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Engineering students' use of creativity and development tools in conceptual product design: What, when and how?

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ABSTRACT

As creativity has become a requisite skill for engineers and a part of their basic training, one of the challenges in engineering education is to supply students with a good understanding of creativity and development tools. The aim of this study was to assess the effectiveness of these tools during a conceptual product design challenge. Students were introduced to creativity and development techniques and were provided the opportunity to choose and apply various methods during a hands-on project over 10 sessions distributed over 8 weeks. The analysis of the workbook used to record their progress showed individual differences in the creative process stages and performance as well as the nature of the tools used, when these tools were applied, and their effectiveness. The most creative students (C+) came up with original unique concepts, employed significantly more tools than the less creative ones (C−) and sustained their effort to find ideas up to the very end of the project. Most students who used Analogies, Personas, mind mapping, purge, and/or reverse brainstorming produced unique ideas, a variety of concepts as well as technological innovations. Structured and rational methods, such as functional analysis were used by both groups C+ and C−. This structured approach resulted in a mere reformulation of the specifications' brief that helped students to clarify the problem and to better understand the functions and the constraints and they felt "ready to get started". As it was observed with TRIZ, FAST, SADT, APTE and IRAD, the majority (78%) of the students who applied functional analysis did not come up with any unique or original kitchen concepts. The findings are discussed in relation to the effectiveness of the creativity training to improve the students' confidence in their creative potential, as well as the fit between the tools used and (a) the conceptual design challenge, (b) the phase of the creative process, and (c) individual preferences such as the need for structure and closure.

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1. Introduction

According to Daniel Pink, author of *A Whole New Mind* (2004, p. 2), "we are moving from an economy and a society built on the logical, linear, computer-like capabilities of the Information Age to an economy and a society built on the inventive, empathic, big-picture capabilities of what's rising in its place, the Conceptual Age". As creativity becomes a competitive advantage which can differentiate commodities in "The Conceptual Age", organisations have adopted diverse strategies to be creative and innovate. Some of them outsource their creative tasks or rely on consultants to assist them with their creative endeavour wheras others use techniques such as Brainstorming (Osborn, 1993), TRIZ (Russian acronym for Theory of Inventive Problem Solving, Altshuller, 1996) and CPS (Creative Problem Solving, ; Isaksen & Treffinger, 1987; Treffinger, 1995) to train the workforce to enhance their creative and innovative capabilities (Burroughs, Dahl, Page Moreau, Chattopadhyay, & Gorn, 2011). Although the products that engineers develop are fundamentally technical in nature and rooted in mechanical, electronic and classical engineering, a growing number of managers, practitioners and teachers in engineering design are integrating design thinking to stimulate innovation (Brown & Katz, 2011; Dym, Agogino, Eris, Frey, & Leifer, 2005; Norman & Verganti, 2012; Patnaik & Mortensen, 2009; Seidel & Fixon, 2013; Selig, 2012).

Creativity involves ultimately the production of original, potentially workable, ideas to solve a problem. The creative process which is the sequence of thoughts and actions that leads to a novel, adaptive production (Farid, El-Sharkawy, & Austin, 1993; Osborn 1993; Torrance, 1963), involves various intellectual abilities a) identifying, defining and redefining problems; b) selectively encoding different aspects of the environment relevant for the creative task; c) using analogies, metaphors and selective comparisons to establish links between different domains; d) selectively combining elements to come up with new ideas; e) generating multiple solutions with the help of divergent thinking; f) auto-evaluating or monitoring one's progress; and g) abandoning, if needed, an initial idea to explore new directions (Lubart & Mouchiroud, 2003; Lubart, 2001). The creative endeavour requires continuous effort and could be discouragingly slow with uncertain outcomes (Bandura, 1997). According to the multivariate approach, resources for the creative process are a combination of specific aspects of intelligence, knowledge, cognitive styles, personality, motivation, affect, and physical and sociocultural environmental contexts (Lubart, Mouchiroud, Tordjman & Zenasni, 2015; Lubart, Zenasni, & Barbot, 2013; Sternberg & Lubart, 1995). One of the mechanisms through which these factors might promote creativity is self-efficacy, which is "the belief one has the ability to produce creative outcomes" (Tierney & Farmer, 2002, p. 1138). Creative self-efficacy is a significant predictor of idea generation and creative performance and it is best achieved through training in cognitive strategies for thinking creatively (Gist, 1989; Locke, Frederick, Lee, & Bobko, 1984; Mathisen and Bronnick, 2009). "By demonstrating the effectiveness of various strategies for performing creative tasks, cognitive training, may, through feelings of efficacy, motivate creative efforts" (Scott, Leritz, & Mumford, 2004, p 383).

Reviewing and summarising 45 years of teaching 'Engineering Design and Product Development' at the Technical University of Denmark, Andreasen (2011 p. 313) stressed that engineering education institutions must prepare students for industrial work and train their "abilities of imagination, awareness, ideation and foreseeing". Product design is, by nature, a profoundly creative process and the difficulties in the design approach concern the choice, the use and the organization of different tools. To face different kinds of innovation projects, engineers are usually taught basic methodologies in order to customize and optimize the process of product design and development. Training engineering students' creativity is a long-standing, but still topical, concern (Daly, Mosyjowski & Seifert, 2014). The first approach that was adopted in engineering curricula was to include creativity exercises, such as brainstorming, morphological analysis or random simulation (Felder, 1987, 1988). Project-based learning, in particular case studies, are also widely promoted to increase critical thinking and creative attitudes (Stouffer, Russell & Oliva, 2004; Zhou, Kolmos & Nielsen, 2012). The educational environment instigated through teachers' attitudes, should also be conducive to fostering creativity: this includes the acceptance of ambiguity and risk taking, viewing failure as an opportunity to learn, or the habit to search for multiple answers, beyond a correct one (Cropley, 2015; Kazerounian & Foley, 2007). Such a creative mindset can be supported by modular computer programming languages and modular building platforms using for example LEGO (Danahy et al., 2014) or multimedia tools (Klemeš, Kravanja, Varbanov & Lam, 2013).

Universities are increasingly expected to implement programs that foster and nurture creative problem solving in engineering students to meet business demands (Baillie, 2002; Barrett, 2013; Jackson, Oliver, Shaw, & Wisdom, 2006). One of the major barriers facing teachers is the need to develop new skills to engage in a creative pedagogical approach as well as the lack of explicit guidelines to help incorporate creativity in the curriculum and assess the effectiveness and the impact of training (Puccio, Firestien, Coyle, & Masucci, 2006; Spencer, Lucas, & Claxton, 2012; Wood & Bilsborow, 2014). Smith (1998, p111) identified 172 idea-generation methods reported in the literature ranging from simple questions like the "What if. . ." to more elaborate methodologies like Synectics. To our knowledge, there is a lack of research regarding how engineering students choose, use and organise different tools during a long creativity project. Over the last decades, several creativity training programs have been proposed in many forms with various contents and methods of delivery. Their effectiveness was questioned by some scholars due to external and internal validity concerns (for a discussion of the effectiveness of creativity trainings see Scott et al., 2004).

This study aims to address some of these challenges by introducing engineering students to creativity and development techniques and assessing their choices of the appropriate tools and the effectiveness in the use of these tools during a hands-on 10-session project distributed over 8 weeks. The training was based on a global approach to product design, named New Product Design (Aoussat, Christofol, & Le Coq, 2000). It provides a rich design and development toolkit divided into four stages applicable once the need has been identified through prototype construction. For clarity's sake, we present these methodologies as a sequential process of the New Product Design process, knowing that each method can be extracted and used independently from the others.

The first stage, *Translation of needs,* aims to define functional specifications of the future product to design. This stage involves methods and tools allowing individuals or teams to understand better the users, the market, and competitors' products. They include surveys, technological watch, trends analysis, field observations and user studies. Some communication tools exist to share the results of these studies, for example product mappings and inspiration boards to illustrate the state of the art and capture design trends (Bouchard, Christophol, Roussel, & Aoussat, 1999), or Personas, to represent archetypes of customer segments (Pruitt & Adlin, 2006). The data collected is synthesized through value/function analysis, which results in a list of functional specifications, associated with key performance indicators and target values to be achieved by the future product.

The second stage, *Interpretation of needs*, draws on the results of the first stage to search for new concepts and new solutions that will meet function specification and key performance indicators. This is the main creative stage of the process. To conduct it successfully, the engineer's toolbox includes basic creativity techniques such as Brainstorming (Osborn, 1993) and its variants, brain purge, analogies, or problem reversals (Van Gundy, 2005), mind-mapping (Buzan, 1991), etc. Engineers are accustomed to collective creativity sessions in order to maximize divergent thinking through multidisciplinary teams and, when possible, integration of users in the session. The creative phase results in a multiplicity of ideas and concepts that are then sorted and ranked using multi-criteria matrices, which include the key performance indicators from function specification. More specific creativity methods, such as those from the TRIZ framework (Altshuller, 1996; Savransky, 2000), can also be used to model technical/physical problems and find inventive solutions. The second stage ends when a satisfactory concept is selected by the project team to serve as a basis for the new product.

The third stage, *Product definition*, is dedicated to detailed design and materialization of the concept: product architecture, which is sometimes modelled using SADT (Structured Analysis and Design Technique) and/or FAST diagrams (Function Analysis System Technique), choice of technical components and materials, mock-up design, product-process link, Computer-Assisted Design, etc. Intermediate user tests can be conducted on representations of the product concept (3D picture, high- or low-fidelity mock-up, storyboard. . .). Finally, the product solution, the associated processes and production means can be assessed through FMECA (Failure Mode, Effects, and Critically Analysis).

The final stage, *Product validation*, aims to validate product design by (1) building an industrially reproducible prototype and (2) having it user-tested.

The students' learning and integration of these methods were evaluated in a hands-on project designed by the teaching team. The project involved the selection and the implementation of the appropriate tools to solve creatively a product design challenge. The aim of this study was to analyse the techniques and strategies that students used at each stage of the creative process and how successful or unsuccessful they were at using them. The project was appropriate for the product design process and provided students with practice in applying diverse strategies and tools. The learning-based project is considered as one of the more effective ways for students to learn by active experiencing (Dym, Agogino, Eris, Frey, & Leifer, 2005; Scott, Leritz, & Mumford, 2004). Although the students are used to solving engineering problems in teams, they were asked to work independently in order to assess their spontaneous personal strategies.

2. Method

2.1. Participants and procedure

The sample included 27 French postgraduate engineering students (4 females and 23 males, mean age = 23.2 years ± 1) in their fifth year at an engineering school (Ecole Nationale Supérieure d'Arts et Métiers). They were introduced to creativity and development techniques through a 150-h program named "Product Engineering" and structured in accordance with the abovementioned New Product Design process (Aoussat et al., 2000). Students had 10 sessions distributed over 8 weeks to propose six different layouts for a functional kitchen located in a campervan. From these, two concerned short-term implementation (<1year), two for medium-term and two for long-term (>10years). The layouts had to respect a set of 16 technical and functional constraints, defined in advance in the specification brief. The 27 students produced a total of 162 layouts for a campervan kitchen.

2.2. Material

To assess the dynamics of the creative process, students were asked to complete a workbook. At each session, they completed four pages, two during the creative session and two pages at the end of each session. The first two pages consisted of an open part (blank pages) in which participants were invited to record their progress, describe their approach and the development and creativity techniques used, make free comments and produce drawings and sketches for different stages of the project. The third page included a set of open-ended questions related to their goals and actions during the session (e.g. What were your goals and plans for this session? What have you done exactly during this session? How do you feel about the advance of your project?). In the fourth page, a checkbox question allowed the participants to select (tick a box) the stages that correspond to their creative approach and problem solving among thirteen stages. These items represent different cognitive phases involved the creative problem-solving approach. A highly selected stage indicated that the participants employed that particular resource frequently. The following thirteen stages and their definitions were considered in the workbook: (1) *definition of the problem*—to focus, to explore the theme, the aims, need to create, need to express, challenge; (2) *questionning*—to ask, to interact with the work, understand; (3) *documentation*—to capture and search for information, to be attentive, to always have the project in mind, to store information, to accumulate, to be impregnated, receptive, available, to observe, to show sensitivity and awareness; (4) *consideration of the constraints*—to define constraints, to identify a customer's request, to set constraints for oneself and define one's rules and freedom; (5) *insight*—to have an idea, to experience the emergence, the sudden appearance of an idea; (6) *association*, *associative thinking*—resonance, to play with forms, materials and significations, imagination, daydream, analogy; (7) *experimentation*, *exploration,*—to try, modify, manipulate, and test; (8) *assessment*—to be self-critical, to stand back, to analyse, reflect, check the quality of a result; (9) *convergent thinking*, *structuration*—to crystallize, to make a prototype, to visualize and structure, to establish order, sequences, to control and organize; (10) *benefit from chance*—the luck of the environment, aleatory processes, be open to chance, to take a walk, to accept accidents and chaos; (11) *implementation*—to transpose, make, illustrate, produce, compose, give shape, apply; (12) *finalization*, *ending*—to edit, develop, complete, justify, explain one's work, exhibit; and (13) *break*—to rest, to digest an idea, to let time pass, to do something else.

This repeated measures methodology was previously tested in research on emotions (Botella et al., 2013; Diener, Smith, & Fujita, 1995; Vansteelandt, Mechelen, & Nezlek, 2005; Zelenski & Larsen, 2000).

2.3. Evaluation of creative performance

A jury of five teachers from the engineering school judged independently the overall creativity level of the students' proposals based on their subjective evaluation using a 7-point Likert scale from 1 (not at all creative) to 7 (extremely creative). The judges received the proposals to be evaluated in random shuffled order: division of the original proposals in 3 sets and rearrangement of the proposals in systematic way so as to occupy different positions. They had no information about the students and no access to the workbooks. The agreement between the jury members was 0.80, which is very satisfactory.

In-depth analysis of the 162 kitchen proposals was conducted based on 4 criteria: originality or uniqueness, flexibility or variety, elaboration and technological innovation. An original kitchen concept was unique, surprising, distinct from the obvious and commonplace. The focus was on the uniqueness of the concept, e.g., proposed by only one student. Flexibility or variety refers to the number of different kitchen concepts proposed (e.g., at least two different concepts among the six designed kitchen). Elaboration measures the amount of detail associated with each kitchen idea. Elaboration has more to do with focussing on each solution/idea and developing it further and adding details. Innovative technologies included green energy, smart or connected kitchen etc.

The workbooks were analysed as well in order to assess the creative process stages and the creativity and design techniques used by the participants. The workbook proved to be very useful to understand the students' creative process. Ideas could emerge at any time and place; they were captured in the workbook and then were developed during the work session.

3. Results

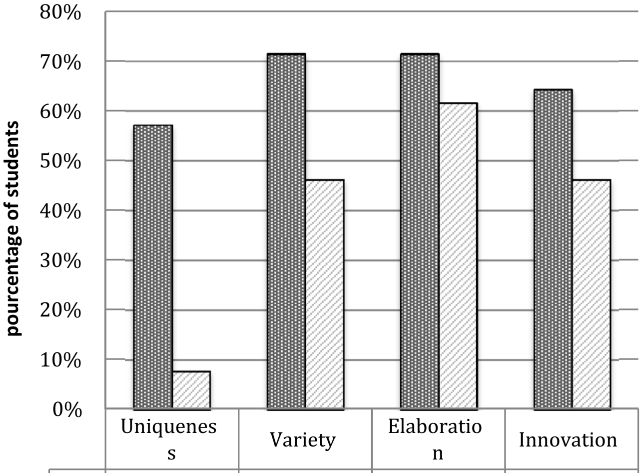
All students managed to produce six proposals for an integrated kitchen in a campervan. The workbook analysis revealed that the most common aspects considered by students were the reduction of the cost and the size of the kitchens, the spatial position inside the car, the kinds of use (outside and/or inside the car, while driving), the modularity (functional cube units as basis of design), practicality (easy to store, deploy and to carry), and technological innovations (energy production, water and waste recycling. . .).

Some students did not integrate the output of their creative sessions into the final designs that the jury evaluated. Therefore, there was a gap between the quality of their approach described in the workbook and the jury mark of the final proposals. In addition, as presented below, some creativity and development techniques were not very well mastered by students leading to a poor execution and weak benefits. In other cases, the chosen creativity tool was not adequate with respect to the aim of the assignment.

3.1. Output and creative performance

The layouts produced were more or less creative. The mean jury creativity mark was 4 ± 1.6 with a maximum of 6.2 and a minimum of 2 (1: not at all creative to 7: extremely creative). To investigate inter-individual differences, the sample was divided in two groups, C+ and C−, respectively above or below the mean (4 ± 1.6). Fourteen students obtained a creativity mark above the average (labelled C+) and thirteen below the average (labelled C−). The participants were attributed an alphanumeric code according to their rank: S1 for the student with the highest average jury mark (6.2 ± 0.8) and S27 for the lowest score (2 ± 1.4).

The most creative students came up with original unique concepts of kitchens, different from a classic home kitchen, which could allow new experiences for the user such as, an all-weather kitchen, inflatable or ecological kitchen, remote control food cooking using smartphones, dehydrated food, magnetic levitating, modular kitchen, smart or connected kitchen, e.g.,



	Uniqueness	Variety	Elaboration	Innovation
C+	57%	71%	71%	64%
C-	8%	46%	62%	46%

Fig. 1. Percentages of students who produced solutions that satisfy at least one of the four creativity criteria: originality or uniqueness, flexibility or variety, elaboration and technological innovation. C+ and C−: creativity mark respectively above and below the average.

touch screen, electronic recipes, automated food preparation according the weather and the journey information as well as the available ingredients, and so on.

In addition, the kitchen layouts were analysed in order to determine whether they were original, elaborated, diversified and innovative (yes or no scale). Among the 27 students, 9 produced at least one "unique" concept, 16 proposed a variety of alternatives, 18 produced elaborate proposals and 15 introduced a technological innovation. Two students satisfied the four above criteria and achieved high creative performance (Jury average mark: 6.2 ± 0.8 (S1) and 5.4 ± 0.5 (S4)). The only student who did not meet any of the four criteria was in the bottom three with an average creativity mark of 2.2 ± 1.3 (S25). The differences between C+ and C− are outlined in Fig. 1. As expected, C+ students produced more solutions that were diverse, technologically innovative and elaborate than C− students. However, the most striking difference was related to the uniqueness of their outcome: Only one C− student (8%) produced a unique solution whereas nine C+ students (57%) came up with at least one unique solution. Indeed, the most creative student (S1) produced 4 original or "unique" kitchen concepts. Several students commented on their struggle to come up with long term innovative solutions as suggested below: "I have been perhaps too much influenced and constrained by the discovery of existing kitchen models. Some of my ideas are perhaps too similar to these concepts. I had an enormous difficulty to imagine things for a distant future. I should perhaps read/watch more science fiction" S11. "I have difficulties projecting myself into the future" S24. "This project is too long, the same ideas came over and over" S22.

How can these such differences be explained? A part of the answer might be linked to the creative process and the techniques used by the participants to develop their proposals.

3.2. Creative stages and strategies

The workbook completed by students over 10 sessions revealed the "path" followed by each student to complete the task and solve the problem. The five most common stages mentioned by students were: consideration of the constraints, association, insight, assessment, convergent thinking/structuration (Table 1). As expected, 78% of them initiated the creative process by the definition of the problem (e.g., focusing, exploring the theme and aims, responding to challenge). The majority (68%) finished the creative process by the "finalization" stage (e.g., editing, developing, completing, justifying, explaining one's work). Indeed, during the five first sessions, students spent more time defining and questioning the problem, collecting information and managing constraints. They all started by reading the brief specifications several times and searching the web for information about existing models of campervans and kitchens for small flats, trains, planes, space shuttles. The last five sessions were devoted to finalization, convergent and associative thinking, implementation, and benefitting from hazard.

The differences between highly and moderately creative students, C+ and C−, were observed mainly during the last five sessions (Table 1). Indeed, in comparison to the less creative students, those deemed very creative were more likely to have "Illuminate, evaluate, associate, experiment and implement", Whereas the less creative participants (C−) continued to "Question, converge, and consider constraints". As suggested in the following comments, C+ students continued the effort

Table 1
Frequency of the creative stages. N: number of citations over the 10 sessions. C+ and C−: creativity mark respectively above and below the average. Differences between C+ and C− are in bold.

		Sessions 1–5		Sessions 6–10	
	n	C+	C−	C+	C−
Association	131	39%	36%	**69%**	**54%**
Consideration of the constraints	128	61%	69%	**29%**	**37%**
Illumination	118	40%	47%	**59%**	**32%**
Evaluation	108	34%	42%	**54%**	**32%**
Convergent thinking	95	20%	41%	**37%**	**48%**
Documentation	90	50%	49%	19%	20%
Question	90	41%	56%	14%	28%
Implementation	86	16%	24%	**54%**	**35%**
Experimentation	78	23%	27%	**43%**	**25%**
Hazard benefit	72	23%	19%	29%	38%
Definition of the problem	60	39%	34%	13%	6%
Finalization	51	7%	8%	24%	37%
Break	45	20%	17%	17%	14%

of finding new ideas, were worried about not being able to finish the assignment on time and were sometimes surprised by their own creativity:

> "I feel I still have lot of work to do". S6 (Comment made at the 7th session). "I am so happy, I managed to finish on time" S5 (Comment made at the 10th session). "I am very excited: many ideas are emerging. . . I needed to write them down to avoid forgetting them (for more information see my 'creativity box' on the opposite page). I'm satisfied: I did not think I could have been able to imagine such things. S1 (Comments between the 4th and the 10th sessions"

In contrast, some C− students complained about the structure of the exercise that required them to work over 10 sessions arguing that it was too long, that they found their six solutions early in the process and felt forced to continue filling the workbook trying to think of ways to optimise their solutions:

> "It was difficult to complete the process in 10 sessions. I could have stopped earlier. It would be better to able to stop when the project development is finished and not when the 10 sessions are over" S27. "Having to complete this workbook helped me to structure my ideas, to have steady and continuous work and to keep track of what I did. However, filling all these pages and imposing ten sessions was discouraging· · ·Creativity is also freedom" S25

These last comments may suggest that the C− students were not motivated to complete the assignment. Paradoxically, S25 and S27 completed each page of the workbook in structured, consistent, neat and thorough way investing lot of time and energy.

The analysis of the open comments in the workbooks suggested that some C+ students sought to "summarize" the specification brief's constraints in terms of key limitations to take into account and seemed to have forgotten about several other constraints. They showed a flexible and even a bold attitude towards the constraints and did not hesitate to criticize, reinterpret, reformulate and even circumvent some constraints as suggested below:

> "After reading several times the specification brief, I realise that the technical and functional constraints fixed in advance are not very limiting as it might initially seems. . .to reformulate, there is no indication about the exact location of the kitchen or the type of use, there is no cost limit, no imposed energy source, . . ."S1

In contrast, C− students were continually preoccupied by constraints such as the size of the campervan trunk, the weight and the volume of the kitchen, energy issues, etc. More importantly, they generated new constraints in addition to the 16 in the specifications brief and tried to find solutions that were feasible within these constraints.

> "Now that I have listed the technological solutions that fulfil the system functions, I am orienting my analysis towards the identification of the constraints that I need to take into account during other phases such as the assembly phase, maintenance. . ." S25

3.4. *Creativity and development techniques: what, when and how?*

The analysis of the open self-report part of the workbook, in which the participants recorded their progress allowed the following questions to be examined: what is the nature of the tools used by the students (Table 2)? When were these tools applied (Table 3, Fig. 2)? and how effective were they (Table 4)?

Regarding the **'what'** or the nature of the tools used by students, Table 2 shows that the students chose to apply 13 tools to solve problems and generate ideas: brainstorming, reverse brainstorming, mind mapping, analogies, TRIZ, IRAD (Innovative Risk Assessment Design), Purge or "Mind dump", Personas, FAST diagram (Function Analysis System Technique), SADT

Table 2
Creativity and development techniques used by both groups, C+ an C−.

	Number of students			Frequency of use		
	C+ (n = 14)	C− (n = 13)	Total	C+ (n = 14)	C− (n = 13)	total
Brainstorming	14	13	27	51	44	95
Analogies	11	4	15	30	5	35
APTE	7	4	11	7	4	11
Bull chart	7	4	11	7	4	11
Octopus diagram	6	3	9	6	4	10
TRIZ	2	2	4	3	3	6
Mindmapping	3		3	5		5
Personas	4	2	6	8	3	11
Reverse brainstorming	2		2	2		2
FAST		1	1		3	3
Purge	1		1	1		1
SADT Analysis	1		1	1		1
IRAD		1	1		1	1
Total	58 (4.14)	34 (2.61)	92	121	71	192

Table 3
Temporal presentation of the methods used throughout the 10 sessions by both groups C+ and C−.

		Sessions 1–10										Total
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
Brainstorming	**C+**	**4**	**3**	**9**	**6**	**5**	**5**	**6**	**5**	**5**	**3**	**51**
	C−	4	3	8	8	5	4	3	5	3	1	44
Analogies	**C+**			**4**	**2**	**3**	**6**	**2**	**6**	**3**	**4**	**30**
	C−			2			1	2				5
APTE	**C+**	**2**	**3**	**1**	**1**							**7**
	C−	1		2	1							4
Bull chart	**C+**	**3**	**2**	**1**	**1**							**7**
	C−	2		1	1							4
Octopus diagram	**C+**	**1**	**3**	**1**	**1**							**6**
	C−	1		2			1					4
TRIZ	**C+**					**2**	**1**					**3**
	C−								1	2		3
Mindmapping	**C+**	**1**		**2**					**2**			**5**
	C−											0
Personas	**C+**			**1**	**1**		**2**		**2**	**1**	**1**	**8**
	C−			1			1		1			3
Reverse brainstorming	**C+**		**1**	**1**								**2**
	C−											0
FAST	**C+**											**0**
	C−				1	1	1					3
Purge	**C+**	**1**										**1**
	C−											0
SADT Analysis	**C+**			**1**								**1**
	C−											0
IRAD	**C+**											**0**
	C−			1								1
Total	**C+**	12	12	21	12	10	14	8	15	9	8	**121**
	C−	8	3	17	11	6	8	5	7	5	1	**71**

(Structured Analysis and Design Technique; named also IDFO for Integration Definition for Function Modelling) and finally the APTE method (French acronym for value and function analysis) and its tools, the Bull chart and Octopus diagram. The main underlying concepts of these methods will be presented in the "how" section.

The three most popular tools were Brainstorming (95 occurrences), Analogy approach (35 occurrences), APTE method and associated Bull chart and Octopus diagram (32 occurrences). The most creative students (C +) employed significantly ($F(1.26) = 10.08$; $p = 0.004$) more tools (4.2 ± 1.6 tools, min = 2; max = 7) than the less creative ones (C−) (2.2 ± 1.9 tools, min = 1; max = 6). The use of more tools by the C+ students could be related to the relentless effort to find new ideas till the end of the 10 sessions. Indeed, they sustained their effort and continued to "Illuminate, evaluate, associate, experiment and implement" over the last five sessions and in general considered the assignment as a rewarding and enriching experience:

> "I found this initiative good and rewarding. This kind of project encourages creativity and set me free from the intellectual techniques and methods that hold back my ability for innovation". S6

All students used individual brainstorming and four of them had group brainstorming sessions. As the brainstorming was the most popular tool, it is therefore not easy to compare C+ and C− groups with regard to its effectiveness. Mind

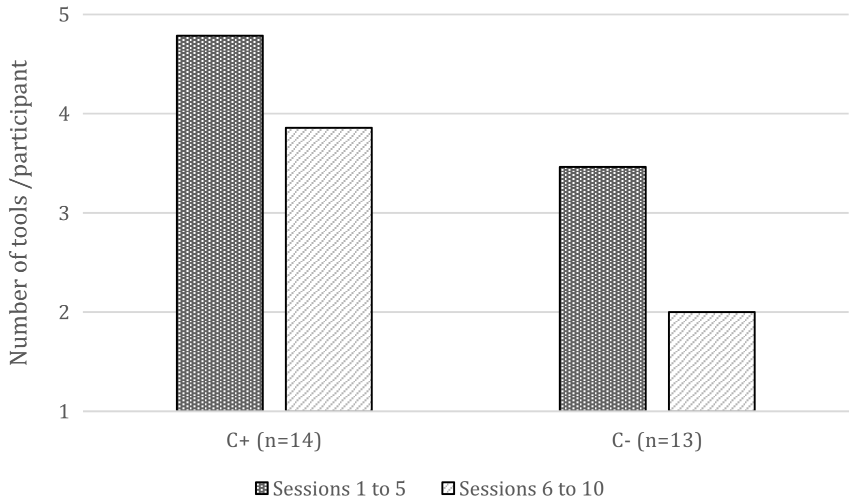


Fig. 2. Average number of tools used during the first and the last five sessions by both groups C+ and C−.

Table 4
Relationship between the quality of the proposals and the creativity and development techniques used. Each cell represents the number of students who used a creativity and development technique and produced proposals that satisfy one of the four quality criteria (uniqueness, Variety, Elaboration, Innovation).

	n	Uniqueness (n = 9)	Variety (n = 16)	Elaboration (n = 18)	Innovation (n = 15)
Brainstorming	27	9	16	18	15
Analogies	15	8	12	10	9
APTE	11	3	8	8	5
Bull chart	10	3	7	7	5
Octopus diagram	9	2	7	7	4
TRIZ	4	0	2	2	0
Mind mapping	3	2	2	0	2
Personas	6	2	2	2	2
Reverse brainstorming	2	3	3	4	3
FAST Diagram	2	1	1	0	1
Purge	1	1	1	1	1
SADT Analysis	1	0	1	1	0
IRAD	1	0	1	1	0

mapping, purge and reverse brainstorming were employed by few students, all of whom were among the most creative (C+). An analogy approach and Personas were mainly used by the most creative students.

Considering the **"when"**, we analysed the temporal use of the tools over the 10 sessions and the results are shown in Fig. 2 and Table 3. A similar temporal pattern was observed with significantly ($F(1,26) = 10.92$; $p = 0.003$) more tools being used during the five first sessions (Fig. 2) of the project by both groups, C+ and C−. However, interestingly, the C+ group tended to use more consistently creativity tools up to the very end. C+ participants continued idea generation (with brainstorming and analogy) and also tried to adopt the perspective of users, an interesting combination for the end stages (Table 3). APTE method, the third most frequently used technique, was applied during the early stages of the creative process. Analogies were applied more frequently in the five last sessions by C+ group, hence the high frequency of "experimentations", "association" and "illuminations" during this period (Table 1). These differences could be one of the contributing causes of the lack of original idea and technological innovation of the C− group.

This leads us to the third question of **how** effective these various tools were. Table 4 show the relationship between the quality of the layouts and the number of students who used each of the creativity and development techniques. Surprisingly, applying several tools with a highly structured approach did not always lead to high creative performance. Indeed, among C− participants, S19 and S25 had a very structured approach and used up to 6 different techniques (Brainstorming, functional analysis, bull chart, octopus diagram, analogies, IRAD (S19), TRIZ (S25) but their layouts were very common with no originality or any technological innovation (average jury marks: 3.2 ± 0.8 for S19 and 2.2 ± 1.3 for S25).

TRIZ, includes 40 inventive principles based upon the analysis of patents and a contradiction matrix of 39 elements; the matrix cells contain a subset of three or four principles that have been applied most frequently in inventive solutions that resolve contradictions between those elements. Surprisingly, none of the 4 students who applied TRIZ had proposed any unique solution or technological innovation. Among the 4 students, S7 was the only one who seemed to master this approach and benefited from it by proposing a variety of solutions to his main contradictions. The second C+ student (S14) was frustrated as he struggled to gain any insight from applying TRIZ to improve one of his designs. The two C− students were satisfied with the outcome of using TRIZ; however, the information they gave in the workbook did not reflect a good understanding of the technique.

The APTE method was the third most frequently used technique during the early stages of the creative process (the three first sessions). It was developed by a French consultant, Gilbert Barbey, by the end of the 60's on the basis Lary Mile's value analysis and other scientific research. It is widely taught in engineering and business schools in France (Zehtaban & Roller, 2012). The associated tools such as the Bull chart and the Octopus diagram allowed students to identify the functions of the campervan kitchen, the requirements and the connections between the product and the external environment. An analysis of the output of these diagrams and charts revealed that it was a mere reformulation of the needs and services to be provided by the kitchen, which were already specified in the brief specifications. Indeed, no new ideas were generated but students felt they gained a better understanding of the problem and declared they were ready to get started. Indeed, among the 11 students who applied functional analysis, 8 (73%) did not come up with any unique or original idea and 6 (54%) did not propose any technological innovation.

The FAST diagram (Function Analysis System Technique), which displays functions in a logical sequence, prioritizes them and tests the dependency (Zehtaban & Roller, 2012), was used by only one student (S25), during the 4th, 5th and 6th sessions. It followed the APTE method and its 2 associated tools (3th session). The creative performance of this student was in the bottom three (average creativity mark: 2.2 ± 1.3) despite a very structured approach and the use of a total of 6 creativity and development techniques including TRIZ and Brainstorming.

IRAD, which is a systematic method for designers to analyse risks related to the physical design was applied only once at the third creative session by S19 (average creativity mark: 3.2). The use of IRAD at this stage of the creative process added new constraints to solve beyond those in the specifications brief.

SADT or IDFO analysis is a modelling language including rules and techniques to standardize a graphical representation of a system (Zehtaban & Roller, 2012). SADT was applied by one student (S7) during the third session just after APTE method, the bull chart and octopus diagram. The "function model" produced by S7 was a basic representation of one of the kitchen functions (represented on the diagram by a box) and data that relate to this function (represented by arrows; input, output, constraints). No immediate or particular insight seemed to be associated with the use of SADT. Interestingly, this student applied 7 techniques throughout the 10 sessions and his approach suggested a good understanding on how to use and benefit from these tools to generate various and elaborated kitchen layouts (average creativity mark: 5.2 ± 1.3). He was, indeed, one of the 4 students (2 C+ and 2 C−) who declared that they read their TRIZ course notes and tried to use TRIZ to find new ideas or improve their kitchen layouts in the latest phases of the creative process (4 last sessions).

Students benefited from techniques such as Personas, mind mapping, purge and reverse brainstorming. They generated original ideas and technological innovations through the full use of their imagination without being obsessed by the brief's specifications and constraints. The purge or 'brain dump' is a creativity tool that helps participants empty themselves of their preconceived ideas or any idea they hold dear. This technique was used only once at the beginning of creativity process by a female student (S1) who received the highest creativity mark (6.2 on average). The purge started by a brief documentation on existing kitchens in small flats, boats, camper van etc.; then she wrote down the specifications as well as a drawing of the classical kitchen to avoid reproducing it. This exercise was completed in an effortless and natural way as if it was evident for this student that this is how a creativity project should start. Her six alternative layouts had little in common with the classical kitchen. Four of them were unique, highly original, diverse and included technological innovations. It is worth mentioning that S1 applied frequently tools such as mind mapping, brainstorming, personas and analogies during the 10 sessions. The quality of the execution and output of these techniques was high and allowed the student to engage in stimulating divergent thinking. Interestingly, S1 did not use any of the analytical rational techniques such as functional analysis and TRIZ. She seemed surprised that creativity tools were helpful as mentioned in her comment at the end of the project: "What I learned is that creativity tools are indeed very useful and also to persevere" (S1).

The Personas technique included narratives about different emotional customer experiences and scenarios of use that helped the students to develop some empathy of target customers such as: explorer in Arctic regions or Amazonian forest, nature lovers (ecological kitchen), tradition seekers, elegant and purist design adepts, technological geeks, etc. Surprisingly, some students did not fully develop the Personas; others did not integrate the output of these creative sessions or failed to produce elaborate details in their final layouts. This could be linked probably to insufficient training or a lack of trust in the benefits of this user-centred design technique.

During the creative sessions, brainstorming resulted in a written list of different technological solutions to solve functional constraints. These solutions were evaluated and graded in tables. The whole process of brainstorming was a simultaneous mix between divergent, critical and analytical thinking. The classical rule of brainstorming, such as generating a long list of ideas including silly and unreasonable ones without any judgement or critics, was seldom observed. This could be explained by the fact that it was mainly individual brainstorming and therefore students might not have applied strictly the rules. Indeed, some students commented on the lack of real challenge and stimulation during individual brainstorming and the difficulty to generate new ideas on their own. One student suggested to renew this creative experience but in groups:

> "This idea of creativity assignment is certainly a very good idea. I think you should continue this initiative the following years, in groups if possible or at least plan one group session with the teacher as facilitator" (S8)

Finally, the analogy approach, which was the second most popular method, consists of taking an idea from one context and using it for a new situation to create something new or innovative or to understand or explain a problem. Scientific discoveries emerge often from analogies by combining in creative ways two concepts to make a single new one. Typically, students created new kitchen' concepts by using a concept or a familiar object such as a suitcase, smartphone apps, stretcher, lego, flexible pastry mould, screen touch, tool case, trailer, magnetic levitation, remote control, backpack, vanitycase, etc. Comparing and establishing relationships between these objects and the campervan kitchen allowed them to come up with unique ideas, a variety of concepts as well as technological innovations (Table 4).

4. Discussion

The analysis of students' outputs and strategies showed individual differences in the creative process stages, their performance as well as the nature and the effectiveness of the creativity and development tools used. The students chose to apply 13 tools to solve problems and generate ideas with more or less effectiveness: brainstorming, reverse brainstorming, mind mapping, analogies, TRIZ, IRAD, Purge or "Mind dump", Personas, FAST diagram, SADT and finally the APTE method and its tools, the Bull chart and Octopus diagram. The task used in this study stretched the students' creativity skills, as they designed conceptually six different proposals of a campervan kitchens.

The more creative students (C+) used more tools than the less creative ones (C−) because they sustained their effort to generate idea (illumination stage) up to the very end of the ten sessions. They engaged in association, experimentation, evaluation and implementation, using mind mapping, analogies, personas, and or brainstorming; the C− group engaged in convergent thinking, structuration and constraints management. The C− group's lack of idea generation in the latest phases of the design process and their comments about their desire to expedite the project in less than 10 sessions could be interpreted as a lack of motivation to engage in the task and as a low level of perseverance and commitment to the task. According to Amabile (1983) when the task is intrinsically motivating creativity is more likely to be facilitated. However, as the great majority of students including C− group invested energy and time to complete painstakingly the assignment, another alternative hypothesis might explain the difference between the C+ and C− groups in the last five sessions, that is the need for cognitive closure (NFC). NFC corresponds to an inclination "to seize and freeze" on early uncreative ideas that came to mind (Kruglanski, 1990, 2004; Van Hiel & Mervielde, 2003). High NFC individuals experience often a need to reach a quick conclusion in decision-making and an aversion to ambiguity and confusion. Once they are confident in their chosen solution, they are less likely to explore diverse alternatives, thereby restricting ideational fluidity, resulting in low creative performance (Chirumbolo, Livi, Mannetti, Pierro, & Kruglanski, 2004). One way to overcome the tendency to "seize and freeze" on ideas that come to mind early is to open the potentially creative mind of high-NFC individuals by first making them aware of uncreative ideas. In a recent study (Ong & Leung, 2013), high-NFC participants were asked to recall and draw what they thought were commonly agreed upon conventional designs before drawing their creative design. To explain these results, Ong and Leung (2013, p. 291) used the dual pathway model to creativity: the flexibility pathway and the persistence pathway (De Dreu, Baas, & Nijstad, 2008). They suggested that the opportunity to be cognizant of uncreative ideas as consensually invalid solutions improved the creative performance of high-NFC individuals through the persistence route.: they exert effort and work hard to search for alternative solutions "until reaching one that they perceive as a normatively prescribed creative answer".

Interestingly, in our study the first tool used by the most creative student was mind-dump or purge, which consisted of writing down the specifications as well as a drawing of the classical kitchen with a tag line "avoid reproducing". This student made herself aware of the uncreative solution early in the creative process (first session), and then searched for and implemented original ideas through the 10 sessions. Therefore, it seemed very useful to have a purge or 'brain dump' just after the phase of examination and reformulation of the problem and before the idea generation stage. As Baillie (2002, p. 3) suggested, a purge allows "to clear the working memory and move ideas to the brain store (just like a computer) so as to leave space for processing ideas. If the working memory is too full the same idea keeps coming to the forefront". And yet, only one student among the 27 participants used the mind dump or purge. The spontaneous and natural way the purge was executed suggest that this student might have a previous experience with this tool and or a strong belief in its effectiveness to produce new ideas. Unfortunately, we did not conduct any interviews when the study was in progress to know why this student was the only one to use the purge method. Nonetheless, creativity instructors of engineering students should put more emphasis on the usefulness to have a purge or 'brain dump' just after the phase of examination and reformulation of the problem and before the idea generation stage.

Most students who used Analogies, Personas, mind mapping, purge and/or reverse brainstorming produced unique ideas, a variety of concepts as well as technological innovations. The analogy approach, which was the second most used method after brainstorming, is routinely used by scientists to comprehend and draw new inferences about a less familiar domain which increase the likelihood of scientists making discoveries (Dunbar, 1995; Gentner & Smith 2012). In his naturalistic study of leading researchers in molecular biology, Dunbar (1995) found that analogical thinking is a key component of all aspects of scientific reasoning and that most of the analogies were biological and only 2 of the 99 analogies were "non-biological" or distant. Similarly, in our study, engineering students created new kitchen' concepts by using analogies with a familiar physical object and none of their analogies came from biology or any other distant field.

Structured and rational methods, such as TRIZ, FAST, SDAT, APTE and IRAD were used by both groups C+ and C−. During the first sessions, some students (41%) used functional analysis (APTE) and its associated tools. This structured approach resulted in a mere reformulation of the specifications' brief. However, the students reported that it helped them to clarify the problem and to better understand the functions and the constraints and they felt "ready to get started". As it was observed with TRIZ, FAST, SADT, APTE and IRAD, the majority (78%) of the students who applied functional analysis did not come up with any unique or original kitchen concepts. This finding should not be considered as evidence to imply that these methods have no value in product design but should be used to understand the reasons and the implications for future trainings.

Three potential hypotheses could explain the differences between the two groups, C+ and C−, as well as the lack of effectiveness of the structured and rational methods in conceptual product design and the improvements to introduce.

First, most students were not confident in their ability to find innovative solutions for the long term suggesting low creative self-efficacy. Even the most creative student was not aware of her creativity potential and the usefulness of the creativity tools which question the effectiveness of the creativity training. Indeed, the analysis of students' workbooks showed that some of the creativity and development techniques were not very well mastered leading to a poor execution and weak benefits. Although the training module was long (150 h) and the content very rich, the passive delivery method (e.g., lecture-based instruction) and the use of only one "treatment" or exposure could explain the lack in student's proficiency to effectively use these tools. In addition, as we were interested in spontaneous individual strategies, the conceptual design project was conducted individually with little interactions with other students and the teaching team. Improvements in terms of the delivery method are therefore necessary to actively involve students and teachers in processing the information during hands-on trainings for each technique as well as during class projects or corporate complex challenges. McWilliam (2009, p. 8) suggested that creativity teachers could extend "their pedagogical repertoire, beyond 'Sage-on-the-Stage' or 'Guide-on-the-Side', to include a third role for the 21st century teacher as a builder of creative capacity—that of 'Meddler-in-the-Middle'... [This last pedagogical category] is descriptive of active interventionist pedagogy in which teachers are mutually involved with students in assembling and/or dis-assembling knowledge and cultural products···Meddling is a re-positioning of teacher and student as co-directors and co-editors of their social world". This would potentially improve the effectiveness of creativity trainings as well as the students' creative self-efficacy which consequently will affect positively their creative performance (Mathisen & Bronnick, 2009). Furthermore, some students failed to integrate the output of their creative sessions into the final designs that the jury evaluated. The gap between the quality of their approach described in the workbook, the effort they invested and the jury mark of the final layouts raise the issue of how teachers should assess creativity to keep students motivated to engage in creative challenges. An assessment framework should be designed to track the development of engineering students' creativity skills.

Second, when starting up the project, the most creative students "summarized" the brief's constraints into some key limitations to take into account, reinterpreting and reformulating them and seemingly forgetting about several constraints. This approach to constraints is similar to the concept of mental constraint removal used by experienced designers ignoring highly fixed constraints to open up for solutions, as found in the design of disposable medical equipment (Onarheim, 2012). On the contrary, the less creative students applied a highly structured approach with a strict adherence to the specifications and the constraints of the design brief. We hypothesise that this could be linked to the concept of Personal Need for Structure (PNS). According to Neuberg & Newsom (1993), the PNS is associated with a preference for well-ordered situations and a chronic need to reduce the cognitive load of complex reality. A recent study (Rietzschel, Slijkhuis & Van Yperen, 2014) showed that the creativity of participants high in PNS improved when they were supplied with a structure or general plan to complete a creative task; however, a highly constraining structured task, which they choose actively to adopt when given free choice, limited their creative performance. The authors concluded that people high in PNS "may choose (and perhaps even actively seek out) situations that 'fit' their individual needs, regardless of the effects on their performance" (Rietzschel et al., 2014, p. 397). This is in line with the assumption that "without constraints there can be no creativity... but too few or too many constraints had a negative impact on creativity" (Onarheim, 2012 p. 324).

Third, while TRIZ is increasingly recognized as a creativity and innovation tool, none of our students who applied TRIZ had proposed any original solution or technological innovation, not even the one student whothat seemed to master this approach. Our hypothesis is that there was a misfit between the task at hand and the creative tool used. Birdi, Leach and Magadley (2012, p. 324) demonstrated in a longitudinal study that a one-day TRIZ based creativity training "can improve both creative problem-solving skills and motivation in the short term and contribute to improved engineer creativity in the workplace over the longer term". This study was conducted in a major international engineering firm which provides power systems and services for use on land, at sea, and in the air. The use of TRIZ fitted the engineers' tasks, e.g., looking for ways to reduce engine weight, improve engine power, or make the production process more efficient. In contrast, the requirements of the task used in our study relate more to the early ideation stage often called "fuzzy front end" of new product development (Cooper, 1990; Khurana & Rosenthal 1997, 1998). The use of TRIZ and the other cognitive and structured methods helped probably students to reduce the complexity of the problem, to structure the relevant functions and constraints in a meaningful and integrated way. However, this should be balanced by human-centred design tools to stimulate their creativity in particular for long-term solutions such as Personas, mind mapping, purge, analogies and reverse brainstorming.

This leads us to our final remark regarding the integration of users' needs and meaning in conceptual product design. "We are used to thinking about innovation in terms of technologies... but we always forget that people don't buy just utility. People buy meaning and emotion and symbols" (Verganti, 2010). Although, the first stage of the creativity training, *Translation of needs*, requires understanding better the users, the market, and competitors, none of our students tried to get in touch with actual or prospective users of campervan to identify directly their needs and experiences or to collect their feedback about the designed layouts. Although some argue that radical innovations do not come from users (Norman and Verganti, 2012), the success of the introduction of a new product depends on the satisfaction of customers' needs, their willingness to adopt the product and even to change their behaviours (Leifer & Steinert, 2011; for a discussion of the role of perspective-taking in creativity see Glăveanu, 2015). Daniel Pink (2004, p. 2) considers that "the future belongs to a very different kind of person with a very different kind of mind—creators and empathizers, pattern recognizers, and meaning makers".

Unlike the most recent research on creativity training for engineering students, this study does not focus on technological tools but provides more in-depth analysis of the creative process of engineering students and highlights possible modulations between core engineering methods and creative thinking. But as it is often the case of creativity and design training studies (Puccio, Firestien, Coyle, & Masucci, 2006), the limits of our study are related to the small size of our sample, the absence of a control group, the delivery of the module, the absence of a pre-test and interviews or debriefing with the students regarding their strategies. The hands-on project did not provide any insight about the change in student's attitudes and behaviour, nor the transfer of knowledge gained for the whole experience. Future creativity and design training studies should address these limits, assess individual differences such as the need for structure and closure and adjust the creative task accordingly. The use of a "pencil and paper" workbook proved very useful to understand the students' creative process and evaluate the nature and effectiveness of the tool used. In the future, other types of support (computer tab, mobile phone, etc.) could be used to capture ideas at any time and place, record one's thoughts and progress as well as to participate in team projects in synchronous and asynchronous ways. Finally, this study concentrated on individuals alone and as Csikszentmilahyi suggests in his system model (Csikszentmihalyi 1999: 315), studying creativity by focusing on the individual alone is like trying to understand how an apple tree produces fruit by looking only at the tree and ignoring the sun and the soil that support its life. Indeed as creativity is multifactorial process including social, cultural and psychological factors that affect each other (Csikszentmihalyi 1999; Sternberg & Lubart 1991), further studies are needed to investigate engineering creativity *in-vivo* taking into account the interactions between these factors.

In conclusion, we emphasize that the nature of the creativity and design tools used needs to fit the type of challenge to be solved, the phase of the process of product design, as well as individual preferences. In the early phase of the creative process, the purge method is recommended before ideation and just after the clarification and the reformulation of the problem. Indeed, the opportunity to be cognizant of uncreative ideas can improve the creative performance of high-NFC individuals. Structured and rational tools such as the APTE method, used in the early stages of the process by engineering students could promote their creativity probably because it fits their need for structure. However, a highly constrained and disciplined approach can hamper their performance. A creativity and development toolkit should describe specifically not only why and how to use the creativity tools but also when it is appropriate to apply them using examples from engineering corporate case studies or hands-on exploratory class projects. The development of such a toolkit would involve further investigations to cover a large number of creativity and development tools and address the above mentioned limits of this study. A conceptual product design challenge may benefit from the adoption of designers' mind-set and tools, balanced with engineers' rational and disciplined methods. Future improvements of training programs should aim to empower students to understand creativity methods, to use them appropriately and judiciously in the productive process in order to maximise the benefits of these methods.

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References

Altshuller, G. S. (1996). *And suddenly the inventor appeared*. Worcester, UK: Technical Innovation Center.
Amabile, T. M. (1983). *The social psychology of creativity*. New York: Springer-Verlag.
Andreasen, M. M. (2011). 45 Years with design methodology. *Journal of Engineering Design*, *22*(5), 293–332.
Aoussat, A., Christofol, H., & Le Coq, M. (2000). The new product design – A transverse approach. *Journal of Engineering Design*, *11*, 399–417.
Baillie, C. (2002). Enhancing creativity in engineering students. *Engineering Science and Education Journal*, *11*, 185–192.
Bandura, A. (1997). *Self-efficacy: the exercise of control*. New York: Freeman.
Barrett, D. (2013). The creativity cure. *Chronicle of Higher Education*.
Birdi, K., Leach, D., & Magadley, W. (2012). Evaluating the impact of TRIZ creativity training: an organizational field study. *R&D Management*, *42*(4), 2012.
Botella, M., Glaveanu, V. P., Zenasni, F., Storme, M., Myszkowski, N., Wolff, M., et al. (2013). How artists create: Creative process and multivariate factors. *Learning and Individual Differences*, *26*, 161–170.
Bouchard, C., Christophol, H., Roussel, B., & Aoussat, A. (1999). Anticipation and Integration of trends in design and engineering design. *Proc. of international conference of engineering design (ICED)*.
Brown, T., & Katz, B. (2011). Change by design. *Journal of Product Innovation Management*, *28*(381–383), 381–383.
Burroughs, J. E., Dahl, D. W., Page Moreau, C., Chattopadhyay, A., & Gorn, G. J. (2011). Facilitating and rewarding creativity during new product development. *Journal of Marketing*, *75*, 53–67.
Buzan, T. (1991). *The mind map book*. Penguin Books.
Chirumbolo, A., Livi, S., Mannetti, L., Pierro, A., & Kruglanski, A. W. (2004). Effects of need for closure on creativity in small group interactions. *European Journal of Personality*, *18*, 265–278.

Cooper, R. G. (1990). Stage-gate systems: A new tool for managing new products. *Business Horizons*, *33*, 44–54.
Cropley, D. H. (2015). Promoting creativity and innovation in engineering education. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(2), 161–171.
Csikszentmihalyi, M. (1999). Implications of a systems perspective for the study of creativity. In R. Sternberg (Ed.), *Handbook of creativity*. Cambridge: Cambridge University Press.
Daly, S. R., Mosyjowski, E. A., & Seifert, C. M. (2014). Teaching creativity in engineering courses. *Journal of Engineering Education*, *103*(3), 417–449.
Danahy, E., Wang, E., Brockman, J., Carberry, A., Shapiro, B., & Rogers, C. B. (2014). Lego-based robotics in higher education: 15 years of student creativity. *International Journal of Advanced Robotic Systems*, *11*(2), 1–15.
De Dreu, C. K. W., Baas, M., & Nijstad, B. A. (2008). Hedonic tone and activation level in the mood-creativity link: Toward a dual pathway to creativity model. *Journal of Personality and Social Psychology*, *94*, 739–756.
Diener, E., Smith, H., & Fujita, F. (1995). The personality structure of affect. *Journal of Personality and Social Psychology*, *69*, 130–141.
Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg, & J. Davidson (Eds.), *Mechanisms of insight* (pp. 365–395). Cambridge, MA: MIT Press.
Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching and learning. *Journal of Engineering Education*, *94*(1), 103–120.
Farid, F., El-Sharkawy, A. R., & Austin, L. K. (1993). Managing for creativity and innovation in A/E/C organizations. *Journal of Management in Engineering*, *9*(4), 399–409.
Felder, R. M. (1987). On creating creative engineers. *Engineering Education*, *77*(4), 222–227.
Felder, R. M. (1988). Creativity in engineering education. *Chemistry Engineering Education*, *22*(3), 120.
Gentner, D., & Smith, L. (2012). Analogical reasoning. In V. S. Ramachandran (Ed.), *Encyclopedia of human behavior* (2nd ed., pp. 130–136). Oxford, UK: Elsevier.
Gist, M. E. (1989). The influence of training method on self-efficacy and idea generation among managers. *Personnel Psychology*, *42*, 787–805.
Glăveanu, V. P. (2015). Creativity as a sociocultural act. *Journal of Creative Behavior*, *49*(3), 165–180.
Isaksen, S. G., & Treffinger, D. J. (1987). *Creative problem solving: Three components and six specific stages. Instructional handout*. Buffalo, NY: Center for Studies in Creativity.
Jackson, N., Oliver, M., Shaw, M., & Wisdom, J. (2006). *Developing creativity in higher education*. London: Routledge.
Kazerounian, K., & Foley, S. (2007). Barriers to creativity in engineering education: A study of instructors and students perceptions. *Journal of Mechanical Design*, *129*(7), 761–768.
Khurana, A., & Rosenthal, S. R. (1997). Integrating the fuzzy front end of new product development. *Sloan Management Review, Cambridge*.
Khurana, A., & Rosenthal, S. R. (1998). Towards holistic front ends in new product development. *The Journal of Product Innovation Management*, *15*(1), 57–74.
Klemeš, J. J., Kravanja, Z., Varbanov, P. S., & Lam, H. L. (2013). Advanced multimedia engineering education in energy: process integration and optimisation. *Applied Energy*, *101*, 33–40.
Kruglanski, A. W. (1990). Lay epistemic theory in social-cognitive psychology. *Psychological Inquiry*, *1*, 181–197.
Kruglanski, A. W. (2004). *The psychology of closed mindedness*. pp. 5–31. New York, NY: Psychology Press.
Leifer, L., & Steinert, M. (2011). Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning information, knowledge. *Systems Management*, *1*(10), 151–173.
Locke, E. A., Frederick, E., Lee, C., & Bobko, P. (1984). Effect of self-efficacy, goals: and task strategies on task performance. *Journal of Applied Psychology*, *69*, 241–251.
Lubart, T. I., & Mouchiroud, C. (2003). Creativity: A source of difficulty in problem solving. In J. E. Davidson, & R. J. Sternberg (Eds.), *The psychology of problem solving* (pp. 127–148). Cambridge, UK: Cambridge University Press.
Lubart, T., Zenasni, F., & Barbot, B. (2013). Creative potential and its measurement. *International Journal for Talent Development and Creativity*, *1*(2).
Lubart, T., Mouchiroud, C., Tordjman, S., & Zenasni, F. (2015). *Psychologie De La Créativité, collection cursus* (2e ed.). Armand Colin.
Lubart, T. I. (2001). Models of the creative process: Past, present and future. *Creativity Research Journal*, *13*(3–4), 295–308.
Mathisen, G. E., & Bronnick, K. S. (2009). Creative self- efficacy: An intervention study. *International Journal of Educational Research*, *48*(1), 21–29.
McWilliam, E. L. (2009). Teaching for creativity: from sage to guide to meddler. *Asia Pacific Journal of Education*, *29*(3), 281–293.
Neuberg, S. L., & Newsom, J. T. (1993). Personal need for structure: Individual differences in the desire for simpler structure. *Journal of Personality and Social Psychology*, *65*, 113–131.
Norman, D., & Verganti, R. (2012). Incremental and radical innovation: design research versus technology and meaning change. Manuscript submitted to *Design Issues. Based on a talk by Norman and Verganti (2011) at the designing pleasurable products and interfaces conference in Milan, 2011*.
Onarheim, B. (2012). Creativity from constraints in engineering design: lessons learned at Coloplast. *Journal of Engineering Design*, *23*(4), 323–336.
Ong, L. S., & Leung, A. K. (2013). Opening the creative mind of high need for cognitive closure individuals through activation of uncreative ideas. *Creativity Research Journal*, *25*(3), 286–292.
Osborn, J. (1993). *Applied imagination: Principles and procedures of creative problem-solving* (3rd ed.). Buffalo: Creative Education Foundation.
Patnaik, D., & Mortensen, P. (2009). *Wired to care, how companies prosper when they create widespread empathy*. Pearson Education.
Pink, D. (2004). *A whole new mind*. New York: Penguin.
Pruitt, J., & Adlin, T. (2006). *The Persona lifecycle: Keeping people in mind throughout product design*. San Francisco: Morgan Kaufmann Publishers.
Puccio, G. J., Firestien, R. L., Coyle, C., & Masucci, C. (2006). A review of the effectiveness of CPS training: A focus on workplace issues. *Creativity and Innovation Management*, *15*, 19–33.
Rietzschel, E. F., Slijkhuis, M. J., & Van Yperen, N. W. (2014). Task structure, need for structure, and creativity. *European Journal of Social Psychology*, *44*, 386–399.
Savransky, S. D. (2000). *Engineering of creativity: Introduction to TRIZ methodology of inventive problem solving*. Boca Raton, FL: CRC Press.
Scott, G., Leritz, L., & Mumford, M. (2004). The effectiveness of creativity training: A quantitative review. *Creativity Research Journal*, *16*(4), 361–388.
Seidel, V., & Fixon, S. (2013). Adopting design thinking in novice multidisciplinary teams: The application and limits of design methods and reflexive practices. *Journal of Product Innovation Management Supplement*, *30*, 19–33, 15p.
Selig, T. (2012). *inGenius: A crash course on creativity*. HarperCollins.
Smith, G. F. (1998). Idea generation techniques: A formulary of active ingredients. *Journal of Creative Behavior*, *32*, 107–134.
Spencer, E., Lucas, B., & Claxton, G. (2012). *Progression in creativity: Developing new forms of assessment*. Newcastle: CCE.
Sternberg, R., & Lubart, T. (1991). An investment theory of creativity and its development. *Human Development*, *V34*, 1–32.
Stouffer, W. B., Russell, J. S., & Oliva, M. G. (2004). Making the strange familiar: Creativity and the future of engineering education. *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, 20–23.
Torrance, E. P. (1963). *Creativity*. Washington, DC: National Education Association.
Treffinger, D. J. (1995). Creative problem solving: Overview and educational implications. *Educational Psychology Review*, *7*, 191–205.
Van Gundy, A. B. (2005). *101 activities for teaching creativity and problem solving*. San Francisco, CA: John Wiley & Sons.
Van Hiel, A., & Mervielde, I. (2003). The need for closure and the spontaneous use of complex and simple cognitive structures. *The Journal of Social Psychology*, *143*(5), 559–568.
Vansteelandt, K., Mechelen, I. V., & Nezlek, J. (2005). The co-occurrence of emotions in daily life: A multilevel approach. *Journal of Research in Personality*, *39*, 325–335.
Verganti, R. (2010). *Speaking at the big rethink conference of the economist*.. Available online at https://hbr.org/2010/03/user-centered-innovation-is-no

Wood, D., & Bilsborow, C. (2014). 'I am not a person with a creative mind': facilitating creativity in the undergraduate curriculum through a design-based research approach. *The Electronic Journal of e- Learning*, *12*(1), 111–125. Available online at www.ejel.org

Zehtaban, L., & Roller, D. (2012). . pp. 12–21. *Systematic functional analysis methods for design retrieval and documentation* (Vol. 6) World Academy of Science, Engineering and Technology.

Zelenski, J. M., & Larsen, R. (2000). The distribution of basic emotions in everyday life: A state and trait perspective from experience sampling data. *Journal of Research in Personality*, *34*, 178–197.

Zhou, C., Kolmos, A., & Nielsen, J. F. D. (2012). A problem and project-based learning (PBL) approach to motivate group creativity in engineering education. *International Journal of Engineering Education*, *28*(1), 3–16.