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Curiosity, creativity and engineering education

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ABSTRACT: It has been stated that the need to know is *an engine of discovery* that motivates humanity to *explore, experiment* and *achieve* (Mario Livio and Robin Tatu). In this article, the authors discuss different opinions and definitions associated with curiosity as the need to know, its relation to creativity and the implication for the models of active learning. The purpose is twofold: 1) to better understand why curiosity, as a powerful human force for intellectual and creative expression, motivates stronger student engagement to find solutions for open-ended, complex problems; and 2) to analyse if curiosity and creativity can be cultivated, supported and encouraged or if they are suppressed by person-centred and context-centred factors or the education system itself. Instructors, when reflecting on what and how we teach, must place equal consideration on teaching creatively and teaching for creativity (Sir Ken Robinson). Case studies discuss the role of curiosity and creativity in engineering design courses at the University of Windsor and the instructor's role in creating an engaging, stimulating teaching and learning environment that encourages curiosity, creativity and intellectual dexterity.

Keywords: Curiosity, creative teaching, teaching for creativity, creative process, motivation, engagement, engineering design

INTRODUCTION

Curiosity and creativity are skills that give academic knowledge its power and usefulness in the real world. These are some of the most valuable skills that engineering graduates should possess as they prepare to enter the global economy. As professionals, they will need to innovate and to find better solutions to diverse problems that exist in our society. According to O'Toole:

> *Curiosity is the force that drives personal development, because thinking through new concepts and ideas is what allows us to mature and to develop more nuanced, open-minded worldviews* [1].

According to Walt Disney, curiosity is the guiding vision in the process of creativity:

> *Around here, however, we don't look backwards for very long. We keep moving forward, opening up new doors and doing new things, because we're curious… and curiosity keeps leading us down new paths* [2].

Different studies confirm the complexity and variability of curiosity [3-7]. At least five different types of curiosity have been described, and the chart in Figure 1 provides an overview of specific characteristics associated with them.

Berlyne, one of the most influential contributors to the theory and research associated with exploratory behaviour, defined perceptual curiosity as …*the curiosity which leads to increased perception of stimuli* [6]. Perceptual curiosity involves interest in, and giving attention to, novel perceptual stimulation, and motivates visual and sensory inspection [5].

Epistemic curiosity was defined by Berlyne as a *drive to know* and is triggered by gaps in knowledge [6], by Leslie as the drive to understand how things work [7], and by Livio as a need to obtain more knowledge [3]. According to Livio, specific curiosity is the need to locate particular information, and diverse curiosity the desire to relieve boredom [3].

Curiosity should be considered as a pre-requisite for creativity, as creative people are curious by default. Like fine red wine, curiosity/creativity is best when decanted - to give enough time to breathe and reflect. There are several quotes regarding creativity. Dr Edward de Bono, a leading authority on conceptual thinking as the driver of organisational innovation, mentioned in regard to creativity 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 [2].

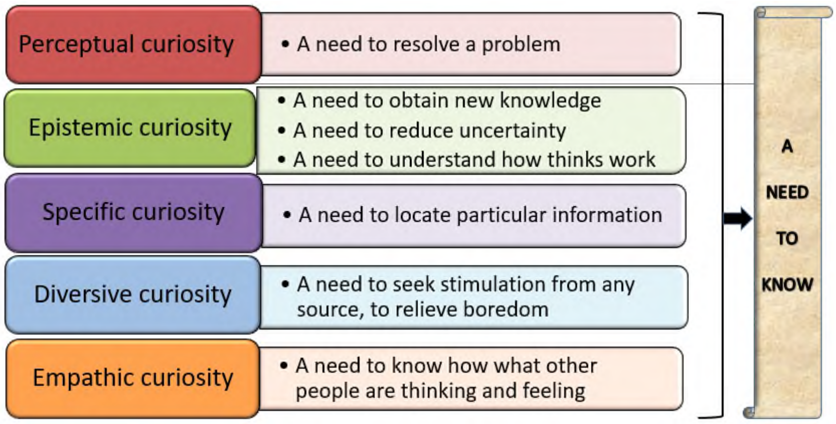

Figure 1: Types of curiosity and their characteristics.

Creativity is related to imagination, it is an act of creating new ideas, new possibilities, so it should be considered a process and not a product. Different studies mentioned that creativity is crucial for designing products and enabling innovation [8][9]. Creativity and innovation encourage a way of thinking. They overlap in the process, and the authors suggest that innovation should be seen as a productive, quantifiable process, with the final result of introducing something new, whereas creativity should be considered as an imaginative process that answers questions on why? what? and how? to innovate. Hunter defines creativity as *the capability or act of conceiving something original or unusual*, while innovation is *the implementation or creation of something new that has realized value to others* [10].

Further analysis identifies the similarities and difference between creativity and innovation. While both are processes, creativity is related to imagination, while innovation is related to implementation of the idea or the product, as shown in the comparison chart between creativity and innovation (Figure 2).

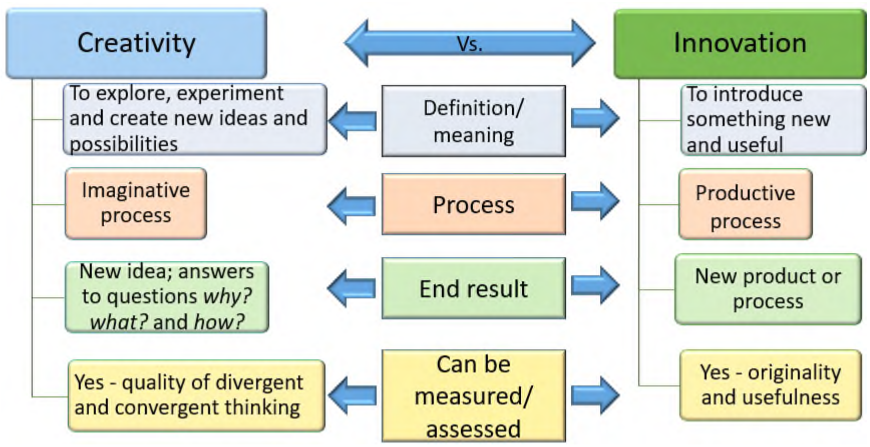

Figure 2: Comparison chart between creativity and innovation.

The creative process has been one of the key topics of creativity research. Table 1 provides a comparative analysis between Guilford's four-stage classic model of the creative process [11][12], and some other proposed models [13-15].

Table 1: Models of creative process.

	Guilford's model [11][12]	Amabile's model [13][14]	Busse and Mansfield's model [15]
1	Preparation	Problem or task identification	Selecting a problem to solve among several possible problems
2	Incubation	Preparation - gathering and reactivating relevant information and resources	Engaging in efforts to solve the problem
3	Illumination	Response generation - seeking and producing potential responses	Setting constraints on the problem solution Changing the constraints and restructuring the problem
4	Verification	Response validation and communication - testing the possible response against criteria	Verifying and elaborating the proposed solution

For a number of researchers, the four-stage model or a variant of it, continues to serve as the basis for understanding the creative process. Some models of the creative process for specific types of work have been formulated. For example, Amabile's model is a version of the basic stage model of the creativity process [13][14]. Based on the outcome of response validation and communication, a final phase of decision making about further work will decide if a successful product/solution was achieved as a result of this process or if there is the need for more iterations. Busse and Mansfield proposed similar stages of the process, with a two-step activity in stage three (Table 1) [15].

These stages describe a creative process in individuals working in small groups and is similar with the stages associated with the engineering design process. It is also important to note that the creative process does not differ if one is either a novice, or expert, in a domain. As in many creative process models framed in terms of problem solving, the term *problem* should be understood as any task that an individual or a group needs to accomplish.

CREATIVITY IN THE CONTEXT OF ENGINEERING DESIGN

As mentioned by Livio [3] and Tatu [4], curiosity motivates engagement and the deep desire to know that further leads individuals to explore, experiment and achieve. Several questions can be asked about the creativity and the creative process:

- Why and how people become curious?
- What are the context-centred variables that may influence the final result?
- What should be the sequence of activities in a creative process that leads to innovation?
- What are the person-centred variables that influence people's creative abilities and what motivates or suppress their interest?
- How can creativity be measured?

Since engineering design thinking is a form of creativity, the authors used information gathered from the first year Engineering Design class at the University of Windsor to help answer these questions.

Why and How People Become Curious?

Curiosity is *inborn* in children and it can be suppressed by the education system. As famously quoted by Albert Einstein:

It is a miracle that curiosity survives formal education [2].

O'Toole implies that you can teach *curiosity* [1]. Where in formal educational syllabi does it say that promoting wonder is an objective? And yet wonder seems like a key ingredient to learning, growing and loving. A key ingredient of being human. The instructor's role is to find ways to encourage and develop curiosity in students, because without curiosity creativity will never follow. Adler states that regardless of age, IQ or talent, anyone can become more creative [16]. Albert Einstein recognised this when he stated that:

I have no special talent. I am only passionately curious [2].

Sir Ken Robinson emphasised that *good teachers know that their role is to engage and inspire their students* [17]. To stimulate learner's interest, the Engineering Design course was planned both to create an environment of active learning and continuous engagement, and to facilitate student motivation, curiosity and desire to know [18].

The challenge for the instructor, as a designer and facilitator for creative learning, was to find ways to engage students and encourage them to be active and independent learners in the context of problem-based and project-based teaching and learning, and also to help them achieve the desired learning outcomes and skills. As noted by Northwood et al in their paper on PBL:

> *PBL emphasizes learning instead of teaching. Learning is not like pouring water into a glass; learning is an active process of investigation and creation based on learners' interest, curiosity and experiences, and should result in expanded insights, knowledge and skills* [19].

Instructors, when reflecting on what and how we teach, must place equal consideration on teaching creatively and teaching for creativity. Teaching for creativity involves *teaching creatively* and *facilitating other people's creative work* [17]. The why, what and how of teaching were examined by the authors [20] and, as a result, different creative strategies to support a transformative learning process and student engagement were identified, for example [21][22]:

- Active learning and students' engagement through hands-on activities, where students are required to use the same digital tools as practicing engineers, to create virtual or physical models.
- Working in groups to find solutions for open-ended, complex problems, so that students need to use their imagination and creativity to explore different possibilities.

What are the Context-Centred Variables that may Influence the Final Result?

Context-centred variables that may influence creativity include learning outcomes, classroom design, time pressure and competition. In regard to learning outcomes for the Engineering Design class, these were designed to address a wide range of skills and graduate attributes including creativity, problem-solving, critical thinking, interpersonal and communication.

It has been shown that there are pros and cons with regard to the adoption of learning outcomes [23][24]. By implementing the learning outcomes, students have a clear statement of what they need to achieve [24], but some authors, notably Furedi, argue that it does not engage the learner and it kills originality and creativity [23]. Furedi goes as far as to describe learning outcomes as corrosive [23]. Northwood, however, argues that:

> *Furedi's solution, i.e. eliminate learning outcomes is somewhat dramatic. It appears to ignore the value that learning outcomes have been shown to bring to curriculum development, to a learner-centred university where students know better what they are expected to learn* [24].

In an effort to address the need for student-centred approaches and to improve teaching and learning in the context of outcome-based curriculum in engineering design classes, a *backward design* approach was considered and implemented [22].

As a result, learning outcomes were identified first, the evidence of how achievement of the results will be assessed was determined second and, finally, the learning activities and instruction methods were planned, with the main priority being the students' engagement through active learning. It was noted that *the outcome must resonate with the learner: a lot of time is spent on wordsmithing outcomes that mean almost nothing to the learner* [24].

How can one ensure that originality and creativity are not killed in the context of outcome-based curriculum? Several initiatives have been implemented to address student engagement through active learning and as a result to support creativity and the creative process. These initiatives include:

- The classroom design was changed from the traditional design to a new, user-centred design (Figure 3), which facilitates student engagement, collaborations, and active learning through problem-based and project-based assignments.
- Students work in groups and are encouraged to develop personal, teamwork, leadership and task completion skills. This environment facilitates competition, and encourages the design based on creativity stimulation techniques like brainstorming, analogy, bionics, using product attributes or trigger questions: why? what? when? and how?
- The concept of flipped teaching was implemented to overcome the issue with the time constrains. In this manner, the instructor will free up more of class time to engage students in active learning [25][26]. Students are using class time to deepen their understanding and improve their skills.

Figure 3: Class design for active learning [22].

What Should be the Sequence of Activities in a Creative Process that Leads to Innovation?

For the development of students' problem-solving skills, critical thinking skills and curiosity, problem-based and project-based teaching and learning are used as inductive methods to address all aspects of the engineering design process. Figure 4 is a schematic representation of the iterative problem-solving process as a design thinking paradigm.

As argued by different authors, the design thinking paradigm is an *effective problem-solving method* [26-28] and it is employed by the students to find novel solutions for open-ended problems. Students use creativity stimulation techniques like brainstorming, analogy and morphological charts [27] and through divergent thinking generate multiple solutions for the problem. Evaluation of these ideas using a decision matrix [28] will lead to one solution - convergent thinking - that will be further analysed and tested. If the solution is not successful, the problem needs to be reformulated and the process repeated.

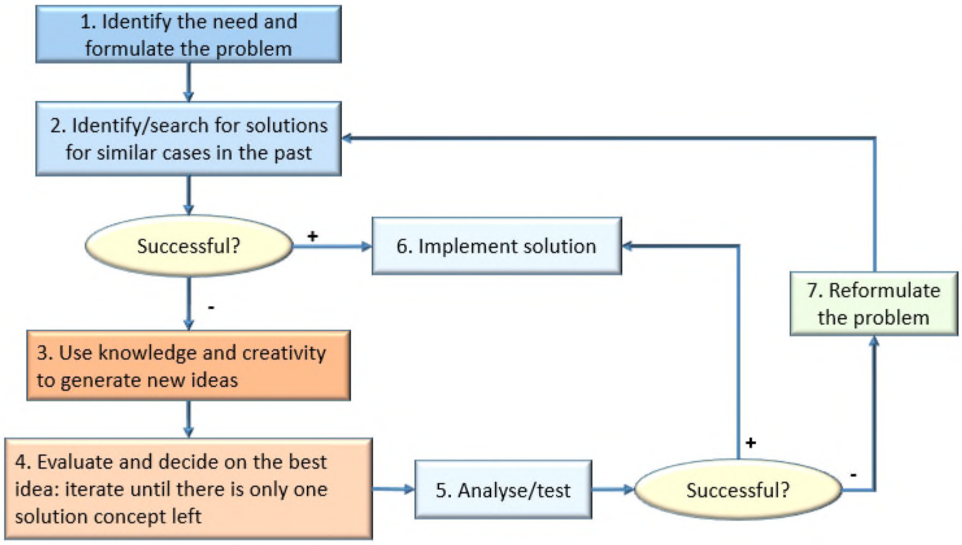

Figure 4: Iterative problem-solving process in engineering design [26].

What Are the Person-Centred Variables that Influence People's Creative Abilities and what Motivates or Suppress their Interest?

A student's level of perseverance and curiosity will have an impact on the creative process. Engagement and active learning, participation in brainstorming sessions and encouraging wild ideas may enhance curiosity and the desire to use of certain creative processes as the engine towards a design solution. Other factors that may have a positive effect on creativity are freedom of expression, encouragement for originality, freedom from criticism, and as stated by Witt and Beorkrem *…norms in which innovation is prized and failure is not fatal* [29].

Some influences can also inhibit or suppress creativity. These include a lack of respect - specifically for originality, red tape, constraints in the problem formulation, inappropriate norms, feedback, time pressure, competition and unrealistic expectations. Leslie argues that technologies - such as computers and the search engine Google - end up limiting curiosity by giving users what they want [7].

How can Creativity be Measured?

Based on a list of high-impact activities as they apply to Engineering Design [30], and in the context of an outcome-based curriculum, from the multitude of approaches selected as class activities, a selection is presented in Table 2 to include only what has been mapped against creativity as desired learning outcomes and the corresponding assessment tools.

Table 2: High-impact practices related to design thinking and creativity.

	High impact practices	Implemented activity in engineering design	Learning outcome	Assessment method
1	Common intellectual experiences	• Open-ended design projects	- Design - Creativity - Critical thinking - Problem solving skills - Analysis and synthesis	Design portfolio
2	Learning communities	• Project-based learning approach	- Problem solving skills - Creativity - Teamwork	Design portfolio
3	Service learning/ community-based learning	• Project-based learning approach	- Problem solving skills - Creativity - Design - Teamwork	Design portfolio
4	e-Portfolios	• Creating a digital presentation • Retrospective reflection	- Communications skills - Creativity - Analysis and synthesis	e-Portfolio

In the context of problem-based teaching and learning, the assessment of students' creativity is based on their design portfolio. Problem identification and formulation, problem solving using creativity stimulation techniques and divergent and convergent thinking, were considered in the assessment of students learning outcomes.

A directed project-based learning approach was introduced, and the lectures were replaced by problem-oriented tutorials. Students worked in groups of five to six students to solve open-ended design problems through research, discussion, sketches and graphical communication. These activities are aimed at integrating knowledge regarding informational retrieval techniques, needs validation, problem identification and formulation, analysis of problem, and problem-solving techniques. Furthermore, the engaging environment and class design are factors that facilitate curiosity and creativity, encourages divergent thinking, allowing students to brainstorm different solutions for the design problem. They communicate their ideas through ideation sketches. To decide on the final solution, each team performed convergent thinking. After elaboration, the creative output was communicated using graphical communication techniques.

According to Charyton et al design is creative, consumes resources (information, material, energy), has a purpose, and therefore, can be assessed and evaluated [31]. Torrance used Guilford's four divergent thinking factors [32] and established them as criteria for measuring creative thinking and for evaluating the quality of creative output. The four factors in the Torrance test of creative thinking (TTCT) are fluency, flexibility, originality and elaboration [33]. These factors can be defined as follows:

- Fluency - the ability to generate quantities of ideas.
- Flexibility - the ability to create different categories of ideas and to perceive an idea from different points of view.
- Originality - the ability to generate new and unique ideas.
- Elaboration - the ability to expand on an idea.

CONCLUDING REMARKS

The instructor's role is to find the appropriate tools and methods not only to motivate students' learning and engage them in the learning process, but also to help them achieve the desired skills. This is done by creating an environment that encourages and motivates students' engagement and creativity. High impact practices and the corresponding models of active learning that foster creativity in Engineering Design course were identified, and the authors have discussed the assessment methods as they relate to creativity.

It has been demonstrated that creativity is a process that can be taught, encouraged and enhanced, in the context of engineering accreditation requirements. It was also mentioned that there are person-centred variables that can inhibit or suppress creativity or context-centred variables that may also influence creativity and as a result the design solution.

The truth is that the students need to learn the value of *knowing* and to have the desire to know more. The French poet and novelist Anatole France explained the instructor's role in this process:

> *The whole art of teaching is only the art of awakening the natural curiosity of young minds for the purpose of satisfying it afterwards* [34].

Anatole France is also famously quoted as saying:

Nine tenths of education is encouragement [34].

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BIOGRAPHIES

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