But there can be made also some remarks; from this large percentage, 20% are fully creative, satisfying all the 8 dimensions, and half of the total number of students present a limited creativity (on three levels), while one third of the total number have low creativity (under 50% of the satisfied dimensions).

At the industrial engineering master programs belonging to the “Lucian Blaga” University of Sibiu, 72 students and 8 students from the doctoral school have answered by completing the creativity test (4 men and 4 women). The results obtained for the master program are shown in table 3 and for the doctoral school in table 4. The Romanian master students have surpassed the specific creativity with a percentage of 52.8%, and at the doctoral school with a percentage of 62.5%.

### Table 3: Results for master students, LBU Sibiu

| Number of accomplished dimensions of creativity | Number of students | %  |
|------------------------------------------------|--------------------|----|
| all accomplished                                | 19                 | 27.1 |
| -1                                              | 8                  | 11.4 |
| -2                                              | 6                  | 8.5  |
| -3                                              | 7                  | 10   |
| -4                                              | 10                 | 14.2 |
| < (-4)                                          | 20                 | 28.5 |
| Total                                           | 70                 | 100% |

Nevertheless, out of the 52.8% of the students who reached the area of creativity specific to the engineering profession, only half have all the creativity dimensions fulfilled. In fact, one third of the total number of students have a limited creative level and 43% of them are under the satisfaction status of half of the creativity dimensions.

### Table 4: Results for doctoral students, LBU Sibiu

| Number of accomplished dimensions of creativity | Number of students | %  |
|------------------------------------------------|--------------------|----|
| all accomplished                                | 3                  | 37.5 |
| -1                                              | -                  | -   |
| -2                                              | 2                  | 25   |
| -3                                              | -                  | -   |
| -4                                              | -                  | -   |
| < (-4)                                          | 3                  | 37.5 |
| Total                                           | 8                  | 100% |

Out of this percentage, more than half (60%) have successfully fulfilled all eight dimensions and only a quarter of the total number of doctoral students show a limited creativity, on a single dimension. An important percentage of the total number of students remain also with a low creativity (37.5%). When attentively looking at the sense of the creativity test dimensions, one can notice that for the engineering job the connection, curiosity, courage, complexity and persistence dimensions have a determining role in obtaining performance while practicing the profession. The doctoral school needs specific abilities for research, during the study years as well as after that, in integrating the engineering doctors within the research-developing organizations, within universities and industrial production organizations. Here, the outstanding abilities are those of abstraction,
connection, curiosity and courage, of complexity and persistence. Regardless of the assessments on abilities prevailing in practicing the engineering profession, respectively in that of engineering doctors, all eight dimensions are essential for the profession (Duse, 2017).

CONCLUSIONS AND PRACTICAL IMPLICATIONS

The results obtained are nevertheless modest for the Polish students but also for the Romanian ones. This result isn’t shocking as on an international level the researchers have reported similar situations and findings, adding the need for support (Felder, Woods, Stice, & Rugarcia, 2000; National Academy of Engineering, 2004; Sheppard, Macatangay, Colby, & Sullivan, 2009). It is worth mentioning and remembering which are the causes that are accepted by researchers for the lack of creativity and innovation in the engineering education. Cropley claims that the action of creativity and of engineering education comprised in an institutional frame requires more changes.

His recommendations of changes can be mentioned. beginning with the contents of study programs completion, comprised in the documents of the independent agencies for the assessment of the quality of higher education, but also the development of new creativity courses, comprised in the curricula of engineering programs (ABET, Charyton & Merrill, 2009; Dewulf & Baillie, 1999; Kazerounian & Foley, 2007; Stouffer, Russel, & Oliva, 2004). These conditions are not easily to fulfil and transposed into practice, because they refer to independent evaluation organizations and to faculty counselors’ decisions, recognized for their aptency for comprising in the curricula of their programs purely engineering subjects.

A possible solution having great chances of success is the help given to educational sciences, of assistance to the professors belonging to the “teacher training” departments. They can give the necessary assistance to the implementation of creativity concepts in the curricula and pedagogy of existing disciplines for the engineering study programs (Daly S. R., Mosyjowski & Seifert, 2014).

The professors could better help students in developing the creative abilities by formulating clear creative objectives, specific for learning. Thus, when it is sustained by adequate evaluations (Wiggins and Mc Tighe, 2005), one can offer a complete learning experience. In the same way, the professor can incorporate more evaluation topics referring to creative abilities (especially during teaching the course) followed by a feedback for improving them. The creativity evaluation is not simple and its division in more components can be done by assimilating the existing evaluations (of labs, projects and applications). The evaluation has an important role in the process of motivating the students, thus the leaving out of evaluations concerning the creative qualification from the disciplines evaluation portfolio can limit the beneficial effect of learning. The students can interpret the lack of evaluation as an indicator for the lack of importance. The lack of evaluation limits also the professors’ knowledge of the zones where the students need supplementary development. A new acting direction is that of introducing in the study of some distinct mentions of the creative process. The explicit knowledge by students of the cognitive indicators of creativity and the self-consciousness of using the cognitive competences can be evaluated and help the students to concentrate on these learning objectives. Besides including the creativity indicators in the evaluation one can recommend the improving of creative abilities training. The open processes can offer opportunities for creativity when there aren’t imposed final results but the student’s freedom is allowed in finding the final solution without a rigid planning of the project’s result (Dewulf & Baillie, 1999; Stouffer, 2004).

The development of creative abilities in the discipline’s content can be achieved by including some topical questions. By means of answers, the students can suggest more ways of solving the technical problem, thus offering practical solutions and the possibility of being evaluated on their divergent abilities of thinking. Crismond & Adams (2012) present multiple examples concerning the
development of divergent and convergent thinking on the educational design system. Folger & LeBlanc (2013) describe many strategies of sustaining the students in the creative solving of problems. The education of students is nevertheless important in the sense of being original, in finding solutions for using the idea instruments. The morphological analysis of ideas, the SWOT analysis and the heuristic design are some examples of creative methods that can be used and by means of which the originality of the presented solutions can be evaluated. The appeal to generate more and more ideas as possible problem solutions, over a limited period of time, is another method of developing the consciousness of the possible solutions’ diversity. The developing of metaphoric thinking, according to Smith & Linsey (2011), can be realized by using analogies in describing products, processes, etc. (ways of measuring different parameters, different means of production). Abstraction, connection and complexity of phenomenon and processes are key abilities for the identification of their characteristics. Multiple ideas can suggest ways to use these characteristics and it is the best way for developing new ideas. The realizing of analyses on different products and processes allow students to discover relations between different categories of information. Using the method of projects during the course activities and during applications (Duse D. M. & Duse C. S., 2014) offers the opportunity to introduce the moments of teamwork, the usage of brainstorming and to encourage a reflection on the creative process.

This research offers a common means for comprising the creativity in the engineering education, respectively in the engineering study programs. Sometimes, modest results, other times excellent results are due to the inconsistency of the way in which specialty courses are promoting creativity. Professors have different ideas on what creativity means and how it can be evaluated. Creativity is an ability that can be developed, this is the message of the paper. Certainly, as a course, a single discipline, it can’t offer all the creative abilities but the attentive planning on the level of a study course can improve the creative abilities of engineering students.

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