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Research Article

Systematic Creativity Tools for Product Concept Generation: Evaluation of Learning Experiences in Engineering Design Education

[1]Barbara Motyl, [2]Domenico Speranza and [1]Stefano Filippi
[1]Department DPIA, University of Udine, Udine,
[2]Department DICeM, University of Cassino and Southern Lazio, Cassino, Italy

Abstract: This study considers the use of systematic creativity tools for concept generation belonging to C-K theory and TRIZ, in addition to traditional ones used for product development. The aim of this study is twofold. On one hand, it aims to contribute to the improvement of the creative and innovation skills of engineering students and designers in general by the introduction of specific creativity enhancement tools. On the other hand, it proposes a method for evaluating the training and learning outcomes of the students involved in the courses based on Kirkpatrick's Four Levels of Evaluation and used a questionnaire to collect students' answers and opinions. This way, some practical cases are carried on and two of these are presented in detail: one concerning the ideation of a new kind of gym towel and one concerning the analysis of a knee implant for total knee replacement surgery for possible improvements. The questionnaire results show that students considered the training and learning experiences and the use of the two new methods in a positive way. In particular, TRIZ method represents the most appreciated at all, while C-K theory is revealed as the newest one and very promising for the students' future professional development.

Keywords: Concept generation, creativity in design, C-K theory, engineering education, Kirkpatrick levels of evaluation, TRIZ, training and learning evaluation

INTRODUCTION

Recent years' trend in product development shows that the success of a new product is due not only to the validity of its physical characteristics (geometrical, mechanical and functional), but also to its creative and emotional dimensions, as well as to its pre-and after-sale services.

Current engineering design methods provide help in designing good products, but designers lack tools to create innovative and commercially successful ones. As reported in literature creativity represents the most important leadership quality to keep under control in coming years (Lombardo and Roddy, 2011; Roussel *et al*., 2012). It is usually identified with ideas generation and it occurs through a process where an agent uses its ability to generate novel and useful concepts. Innovation, on the other hand, refers to the transformation of ideas into new products or services. In this sense, innovation is intended as the implementation of creativity results for developing new products, processes or services, while creativity represents the starting point of the whole innovation process. For these reasons, the education of engineers and designers to innovation, by increasing their creativity and ideation skills, is considered of fundamental importance in academic institutions (Barak, 2004; Alves *et al*., 2007; De Vere, 2009; Saunders *et al*., 2009; Choulier and Weite, 2011; Genco *et al*., 2012; Chulvi *et al*., 2012).

Thus, the aim of this study is twofold. On one hand, its goal is the improvement of the creative and innovation skills of designers starting from their engineering education by the introduction and exploitation of creativity and systematic innovation methods and tools, next to traditional ones, since the earliest stages of product design and development. For these reasons, to promote the improvement of the creative and innovation skills of engineering students, this study considers the application of some different tools for concept development belonging to C-K theory and TRIZ in addition to traditional ones, such as Brainstorming, into some case studies developed during two engineering design courses held in two different universities.

On the other hand, it proposes an evaluation framework, based on Kirkpatrick's Four Levels of Evaluation, to consider the training and learning

Corresponding Author: Barbara Motyl, Department of DPIA, University of Udine, Udine, Italy

outcomes of the students involved in these courses. This, to consider how students apply these methods and tools and what their personal considerations are.

OVERVIEW ON SYSTEMATIC CREATIVITY TOOLS IN ENGINEERING EDUCATION

As indicated in the introduction section, one of the objectives of this study is to promote the development of creative skills in engineering design students and in designers in general, using appropriate methods and tools.

As reported in Shah *et al*. (2003), formal idea generation methods are broadly classified into two categories: intuitive and logical. Intuitive methods, such as Brainstorming, Morphological Analysis, SCAMPER, use mechanisms to break what are believed to be mental blocks. Logical methods, such as TRIZ, Pahl and Beitz systematic design approach, involve systematic decomposition and analysis of the problems, relying heavily on technical databases and direct use of science and engineering principles and/or catalogues of solutions or procedures (Shah *et al*., 2003). Also, as reported in the work of Chulvi *et al*. (2013) logical methods such as TRIZ seems to provide better creative outcomes because of the better novelty achieved that intuitive methods, but not in comparison of the simple Brainstorming technique. Consequently, the authors felt the need to introduce engineering students to the use of logical creativity and innovation enhancement methods during their engineering design courses and to contribute to dispel the common vision of creativity as an innate characteristic (Choulier and Weite, 2011). Moreover, the authors retain that the use of these methods may be extended, by the students, even to the industrial environment, where commonly many of the companies use only Brainstorming or some variations of it during product concept generation phases (Ryynänen and Riitahuhta, 2010). As reported in Nakagawa (2011), how to think creatively in problem solving, especially in technological fields, has been difficult to explain, teach and train, but TRIZ represents a structured methodology and may be adapted and re-organized for an easier learning. In literature, there are different example of introducing TRIZ theory and its tools in academic courses or workshops, especially using TRIZ Inventive Principles or Contradictions matrixthan Trend of Evolution (Hipple, 2005; Moehrle, 2005; Belski, 2009; Ilevbare *et al*., 2013; Filippi *et al*., 2011). Given these premises, the choice of which methods to introduce in our courses, next to the use of traditional ones, has fallen on C-K theory and TRIZ because they represent two different logical approaches for introducing creativity and innovation in a systematic way into product design and development.

Introducing C-K theory and TRIZ: C-K theory-or Concept-Knowledge theory - is a unified design theory introduced by Hatchuel *et al*. (2004). The name C-K reflects the assumption that design can be modelled and analyzed as the interplay between two interdependent spaces, the space of Concepts (C) and the space of Knowledge (K). C-K theory models the design process through interactions and expansions of the concept space C and the knowledge space K. C-K map represents a fundamental tool of this theory. It models the space C as a tree structure and reflects the concept partitioning while the K space assumes an "archipelagic" structure where each knowledge base contains propositions with logical status for designers. Four kinds of operators can be used to model these two spaces expansions and interactions: K→C, C →K, C→C and K→K (Hatchuel and Weil, 2003; Hatchuel *et al*., 2004; Le Masson *et al*., 2010).

TRIZ-the theory of inventive problem solving-was developed by Altshuller (1996, 1999) to support engineers and scientists in solving problems using the knowledge of former inventors. TRIZ offers a large set of tools to analyze and solve problems in different perspectives. For the purpose of this research, the students were only introduced to the use of the Inventive Principles and Trends of Evolution. IP is a set of forty rules, recommendations or suggestions that describe how a product or a system can be modified in order to improve it. The IP and their use are relatively easy to explain and to employ, even if the users have never seen them before. Trends of Evolution represent the technological evolution and development of different kinds of technical systems. At the beginning, these trends were discovered considering different products taken from very different situations. Some recurring changes in their evolution were highlighted and named patterns. A final synthesis of these patterns, considered altogether and independently from the specific situations, generated the Evolution Trends. Some examples of these trends are: Increasing Ideality; Increased dynamism and controllability; Change of symmetry and asymmetry (Rantanen and Domb, 2002; Gadd, 2011).

In particular, introducing the new tools belonging to C-K theory and TRIZ during the performance of these steps may add more efficiency and freshness to this process improving the design and engineering skills of the students and their ability of product innovation. C-K theory and TRIZ represent two different kinds of well-structured logical approaches for concept exploration. Today, TRIZ represents a well-known and widely used method introduced in academic education, for many engineering and management courses, as well as in the industrial context for training improvement of R&D, marketing or technical departments (Tetris Project, 2007; Howard *et al*., 2009; Saunders *et al*., 2009; Ryynänen and Riitahuhta, 2010; Choulier and Weite, 2011). On the other hand, C-K theory is newer; it has been developed more recently and is not diffused so much either for teaching in university courses or in

Table 1: The revised Kirkpatrick's four levels of evaluation used in this study and relative metrics

Level	METRICS	Questions
Reaction: students' view on the learning experience	Interest: how students consider the course arguments as interesting and pertinent to their needs.	Q1
	Materials: completeness and quality of course materials regarding organization and structure.	Q2, Q3
	Usefulness: perceived utility value, or usefulness, of the training for subsequent study/job performance	Q4
	Difficulty: reactions that cover the cognitive effort required to perform well in training.	Q5
Learning: changes in attitudes, knowledge and skills	Understanding: the students' knowledge and the processes of knowledge acquisition, organization and application.	Q6
	Skill outcomes: the trainee development of technical skills.	Q7, Q8, Q9
Behavior: changes in practice and application of learning to practice	Attitudinal outcomes: attitudes, motivation and goals relevant to the objectives of the training program.	Q10
	Behavioral: evidence of students' use of knowledge and skills learned in the course for subsequent study or work.	Q11
	Motivation to transfer: the extent to which trainees are motivated to apply the material they have learned.	Q12
Results: changes at learners' and organizational levels	Results: the organizational and business impacts of the training, such as alumni career success, professional improvement, etc.	Q13

the industrial world (Le Masson *et al*., 2007; Zeiler, 2010; Hooge *et al*., 2012; Agogué and Kazakçi, 2014). It also represents an interesting topic to deepen knowledge about it also in comparison to TRIZ and to traditional methods and tools. Furthermore, the authors have considered interesting to investigate the possibility of applying these two methods in an integrated way because in literature there are still few studies dealing with their combined application for product design and development.

MATERIALS AND METHODS

Courses and participants: To test and validate the training and the learning outcomes of the students, who use these creativity enhancement tools, some practical experiences were developed in the "Product design" course, Master in Industrial Engineering at the University of Cassino and Southern Lazio and in the "Methods for representation and development of the industrial product" course, Master in Mechanical Engineering at the University of Udine. The experiences involved two groups of ten students, one for each of the two universities.

The two courses are provided during the second period of lessons, for a total of 60 h in Udine and of 48 h in Cassino. About ten hours were dedicated to the guided-experiences development. After an introductive lesson of two hours for presenting in general C-K theory and TRIZ, students work in two dedicated workshops of four hours each used for the introduction and the practice of the new methods, related exercises and practical experiences. During the first workshop, students were introduced to C-K theory and they work using C-K mapping. In the second workshop, they were introduced to TRIZ and used Inventive Principles and Trends of Evolution. The specific learning objectives set for these experiences are: to possess a set of creativity/innovation tools that can be useful in designing and developing products; to understand the key principles of TRIZ and C-K theory; to gain proficiency thinking "outside the box" and to develop formal skills in creativity and inventive problem solving to solve practical problems.

Proposed evaluation framework: In order to evaluate how effective were the training and the learning experiences, authors seta questionnaire to be submitted to students. To allow the assessment of students' learning experiences, a revised version of the Kirk patrick's Four Levels model was defined considering the previous authors experiences presented in Motyl and Filippi (2014b). Kirkpatrick's model is considered a standard in professional training evaluation and it describes four levels of learning outcomes: learners' Reactions, Learning, Behavior and Results (Kirkpatrick, 2007; Praslova, 2010; Shartrand *et al*., 2012). The simplicity of the Kirkpatrick's four level model structure allows gathering and organizing the survey data in a qualitative way. Table 1 reports the revised version of the Kirkpatrick's Four Levels of Evaluation used in this study, with the description of the evaluation metrics and references to the questions used for data collection and reported in the next paragraph.

The questionnaire was set to collect information from all the participants. It was designed referring to the metrics described in Table 1. All the students were asked to answer ten closed questions using a one-to-five scale where one represents the lowest value and five the highest value as explained in the questionnaire. Each question evaluates the two methods singularly. Moreover, an open question was added to collect the personal opinions of the participants. All of the submitted questions are reported in Table 2.

DESCRIPTION OF STUDENTS' TRAINING AND LEARNING EXPERIENCES

First of conducting the workshops experiences, the engineering students belonging to the two courses were introduced to the traditional methods and techniques for

Table 2: Questions submitted to the students

#	Questions text	Methods
Q1	How do you consider the new creativity methods introduced by the workshops?(1 = Not pertinent, 5 = Very interesting)	C-K theory … TRIZ …
Q2	How well was the training structured (e.g., manageable chunks, logical order, linked to objectives)?(1 = Not structured, 5 = Very structured)	C-K theory … TRIZ …
Q3	How do you judge the completeness of the materials supplied? (1 = Incomplete, 5 = Complete)	C-K theory … TRIZ …
Q4	How effective were the materials in helping you to learn? (1 = Noteffective, 5 = Veryeffective)	C-K theory … TRIZ …
Q5	How did you find the content of the training, e.g. amount and difficulty?(1 = Very poor, 5 = Very good)	C-K theory … TRIZ …
Q6	Did you need to clarify some basics concepts during the application of the new methods?(1 = Quite always, 5 = Not at all)	C-K theory … TRIZ …
Q7	Please rate your ability to generate new concepts. (1 = No skill, 5 = Very good skill)	C-K theory … TRIZ …
Q8	Please rate your ability to problem-solving activities.(1 = No skill, 5 = Very good skill)	C-K theory … TRIZ …
Q9	Please rate your ability to manage creativity methods. (1 = No skill, 5 = Very good skill)	C-K theory … TRIZ …
Q10	Overall, how effective do you believe the training was in improving your job performance? (1 = Not effective, 5 = Very effective)	C-K theory … TRIZ …
Q11	Did you perceive an improvement of your engineering design skill during the course?(1 = Not at all, 5 = Very much)	C-K theory … TRIZ …
Q12	Do you think you will be motivated to use and apply the new methods in the future?(1= Not motivated, 5 = Very motivated)	C-K theory … TRIZ …
Q13	Do you think that the creativity methods you have learnt will improve your professional background in product design? (1= Anyimprovement, 5= Severalimprovements)	C-K theory … TRIZ …
Q14	Which tool do you think you know better? (motivate your answer)	Open question

product design and development (Ulrich and Eppinger, 2008). Then, they, during two workshops were introduced to the two selected creativity enhancement methods and they were guided by the instructors in the application of some specific tools belonging to these methods. A preliminary survey allowed verifying that there was no prior knowledge of the two methods between the participants. This way, students have been introduced to the fundamentals of C-K theory or TRIZ by some lectures and using some relevant examples of application taken from literature (Blanchard *et al*., 2013, 2014). After that, the students were invited to apply the new methods, together with traditional ones, such as Brainstorming to some practical engineering design experiences. The instructors suggested the application order of these methods and tools and their execution order was sequential, supposing that order do not affect the development of the experiences.

Two of these experiences, one performed at Cassino and one at Udine, are described in the following sections. They regard the development of a new kind of gym towel and the analysis of a knee implant respectively.

Experience 1: development of a new kind of gym towel: During the first workshop, the students of the "Product Design" course-Master in Industrial Engineering at the University of Cassino were introduced to the problem of the development of a new kind of gym/towel. This way, they first, performed a Brainstorming session, guided by the instructor and focused on the problem of providing a more hygienic, breathable and non-slippery towel than those ones currently available on the market. Some interesting concepts were produced and the attention was focused on the hygienic and breathable characteristics requested for the new towel. Moreover, the session highlighted the ideas that the towel should be more sustainable and eco-friendly in terms of materials and manufacturing process.

After that, an initial concept, namely the C0 concept, was chosen to refine the analysis and to test the application of the C-K mapping technique. The C0 concept selected by the whole group of student was "more hygienic and eco-friendly gym towel". Thus, the concepts and ideas previously generated were re-organized by the students in a C-K map (Fig. 1) to analyze the new problem in a more structured way. The concept space was explored using a depth first strategy and then, in parallel, the knowledge space was built.

The systematic exploration of the concept space conducted the students to the development of some new concepts such as the use of green and organic materials, for example bamboo, or to the implementation of a layered structure of the towel. Another interesting concept, emerged during the experience development, was the possibility of maintaining the hygienic condition of the towel or restoring its initial state with a special container or a sanitizer bag where to store the towel before and after its use.

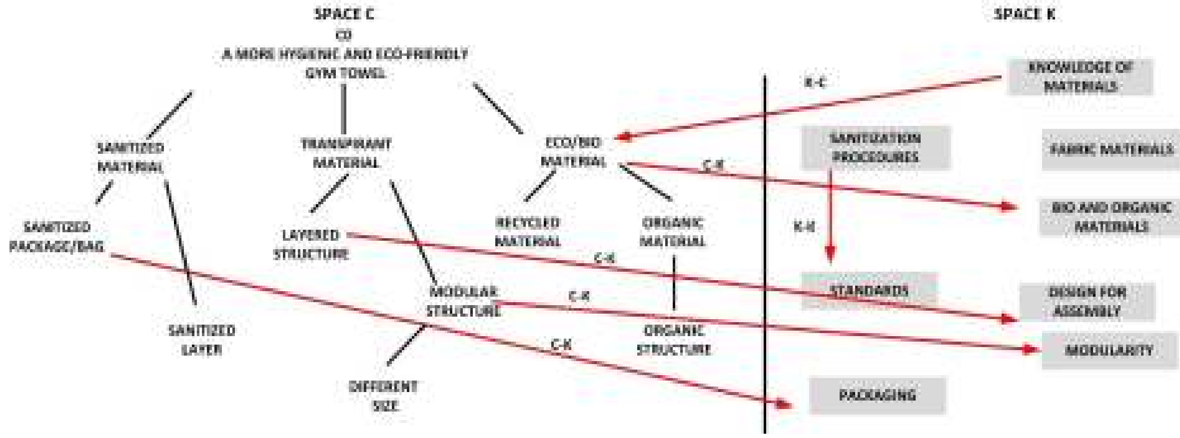


Fig. 1: C-K map for the "more hygienic and eco-friendly gym towel" concept

Table 3: Some prototypes of the solutions for the layered structure proposed by the students

	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Characteristics	Layers sewn only externally	Layers sewn only externally	Layers sewn and quilted externally	Layers sewn and quilted externally
	Network structure of the lattice layer	Drop structure of the lattice layer	Network structure of the lattice layer	Drop structure of the lattice layer

During the second workshop, students were introduced to TRIZ and some of the concepts found by the C-K map were reconsidered as specific sub-problems and were analyzed using TRIZ tools. In particular, the systematic schematization of the concepts highlight that the first problem suggested by the C0 concept "develops a more hygienic and green gym towel" was decomposed into some sub problems. Consequently, two of these sub problems, connected to the definition of the structure of the new towel and to the material or manufacturing process to make the fabric more hygienic were further analyzed. In particular, TRIZ IP were explored to find possible solutions. For example, the "segmentation principle"-IP 1 - may be used to solve the problem of producing a towel with a layered structure. In fact, "segmentation principle" suggests to divide an object or system into independent parts and/or to make an object easy to disassemble. In addition, the "nesting principle"-IP 7- suggests a possible towel structure obtained by placing an object inside another or placing each object, in turn, inside the other and in the current case study this could drive to the definition of a towel structure made by layers of different types of fabric/coating.

On the other hand, the principle "preliminary action" -IP 10-proposes solutions for the sanitation problem by suggesting performing an action before it is needed, to change the object or the system fully or partially. In addition, the principles "dynamics"-IP 15- and "porous materials" -IP 31-may be used to solve this problem. In fact, the principle "dynamics" suggests changing the characteristics of an object, an external environment, or a process to be optimal or to find an optimal operating condition. While, the principle "porous materials", suggests making an object porous or adding porous elements (inserts, coating, etc.) or if an object is already porous, use its pores to introduce a useful substance or function coatings, etc.

After this analysis, the group of students at Cassino arranged to realize the physical prototypes of some of the solutions elaborated in relation to "porous materials"-IP 31. The characteristics of the proposed prototype solutions are summarized in Table 3.

Experience 2: analysis of a knee implant: The group of students of the "Methods for Representation and Development of the Industrial Product" course - Master in Mechanical Engineering at the University of Udine during the first workshop was introduced to the analysis of a knee implant used for Total Knee Replacement - TKR -surgery.

Before starting with the conduction of the case study, given the specificity of the chosen topic, students were introduced, by the instructors, to the basic principles of functioning of knee implants. After that, the fundamental of C-K theory and C-K mapping were introduced to them. During the Brainstorming session, guided by the instructor, the concepts/ideas to generate were focused on finding possible ways of improvement of a knee implant. This Brainstorming session, connected to the analysis of the state of the art in knee prosthesis design, gave some interesting observations. Some of these concerned the need of developing implants for different genders or for different physical and anthropometrical features (the diffusion of the global market has extended the use of knee implants also in the emerging and developing countries where people do not belong to Caucasian race but for example

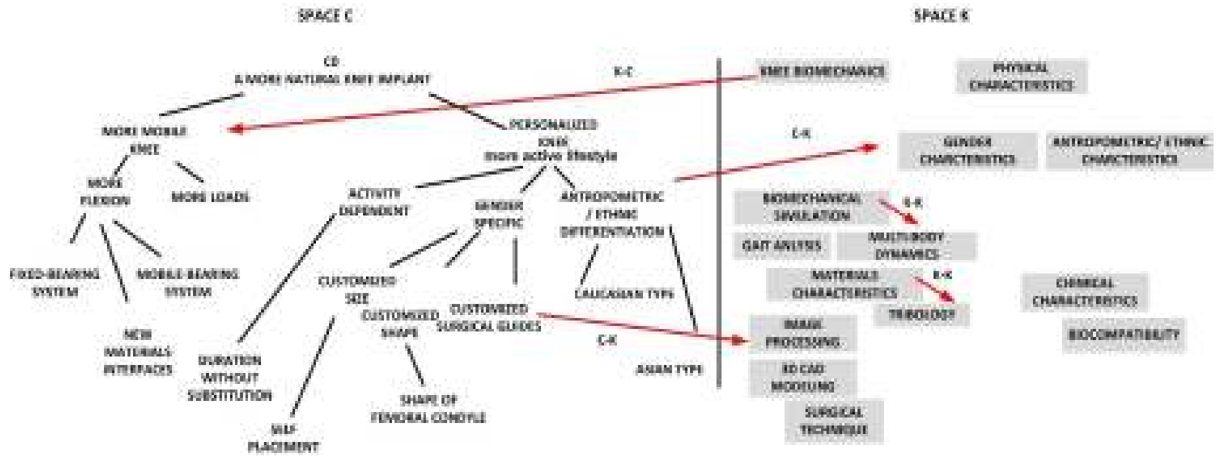
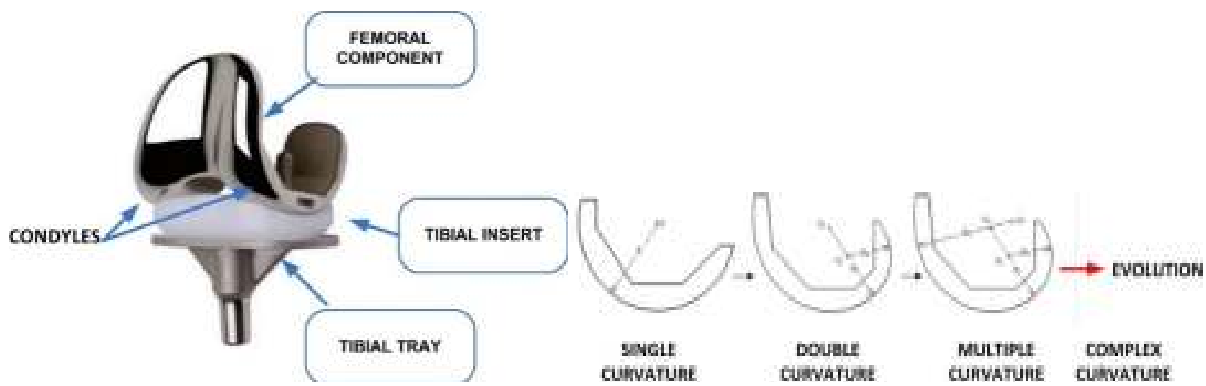


Fig. 2: C-K map for "a more natural knee implant" concept



(a) (b)

Fig. 3: (a): TKR implant and its components; (b): Suggested tend of evolution: Change of implant's femoral condyle curvature in time; adapted from Zhang *et al*. (2009)

to Asian). Moreover, another frequent requirement for TKR implants concerns the improvement of the design of components. Generally, increasingly younger patients ask for more possibility of movement, to consider their need of more active lifestyle. On the other hand, other new requests are connected to cultural habits such as squatting, religious practices, kneeling and sitting cross-legged habits for North Africans population (Hsu *et al*., 2006; Nägerl *et al*., 2008; Carr and Goswami, 2009; Zhang *et al*., 2009; Benabid *et al*., 2011; Motyl and Filippi, 2014a).

From the ideas emerged during the Brainstorming, all the students were asked to realize together a C-K map for the chosen initial C0 concept "a more natural knee implant". First, they explored the space C using a depth first strategy to add some new attributes to the C0 concept and then consequently they built the space K. Figure 2 shows the resulting C-K map.

After the realization of the C-K map, students were asked to choose and analyze some specific concepts, considered as sub-problems using the learned TRIZ tools, in particular the Trends of Evolution. Starting from the ideas collected with the C-K mapping, students used Trends of Evolution to analyze the development of TKR implants under the trends "increased dynamism and controllability" and "increasing ideality" for finding possible connections. The students, guided by the instructor noticed that the shape of the implant's femoral condyles has changed and evolved in the history of TKR implants (Fig. 3a). In particular, the geometry of the implant's femoral component, in correspondence of the condyles, considered in direction of the sagittal plane, evolved, through the years, from single-curvature radius to double-curvature up to three-segment radius and now it is oriented towards multiple-segment radius (Fig. 3b) as suggested in Zhang *et al*. (2009).

Consequently, a possible evolution of the system, following the trends "increased dynamism and controllability" -trend 4 and "increasing Ideality"- trend 2, is directed toward the use of a complex-curvature to mimic the profile of the human femoral condyle. In fact, the use of a complex curvature shape allows considering multiple curvature centers to simulate the

Table 4: Questionnaire results: Average values for each question and average values calculated for each level (Score levels: 1= Poor – 5= Good)

		Average value for collected questions		Average value grouped by evaluation level	
Evaluation levels	Questions	C-K theory	TRIZ	C-K theory	TRIZ
Reaction	Q1	3.25	3.5	3.49	3.59
	Q2	3.35	3.65		
	Q3	3.30	3.85		
	Q4	3.75	3.90		
	Q5	3.80	3.05		
Learning	Q6	2.75	3.50	3.063	3.513
	Q7	3.20	3.30		
	Q8	2.90	3.75		
	Q9	3.40	3.45		
Behavior	Q10	3.50	3.60	3.733	3.883
	Q11	3.95	4.05		
	Q12	3.75	4.00		
Results	Q13	3.80	3.95	3.80	3.95

real rollback movement of a normal knee. Another trend to study could be the “change of symmetry and asymmetry” -trend 6. In fact, regarding the shape of knee implant components, considering the models currently available on the market, it could be noticed a change from symmetric to asymmetric shape for the lateral and medial compartments of the knee implant, represented in the sagittal plane.

RESULTS AND DISCUSSION

After the experiences development, all of the students, involved in the research, were asked to answer to the questionnaire previously illustrated. Then, the collected data were analyzed using the metrics previously defined and grouped level by level considering the revised version of Kirkpatrick’s Four Levels. The values for each method are calculated, level by level, as the arithmetical average of the averages values calculated for each group of questions belonging to a specific level on the basis of the collected students’ answers such as reported in Table 4.

The results of the interview show that the participants have differently experienced the two methods. The main observations, related to the characteristics highlighted thanks to the questionnaire results, are reported in the following, using the level by level distinction introduced with the new proposed evaluation framework.

At Reaction level, information on participants’ view on learning experience, such as the interest in the topics of the training, in the completeness and usefulness of supplied materials, in the training structure and in encountered difficulties, were collected. For this level, the differences perceived for the two methods are quite pronounced, with a prevalence of TRIZ on C-K theory. The course organization and materials completeness are positively judged by all the participants. In particular, students highlighted the differences of completeness of C-K materials compared to those of TRIZ tools and the consequent need have clarified some C-K concepts during the lessons. The reason for this judgement may be dueto that C-Ktheoryis much younger, as it has been formulated quite recently and it has a limited series of examples and case studies available in literature.

The cumulative data of the Learning level, which evaluates the changes in attitudes, knowledge and skills, such as the ability to generate new concepts, the problem-solving skill or the creativity method management, also highlighted a strength prevalence of the TRIZ in respect to C-K theory.

In particular, regarding the acquisition or the improvement of new skills, considered with questions Q7, Q8 and Q9 that are reported in detail in Table 2, the ability of generating new concepts, TRIZ method reached the highest evaluation. In addition, regarding the problem solving expertise TRIZ, with is well-structured framework, gained the highest evaluation. Finally, considering the skills in managing creativity methods, TRIZ and C-K theory collect quite the same score.

For the Behavior level, which considers changes in practice and the application of learning to practice, the collected answers highlighted a prevalence of TRIZ.

Finally, in the Results level, where the changes at the level of the learner and of the organization are investigated, TRIZ and C-K theory reach quite the same score.

The overall results show different perceptions of easiness of use and learning by the students. The analysis of the data highlight the advantage of using structured methods by the students since they guide the user during creativity and idea generation processes. In particular, TRIZ has been highlighted by the majority of them because of its structured form. Considering the questionnaire overall results and considering all levels grouped by methods, (Fig. 4), it is possible to assume that the Learning and Reaction levels obtained the lowest rate. This may be a sign that students have not yet perceived a mastery of the methods in such brief time, while for the two other levels they consider

Fig. 4: Average level results grouped by methods

positively the new tools learned as potential sources of improving their design and professional skills, considering them useful for subsequent future professional activities.

Considering the answers related to the open question the majority of students (16 of 20 students in Udine and 13 of 20 in Cassino) indicated that the method which they think to know better, after lectures and practical exercises, is the TRIZ. Inparticular, it is noted that the students' comments on TRIZ reported that it is a well structured method, rich of application examples also available for the students. On the other hand, the comments reported for the C-K theory concerned the fact that, this method is very recent and it is perceived by students as an advantage to be exploited at the professional level.With regard to the analysis of the two experiences, it highlighted the possibility of the application of the creativity enhancement tools in combination with traditional tools, such as Brainstorming, traditionally used for concept and idea generation steps.

Only some tools coming from TRIZ and C-K theory where used and students were guided during the development of the case studies to simplify the application of the new tools. In particular, they were suggested to follow the application of the methods and tools in sequence: Brainstorming first, then customers' interviews, C-K mapping and TRIZ tools. This way, students directly executed the application of Brainstorming -the most used traditional tool - in combination with the new ones. With regard to the effective implementation of the concepts learned while the application of C-K maps it has been possible in both experiences and it was judged quite simple by the students. The application of TRIZ tools was not performed in the same manner in the two experiences due to the different content of the two courses' programs. In fact, during the first experience, students easily found some IP to apply to the gym -towel problem. However, they highlighted difficulties in the definition of a functional map or in the application of Trends of Evolution mainly due to the shorter time spent on dealing with these arguments within the course. On the contrary, during the second experience, the application of TRIZ tools resulted more complete and the students encountered fewer difficulties in achieving a functional diagram for the given problem and in the application of Trends of Evolution. The overall results of the experiences evaluation highlight the advantage of using structured methods by students as non-expert users since they guide the user during creativity and idea generation processes. In particular, TRIZ method and tools has been highlighted by the majority of the participants because of its structured form while C-K theory method was perceived as the most new, less know and more promising. Finally, this study represent one of the first examples of the combined introduction of TRIZ and C-K theory methods and tools in an Engineering Education context and it also may be considered a practical application of the proposed evaluation framework.

CONCLUSION AND FUTURE DEVELOPMENT

In this study, the application of some TRIZ and C-K theory tools as creativity enhancement tools during concept development and idea generation steps is described. In addition, the description of some experiences performed in university courses to improve students engineering design skills is reported. Then, an evaluation of the student's learning experience, based on a questionnaire, designed in function of a revised version of the Kirkpatrik' straining evaluation levels was done.

As a result, starting from the qualitative survey done at the end of the courses, it turned out that students appreciated the possibility to extend their design skill thanks to learning how to use systematic, creativity and innovation methods and tools. The structured and sequential application of C-K theory and TRIZ tools highlighted their easiness of use and their potentiality as creativity enhancement tools. Students, who had not previous experiences about these methods, appreciated the introduction of the new tools and theories during the courses. Likewise, they have shown interest in the application of these methods to real case studies and appreciated the opportunity to work in groups. Even according to the students, the use of the C-K map has contributed to a better organization of ideas and the usage of TRIZ has highlighted some difficulties, in particular in the practical application of the learned methods and tools. Also, in authors' opinion, C-K mapping represents a valid tool to explore the design space in a structured way, mainly at the concept development level, also considering knowledge requirements of the its users. In addition, the link between knowledge and concepts obtained by the map puts to evidence the feasibility of the developed concepts. Moreover, C-K map allows a more precise characterization of the design problem under consideration and it allows the consequently aware introduction of other analysis tools such as the TRIZ tools.

Moreover, these experiences represented a valid mean for engineering design training and for self-training if adequately structured and supplied with materials containing relevant examples of application.

Future developments may consider the use of a customized questionnaire and the definition of specific metrics for assessing the experience gained by the students in a quantitative way and the evaluation of the creativity potential reached by using the different methods. It may also be consider the influence of cultural and previous knowledge of the students and the level of understanding of the new methods. Furthermore, it may also be evaluated the iteration of the experiences and a more emphasis on the explanation of TRIZ procedures such as the use of different kinds of Functional Analysis and of the Trends of Evolution. Moreover, the evaluation framework may be extended to other creativity and idea generation methods focused on product/process or service innovation and improvement.

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