Creativity and its constraints in engineering education

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ABSTRACT: In this article, the authors discuss different opinions associated with creativity. There are various views as to whether constraints aid or harm creativity, including those who view that even the definition of creativity requires constraints. Using evidence, the authors argue that constraints trigger creativity, and examine the influencers of practical creativity in the context of engineering education. It is the authors' opinion that teaching and learning should be done *creatively*, and several practices for creative development are analysed in the context of engineering design courses at the University of Windsor, Windsor, Canada. As a result, not only the student experience is improved, but also the teaching moments become more enjoyable, and will trigger the instructor's enthusiasm in the process. The authors also examine *why* is creativity important to engineering and engineering education, *how* to practice creativity and *what* is the role of constraints on creativity.

INTRODUCTION

Creativity is present in all areas of life, from art and design to technology, science, even modern business. Dr Edward de Bono, a driver of organisational innovation, mentioned that:

> *There is no doubt that creativity is the most important human resource of all. Without creativity, there would be no progress, and we would be forever repeating the same patterns* [1].

Several authors identified two types of creativity: *practical* creativity and *artistic* creativity [2][3]. The later represents another type of value that, as described by Harnad *…has little to do with practicality and perhaps not much more to do with intellectuality* [2]. Most creative activities involving practical creativity take place outside the arts, and lead to new ideas that are useful [4-5].

Creativity, a person's distinguishing characteristic or quality of creating new ideas should be considered as a process and not a product. Pusca and Northwood [6] have provided a comparative analysis for different models of the creative process in individuals working in small groups, and suggested that it is similar to the engineering design process, as shown in Figure 1:

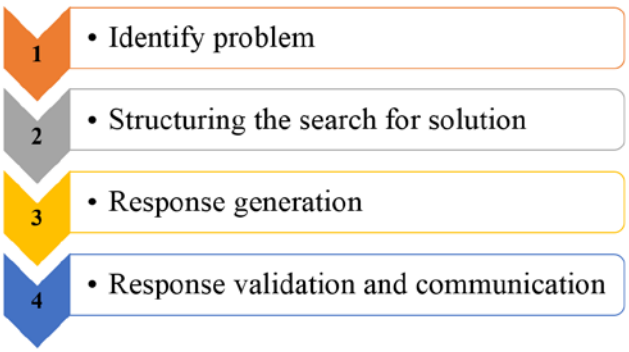

Figure 1: Model of creative process.

In this article, the authors further analyse several characteristics concerning practical creativity, the role of constraints as enablers for creativity, and the *assassins of creativity* as described by Henry in the book *The Accidental Creative* [7].

CONSTRAINTS AND CREATIVITY

There are various views as to whether constraints aid or harm practical creativity [8].There are also those whose view is that *even the definition of creativity requires constraints* [2]. Consistent with prior theory and research, the authors' opinion is that constraints are tools that trigger creativity, but the level of creativity may be influenced by external/contextual factors [6-8]. There are two types of constraints that should be considered as having a substantial impact on practical creativity: person-centred variables/constraints and problem-related constraints. Both types can act as enablers or inhibitors of creativity. These types of constraints are critical in the context of problem solving and practical creativity, where the goal is to find novel solutions for open-ended, complex problems. Research has shown that successful designs are more likely to occur as part of a creative process [6][9].

Person-centred Constraints

According to Harnad, the internal, person-centred variables/constraints relate to how *favoured* a mind is [2]. In their research studies, Dewulf and Baillie [9] identified three internal variables/constraints of creativity in students' learning (Figure 2):

- *Ability to visualise ideas:* i.e. spatially, and able to perform imaginative manipulation.
- *Effective use of memory*: i.e. ability to make connections and associations, based on previous knowledge.
- *Convergent and divergent ways of thinking:* i.e. logical reasoning, analysis to produce one answer, and intuition, imaginative processes to produce alternative solutions.

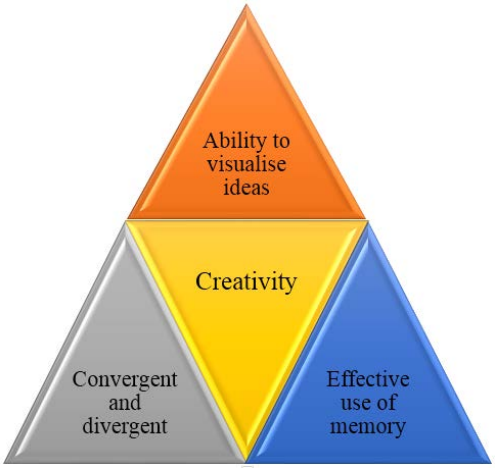

Figure 2: Person-centred constraints.

Based on the information provided by Harnad, it appears that *…the best strategy one can adopt to maximise the likelihood of creativity is to maximise preparation* [2]. Dr Edward de Bono emphasised the role of creative thinking in problem solving:

> *Creative thinking is not a talent, it is a skill that can be learnt. It empowers people by adding strength to their natural abilities which improves teamwork, productivity and where appropriate profits* [1].

Problem-related Constraints

In engineering, to find a creative solution to a problem, the starting point is the problem statement. This must provide both the functional requirements and the constraints associated with the problem to be solved. A problem statement will mention clear project objectives and will cover the 5 *W* questions: *Why? Who? What? When? Where?*, but never the question *How?* [7]. For example, the problem statement should consider *what* the product is supposed to do, but never *how* the design will do it (i.e. excess heat must be dissipated into the ambient air), to leave space for creative solutions. A well-designed functional requirement will never mention the final shape of the product. This will further enable the creative strategy associated with *How?* Functional requirements are in fact the functions that a product needs to provide to meet the customer requirements, written as requirements.

Constraints, as necessary components of the problem statement, are limits on particular attributes or variables. In the engineering design process, design constraints are defined in the initial problem (i.e. the maximum cost of manufacture, maximum weight) and can also be added during the development of a solution. For example, there may be the need to add a design constraint later in the creative design process to come up with a viable solution that meets the desired customer requirements. As a result, the initial problem formulation will be revised to reflect this change. Once a constraint is defined, creative thinking will produce solutions in that context. The types of design constraints normally considered in the engineering design process are shown in Figure 3.

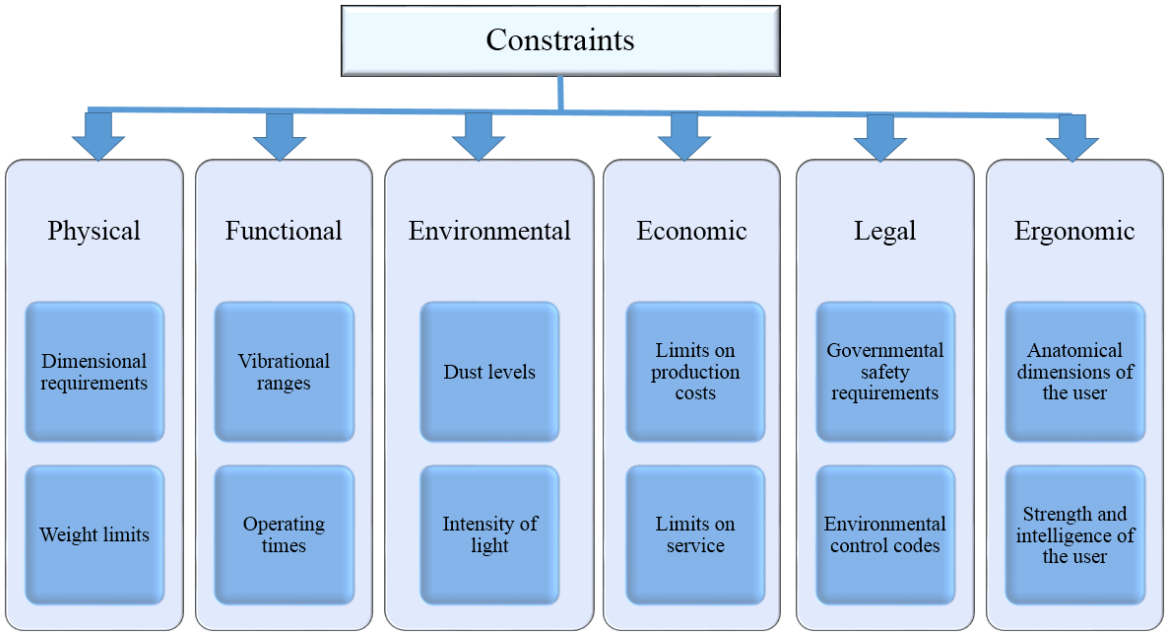

Figure 3: Design constraints as enablers of creativity.

Stokes, in her book *Creativity from Constraints: the Psychology of Breakthrough* [10], mentioned that the success of a design depends on creative choices and suggested some constraints for creativity in architecture including:

- Stylistic constraints: what shape should modern architecture take?
- Functional constraints: the shapes that containers take.

According to the creativity from constraints theory, well-designed constraints improve creativity:

> *While creativity is commonly seen as a product of imagination, widely appreciated results of creativity such as …designs and innovations typically result from a constraints such as culture, influences, schools of thought, schools of art, traditions, methods, techniques and styles. If creativity is free to bend constraints, it rarely works without them altogether* [11].

Factors Affecting Practical Creativity

Some influences can inhibit or even suppress practical creativity. These factors can be directly or indirectly associated with the problem to be solved. Henry analysed the dynamics in a creative workplace and identified *dissonance* as one of the *assassins of the creative process* [7]. He explained that d*issonance* occurs when the *why* of the work does not line-up with the *what* of day-to-day activities. In this case, the *waste* consists in that the mind tries to solve these environmental misalignments in the workplace, and it loses its focus from creative solving activities. The following were identified as sources of dissonance:

- *Unnecessary complexity*: the author mention that this is a form of waste of creative brainpower, since creative energy is consumed toward making the complicated simple, *rather than toward the actual work.*
- *Unclear objectives*: when the problem/project strategy lacks clarity and focus. In this case, the solution is to eliminate things that are getting in the way of clarity and focus, producing dissonance. The proposed solution is to make sure to start with *why*, and that *why* and *what* are aligned. This is achieved by a clear set of project objectives. Once these are established and understood, the work can focus on the creative strategy, by employing creativity thinking to answer the question *how*.

Some other influences or factors, not directly related with the actual problem, may also inhibit or suppress creativity. These include a *lack of respect - specifically for originality, fear of success or failure, red tape, inappropriate norms, feedback, time pressure, competition, and unrealistic expectations* [6][7]. Leslie also argues that technologies, such as computers and the search engine Google, end up limiting curiosity and, as a result, the creativity by giving users what they want [12].

These factors create undesirable tension during the creative process leading to the final solution for the problem. The negative side effects on creativity can be diminished by:

- recognising if there are factors that affect the creativity;
- identify the factors;

- understanding why and how they can derail the creative process;
- learning how to mitigate them by applying principles related to time, focus and group work.

For example, a solution to overcome d*issonance* as a damaging influence on creativity is to implement lean practices [13] in the creative process of problem solving. This will allow making the most of the practical creativity possible. Two of the lean practices that apply in this context are to reduce waste and to sort. First, *reduce waste of creative power*, and as a result waste of time. This can be accomplished by eliminating the *dissonance* between *why* and *what* by eliminating the tendency toward *unnecessary complexity*. Second, *sort* from the first stages of the creative process starting in the problem formulation by eliminating things/requirements that obstruct clarity and focus, and by formulating a *clear set of project objectives.*

The other important aspect of lean, at least in the management sense, is respect for people [4]. The application of lean principles should result in a win-win situation for all involved in the creative process, as a solution to overcome the tensions and/or obstacles that may inhibit or suppress creativity.

THE GOLDEN CIRCLE FOR PRACTICAL CREATIVITY AND ENGINEERING EDUCATION

Using a *naturally occurring pattern* that Simon Sinek calls *The Golden Circle* [14] shown in Figure 4, the authors have adapted it in the context of practical creativity in engineering education:

- *Why* is creativity important to engineering education?
- *How* to practice creativity from constraints in engineering design classes?
- *What* factors affect creativity at the course level in engineering design classes?

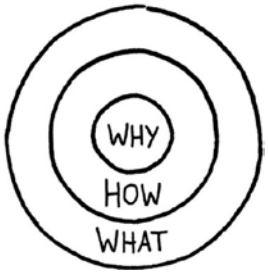

Figure 4: The golden circle.

Why is Creativity Important to Engineering and Engineering Education?

Different studies mentioned that creativity is crucial for designing products and enabling innovation [6][15][16]. In his quest to make higher education *a more creative place* [17], Jackson provides this answer to the question above:

> *We live in a complicated and messy world in which work for most of our graduates is a continuous stream of* problems *that have no simple or unique solutions. Being able to work creatively will help your students survive and thrive in this world and help them lead more satisfying and meaningful lives* [18].

Enabling students to be creative became part of higher education mission. Designing a curriculum to support creativity in student learning is the way forward, and it has been shown that creativity *leads to greater student engagement*, and *better achievement of desired graduate attributes* [19]. It is the authors' opinion that both teaching and learning should be done *creatively*. As a result, student experience is improved and the teaching moments become more enjoyable and trigger the instructor's enthusiasm in the process.

How to Practice Creativity from Constraints in Engineering Design Classes

Since creativity is a skill that can be learnt and is a required learning outcome, it is the instructor's responsibility to design and implement high impact practices as teaching techniques, and to foster a teaching and learning environment that enable the development of the creative minds. This objective was achieved at the University of Windsor in engineering design classes. Some initiatives that were implemented to support creativity in teaching and learning are [6][19]:

- User-centred classroom design that facilitates student engagement and collaboration.
- Students work in group to find solutions for open-ended, complex problems, and are encouraged to implement creativity stimulation techniques.

Instructors, when reflecting on what and how to teach, place equal consideration on teaching creatively and teaching for creativity. Teaching for creativity involves *teaching creatively* and *facilitating other people's creative work* [20].

The instructor provides the students the tools they need to become creative thinkers, and creates an environment that allows for student engagement and creative thinking.

What Affects Creativity at the Course Level?

To answer this, one further analyses the external factors that affect creative personality and, as a result, practical creativity in the engineering design class. It should be mentioned that these factors are not directly related with the actual design problem, but they may inhibit or suppress creativity and, as a result, have an impact on the final solution. The goal is to find solutions to overcome these damaging influences on creativity. Several requirements were considered in order to find an answer for this question; namely, classroom design allows for group work; each group has creative team members and team members with less creative personalities; students are encouraged to applying creative thinking techniques; students are provided with a problem statement, including functional requirements and constraints; graduate assistants have a supervisory role; instructor provided feedback and engages students.

The external factors that affect creative personality were identified and analysed in the context of group work. The students worked in groups of four to five to find solutions for open-ended, complex problems. They need to use their imagination and creativity. It was observed that they have different creative abilities that are more or less developed, based on their natural abilities or previous experiences, as mentioned before. These person-centred constraints may affect their ability to visualise ideas or to recall past experiences and may inhibit their creativity. In this context, it was assumed that in each design team there are creative team members and team members with less creative personalities.

Using Zhou's approach in his study on employees' creativity and the factors affecting the creative personality [21], only the following influences have been analysed in the context of group work in engineering and design classes:

- How *close monitoring* by instructor and/or teaching assistant in the presence of creative team members will affect the level of creativity in some students with less creative personalities?
- How *developmental feedback* provided during the design process in the presence of creative team members will affect the level of creativity in some students with less creative personalities?

As expected, less monitoring and the presence of creative team members enabled the students with less creative personalities to acquire creativity-relevant skills and strategies and maintain their motivation. Observational learning, where the creative team members served as role models was possible, because the students did not worry about doing something their graduate assistant might disapprove of and be distracted with task-irrelevant concerns. There was little external pressure, because the graduate assistants did not micromanage the project groups, and therefore, the less creative members were able to concentrate on the task, and become more creative. This strategy is characterised by freedom of expression and freedom from criticism. These results are consistent with the previous research, indicating that both, strategies and motivation are the key ingredients for creativity [21-23].

The same trend was observed regarding the influence of developmental feedback on creativity. Students with less creative personalities have exhibit greater creativity, if provided with developmental feedback. These informational practices provide students with relevant information regarding their performance, guidelines for further improvements, and there is no pressure for a particular outcome. Encouragement for originality, and as stated by Witt and Beorkrem *…norms in which innovation is praised and failure is not fatal* [24], lead to improvement in their performance, increased their motivation and, as a result, increase their creativity. As mentioned in other studies for students to actually exhibit high level of creativity, they also need to have high level of intrinsic motivation [22][25].

The challenge for the instructor, as a designer and facilitator for creative learning, is to find creativity-enhancing practices. As indicated in the above analysis, both the instructor and the graduate assistants can greatly influence students' creativity by:

- employing strategies that improve creativity;
- finding ways to boost their motivation and, as a result, their creativity.

Sir Ken Robinson emphasised that *good teachers know that their role is to engage and inspire their students* [20]. For engineering design courses, a contextual factor that may have substantial impact on students' creativity is the presence of an instructor as a creative role model, capable to indirectly monitor their progress and provide meaningful feedback on their practical creativity. Albert Einstein is famously quoted as saying:

Creativity is contagious. Pass it on [1].

CONCLUSIONS

In this article, two types of constraints associated with practical creativity are identified; namely, person-centred constraints and problem-related constraints. The authors emphasise on the importance of knowing *why* is important to

identify and use constraints as part of a creative process, *how* to design constraints for creativity, and *what* are the undesirable factors affecting practical creativity. It is also shown *why* creativity is important to engineering education, *how* to practice creativity from constraints in the context of problem-based learning, and *how* to mitigate influences that may inhibit students' creativity in the context of engineering design classes.

The truth is that there is a strong correlation between creativity and constraints, and as Lehrer explained:

> *...the imagination is unleashed by constraints. You break out of the box by stepping into shackles* [26].

In this article, the authors concentrated on practical creativity, but it is equally applicable to artistic creativity. As famously quoted by Orson Welles:

> *The enemy of art is the absence of limitations* [27].

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Creativity in engineering education. M.V. Kuimova1, D.D. Burleigh2, D.A. Rodionov1. 1National Research Tomsk Polytechnic University, Tomsk, Russia.Â clearly understand the problem and its potential impacts. They must have the ability to think. â€œoutside the boxâ€ and to solve problems in creative ways. This paper discusses the importance of teaching and encouraging creativity in. engineering education as well as methods of developing programs to accomplish this. Keywords: creative problem solving; creativity; curiosity; engineering; higher education; innovations, open-mindedness. I never made one of my discoveries through the process of rational thinking.