Comparison of Creativity Enhancement and Idea Generation Methods in Engineering Design Training

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Abstract. The research presented in this paper aims at evaluating how simple and intuitive are the learning, understanding, and application of some creativity enhancement methods by non-expert users in an engineering design context. The three methods under investigation are TRIZ, C-K theory and SCAMPER. To evaluate the training experience the authors set an evaluation framework based on Kirkpatrick's Four Levels of Evaluation and used a questionnaire to collect students' experiences. The results show that the understanding and the consequent application of the three creativity enhancement and idea generation methods are judged positively by the participants. In particular, TRIZ method represents the most appreciated at all, while SCAMPER stands out for its intuitiveness and easiness of use. Finally, C-K theory is revealed as the newest one and very promising for future developments.

Keywords: TRIZ, C-K theory, SCAMPER, training evaluation, engineering education.

1 Introduction

The research presented in this paper aims at evaluating how simple and intuitive are the learning, understanding and use of some creativity enhancement and idea generation methods by non-expert users in an engineering design context.

Product design and development methods are composed by techniques and tools that help engineers and designers in carrying out their task. These methods usually belong to design theories with a proper ontology that describes the rationale of design thinking that characterizes the designers during all the phases of product development.

There are many methods to be used for these purposes. Among the best known there are brainstorming, lateral thinking, six hats, analogies, functional analysis, morphological analysis and SCAMPER. Among design theories that stimulate creativity, C-K theory and TRIZ represent the most structured ones, with dedicated tools to help designers in the development of their work [1-3].

This research aims at investigating how simple is to teach and to learn enhancement creativity methods which are mostly used in the first phases of the product development for concept and idea generation. To test the teachability and learnability of these methods, three of them were selected to assess these skills, considering the experience of involving users with any knowledge of these methods.

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In particular, the selected methods were TRIZ, C-K theory and SCAMPER. The choice fell on these methods because although they are known, literature lacks of studies concerning their ease of learning and use. In addition, in literature a great variety of examples belonging to the application of TRIZ and C-K theory and their relative tools are present. On the other hand, SCAMPER method was chosen because it represents an intuitive methodology for the development of creative thinking skills a little less widespread than brainstorming but also well-structured and intuitive [1-3].

The paper is outlined as follows. After the introduction section that motivates the research, in the second section, the background, the three methods under investigation are presented. Third section explains the development of the experiment with the description of the activities done and of the measured characteristics. In the fourth section, data collected by a questionnaire survey are analyzed and results are reported. Finally, conclusions and future development are set.

2 Background

The methods considered are TRIZ, C-K theory, and SCAMPER. These methods have been chosen because of their application in a wide range of literature publications and for their emerging interest by companies, including SME's. Moreover, knowledge and use of these methods represent an interesting addition to engineering design education and training for new graduates and for their introduction in the world of work. For this reason, the research has been developed during a post-graduate engineering course for mechanical engineers.

2.1 TRIZ

TRIZ - the theory of inventive problem solving - was developed by G. Altshuller to support engineers and scientists in solving problems using the knowledge of former inventors [4]. 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 - IP. This tool 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 [5-6]. The IP and their use are relatively easy to explain and to employ, even if the users have never seen them before.

2.2 C-K Theory

C-K theory - or Concept-Knowledge theory - is a unified design theory introduced by Hatchuel et al. [7]. The name 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. A fundamental tool of this theory is represented by the C-K map. 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 [7-9].

2.3 SCAMPER

Finally, SCAMPER - the acronym for Substitute-Combine-Adapt-Modify-Put_to_other_uses-Eliminate-Rearrange - refers to a problem solving method developed by Eberle for generating creative concepts. It uses a general-purpose checklist with direct and idea-spurring questions to suggest some addition to, or modification of, something that already exists. The stimulus comes from being asked for answering questions that one would not normally pose [10-11].

3 Activities

In order to compare the methods, the authors have set up the following approach. The methods have been presented to the audience, consisting of students, master thesis students and Ph.D. fellows. Then, after the definition of some evaluation metrics, data about the user experiences have been collected and analyzed.

3.1 Introduction of the Methods

The three methods under investigation have been introduced during the lectures of the course “Representation methods and product development” of the MS in mechanical engineering. The participants have been introduced to the fundamentals of the three methods by classroom lessons with the use of slides and selected papers to read. Then, some relevant examples of application, selected form literature, have been presented, without any particular comment on their development [4-11].

Specifically, TRIZ theory was presented focusing only on one of its tools: the Inventive Principles. C-K theory fundamentals were introduced, together with some C-K mapping examples; finally, SCAMPER method was described, focusing the attention on the list of questions to follow for its application in an ordered way.

3.2 Methods Application/Experiences

After a few days, participants were invited to apply the three methods to some practical engineering design problems and design situations extracted from literature or suggested by the instructors' experience.

These design situations focused on: 1) the design of a new office table for alternating standing and sitting positions [1-2]; 2) the design of a novel kind of nut for long threaded shafts [12]; and 3) the design of a novel kind of gym towel. The first two problems were chosen because they appear in some literature examples that the authors consider of future interest for making further comparisons. The third problem was suggested by the instructors because it was used in another experience during previous editions of the course.

A design of experiments with twenty participants was planned. The participants were fifteen students of the MS course, three MS thesis students and two PhD students.

The participants were divided into five teams of four members each: three graduated students plus one MS thesis or a PhD student. Each team was asked to work in a two-hour session and to apply all the method to solve the three different problems in a random order. The experience was developed in three weeks.

During the experiences, teams were supervised by the instructors but they do not receive any suggestion from them; anyway, each team was allowed to consult course materials (slide, lectures and examples) but they are not provided with internet connection.

3.3 Evaluation Framework

In order to evaluate how effective the training was, authors adopted a revised version of the Kirkpatrick's Four Levels of Evaluation [13-16]. This model is considered as a standard in professional training evaluation. It describes four levels of outcomes: learners' Reactions, Learning, Behavior, and Results.

Table 2 reports the revised version of the Kirkpatrick's Four Levels used in this work, with the description of the evaluation metrics and references to the questions for data collection reported in the next section.

Table 1. The revised Kirkpatrick's Four Levels of Evaluation used in this study

Level	Metrics	Questions
Reaction: participants' view on the learning experience	Interest: how participants 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 trainee knowledge and the processes of knowledge acquisition, organization and application.	Q6
	Skill outcomes: the trainee development of technical skills.	Q7 Q8 Q9
	Attitudinal outcomes: attitudes, motivation, and goals relevant to the objectives of the training program.	Q10

Table 1. (*continued*)

Behavior: changes in practice and application of learning to practice	Behavior: the degree of transfer from what was learned to how the trainee behaves on the job, which in turn determines how much organizational impact the training can have.	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.	Q13

3.4 Data Collection

A questionnaire was set to collect information from all the participants. The questions were designed referring to the metrics described in table 2. Participants were asked to answer the 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 all the three methods singularly.

At the end of the survey, one open question collects possible participants' opinion to consider for future improvements of course contents and organization. Questions are reported in table 2.

Table 2. Questions of the survey

#	Questions text
Q1	How do you consider the creativity methods introduced by the course? (1 = Not pertinent, 5 = Very interesting) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q2	How do you judge the completeness of the materials supplied? (1 = incomplete, 5 = complete) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q3	How well was the training structured (e.g., manageable chunks, logical order, linked to objectives)? (1 = Not structured, 5 = Very structured) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q4	How effective were the materials in helping you to learn? (1 = Not effective, 5 = Very effective) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5

Table 2. (*continued*)

Q5	How did you find the content of the training, e.g. amount and difficulty? (1 = Very poor, 5 = Very good) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q6	Did you need to clarify some basics concepts during the application of the three methods? (1 = Quite always, 5 =Not at all) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q7	Please rate your ability to generate new concepts (1 = No skills, 5 = Very good skills) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q8	Please rate your ability to problem-solving (1 = No skills, 5 = Very good skills) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q9	Please rate your ability to creativity method management (1 = No skills, 5 = Very good skills) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q10	Overall, how effective do you believe the training was in improving your job performance? (1 = Not effective, 5 = Very effective) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q11	Did you perceive an improvement of your skills during the course? (1 = Not at all, 5 = Very much) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q12	Do you think you will be motivated to use and apply the learned creative methods in the future? (1= not motivated, 5 very motivated) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q13	Do you think that the creativity contents you have learnt will improve your professional background in product design? (1= No improvement, 5= Several improvements) SCAMPER 1 2 3 4 5 C-K theory 1 2 3 4 5 TRIZ 1 2 3 4 5
Q14	How do you think the training materials and course could be improved?

3.5 Analysis and Synthesis of Collected Data

The collected data from the survey have been analyzed using the metrics defined previously and grouped considering the Kirkpatrick's Four Levels of Evaluation: Reaction, Learning, Behavior and Results.

The synthesis of the collected data, subdivided for the three creativity methods is reported in figure 1. The values for each method are calculated, level by level, as the arithmetical average of the averages values calculated based on the values obtained for each group of questions and in function of the students' answers.

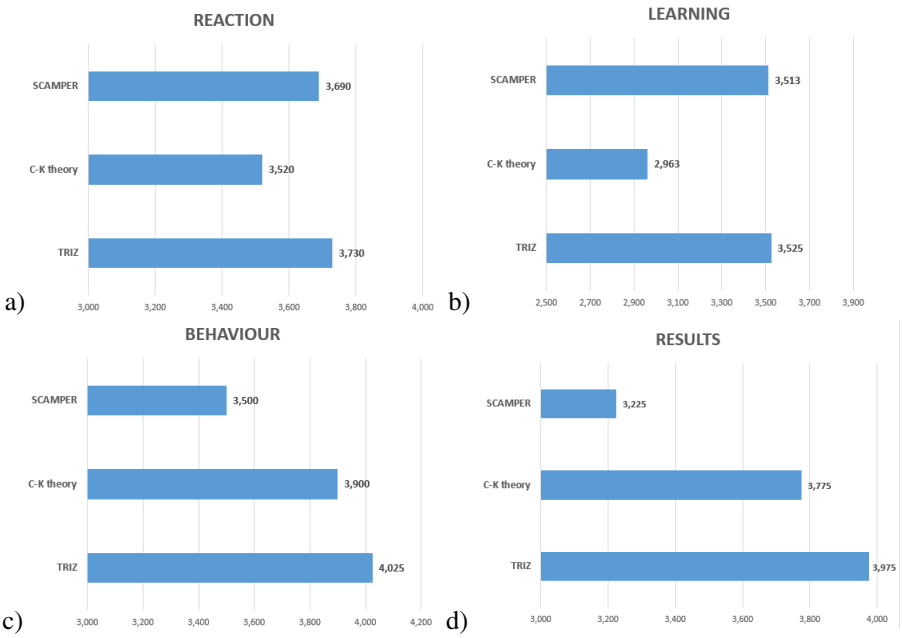

Fig. 1. Cumulative results for the three methods: a) Reaction level; b) Learning level; c) Behavior level and d) Results level

4 Results and Discussion

The results of the investigation show that the three methods have been differently experienced by the participants. The main observations, related to the characteristics highlighted thanks to the questionnaire, are reported, level by level, in the following.

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, TRIZ and SCAMPER methods report similar evaluations with a slight prevalence of TRIZ.

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, highlighted a prevalence of the TRIZ and SCAMPER methods in respect to C-K theory. In particular, regarding the acquisition or the improvement of new skills as the ability of generating new concepts, the SCAMPER method has reached the highest evaluation, followed by TRIZ and C-K theory. 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 the same highest 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 followed by C-K theory on SCAMPER method. 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 are slightly ahead on SCAMPER as well.

The three methods show different levels of easiness of use perceived by the participants. The training organization and materials such the use of frontal lessons, slides and their direct application to some real cases of study are positively judged by all the participants. The need of further in-depth study has been highlighted by only few of them in the case of C-K theory that is also the youngest of the three method, as it has benne formulated quite recently and it has a limited series of examples and case studies available in literature.

The overall results of the analysis highlight the advantage of using structured methods by non-expert users since they guide the user during creativity and idea generation processes. In particular, TRIZ has been highlighted by the majority of the participants because of its structured form. Then SCAMPER and C-K theory follow. SCAMPER has been indicated as the most intuitive and it represent a method that can be learned easily in comparison to C-K theory.

5 Conclusions

This paper describes the comparison of three different creativity and idea generation methods, TRIZ, C-K theory and SCAMPER, against their learnability, use and easiness of understanding.

For this evaluation, the authors set an evaluation framework using a revised version of the Kirkpatrick's Four Levels of Evaluation and designed a specific questionnaire.

The results show that the understanding and the consequent application of the structured and intuitive methods for creativity enhancement and idea generation are judged positively by non-expert users. Regarding the four levels of evaluation considered, TRIZ represents the most rated method, while SCAMEPER was appreciated mostly for its intuitiveness and easiness of use. Finally, C-K theory has proved to be the newest and most promising for future developments.

As a result, the training experience proposed by the course with the introduction of the three methods was judged very positive.

Moreover, this course represents a valid tool for engineering design training and also for self-training if adequately structured and supplied with materials containing relevant examples of application.

Further developments may concern the quantitative evaluation of the characteristics used in the research or the introduction of other adequate metrics. 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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