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TESTING THE VALUE OF TRIZ AND ITS DERIVATIVES FOR KNOWLEDGE TRANSFER IN PROBLEM SOLVING ATTEMPTS BY MULTIDISCIPLINARY TEAMS

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ABSTRACT
The design process of ever more complex products requires an increasing amount of knowledge originating in ever more distant domains of expertise. However, in order to make the knowledge transfer (KT) process more effective, researchers ask for processes which foster the transformation and translation of knowledge. In this respect, KT approaches which are based on the systematic use of electronic databases have their limits.
Therefore we claim that there is a need for a framework capable of facilitating multidirectional knowledge sharing and thus knowledge transfer during face-to-face working sessions. We think that the well recognized performance of TRIZ and its derivatives in technological problem solving can be transferred to problem identification, modeling and solving in other domains like life sciences. Thus the said methodologies could contribute significantly to innovative product design by linking problems to solutions in distant domains.
In this article, we report on a large scale experiment to test this assumption and present some interesting findings on the influence of group composition and methodology on KT during problem solving attempts by multidisciplinary teams.

Keywords: knowledge management, design management, teamwork, TRIZ, creativity

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1 INTRODUCTION

Knowledge Transfer (KT) both from ‘applied’, and ‘basic’ research, is vital to modern research and development (R&D) processes (Luintel and Kahn, 2011) and thus also to design processes. Scientific knowledge is especially important when technological progress is the result of recombination of highly coupled components (Fleming and Sorenson, 2004). However very often industrial companies, particularly small and medium size enterprises (SMEs) which are frequently the main drivers of technological innovation, are dependent on external knowledge (Braun and Hadwiger, 2011). Due to increased costs, smaller companies are less active in international KT projects (Huggins et al., 2010) and thus they are more reliant on regional partners. Finally, Kaufmann and Toedtling (2001) state a lack of success of technology centers in stimulating the collaboration between science and industry. In order to improve this situation, they suggest a shift from mediation to translation of scientific knowledge in order to improve the KT process. Based on findings on KT research, knowledge sharing (KS) and group creativity, we argue for a framework capable of facilitating the sharing and transfer of knowledge from distant domains in face-to-face problem solving sessions. We shall be testing the appropriateness of the Theory of Inventive Problem Solving (TRIZ) and its derivatives as such a framework in an experiment with 20 mono- and multidisciplinary groups on a problem related to life sciences. We shall discuss some interesting findings on the value of this methodology for the products of multidisciplinary problem solving and its implications for KT.

2 STATE OF THE ART

In order to develop an approach for the facilitation of the transfer of distant domain knowledge for collaborative problem identification and problem solving, it is important to recall basic concepts of knowledge and KT. When it comes to problem identification, problem solving and knowledge sharing, TRIZ is interesting. Hence we will be introducing this theory here.

2.1 Knowledge creation, knowledge transfer and associated problems

Nonaka (1994) states that knowledge creation happens through the ‘flow of information, anchored on the commitment and beliefs of its holder’ (p. 15) and stresses the important relation between knowledge and human action. He also defines four modes of knowledge creation and distinguishes between the processes of conversion between tacit and explicit knowledge (Table 1). According to Polanyi (1966), tacit knowledge is here, referred to as having a personal quality making it hard to communicate whereas explicit knowledge can be codified in signs.

Table 1: Modes of knowledge creation through knowledge conversion

		To	
		Tacit knowledge	*Explicit knowledge*
From	*Tacit knowledge*	**Socialization**	**Externalization**
	Explicit knowledge	**Internalization**	**Combination**

Blackler (1995) identifies five types of knowledge in literature: embrained knowledge which depends ‘on conceptual skills and cognitive abilities’ (p. 1023); embodied knowledge which is ‘action oriented and likely to be only partly explicit’ (p. 1024); encultured knowledge which represents ‘the process of achieving shared understandings’ (p. 1024); embedded knowledge which is inherent to systemic routines; and encoded knowledge which is communicated through signs and symbols. According to Blackler, trends of increasing emphasis on encultured and embrained knowledge can be observed in organizations. Regarding academic-industrial cooperation and KT (particularly including SMEs), Braun and Hadwiger (2011) identify several problems which they classify as problems on the donor (academic) and on the receiver (SME) side (Table 2). Van Dierdonck and Debackere (1988) identify so called collaboration barriers, which are classified into cultural barriers, institutional barriers and operational barriers (Table 2).

Some of the above mentioned problems in KT can be linked to problems in KS. According to Cummings (2004), KS is defined as a provision or a receipt of information, know-how and feedback specific to a task. It includes the implicit assessment and coordination of expertise in a working group. Wang and Noe (2010) stress the differences between KS and KT which has been used in order to describe knowledge movement between units, divisions, and organizations. In the same paper, Wang and Noe stress the importance of face-to-face interactions when it comes to the sharing of more ‘sticky’ knowledge (Szulanski, 2000). The importance of face-to-face interactions for KT is empirically supported by Almeida and Kogut (1999) who found that inter-firm mobility of engineers is closely linked to local knowledge transfer. Authors like Autio (1997) and Fontes (2005), in spite of ‘simple transfer’ (p. 339), ask for the transformation and translation of knowledge in order to increase its accessibility to different cognitive contexts. Finally, Roberts (2009) states that the increased use of information and communication technologies in knowledge management can lead to ignorance since it often reduces complex and rich knowledge to small components that seem most important. Attempts of this kind of transformation and translation are those of Shai et al. (2009) and Schöfer et al. (2012) who try to bridge the processes of scientific and industrial design knowledge creation. The former describe creativity in science as a design process and model the process of discovery of a physica force with a C-K perspective (Hatchuel and Weil, 2003). The latter, after giving a literature review on scientific research methodology, use the C-K framework in order to model scientific reasoning and insight. Furthermore, they propose the use of TRIZ tools for problem structuring and KT in the domain of life sciences.

Table 2: Problems and reasons for problems in KT

<table>
<tr><th>Braun and Hadwiger (2011)</th><th>Van Dierdonck and Debackere (1988)</th></tr>
<tr><td>Problems on donor side:
- assumed advantage of exclusive knowledge possession
- lack of ability for knowledge transfer to non-specialist
- lack of direct contact with industry partner
- language and culture barriers</td><td>Cultural barriers:
- different missions and goals
- diverging Intellectual Property (IP) and secrecy policies
- lack of harmony of assumptions and harmony of languages</td></tr>
<tr><td rowspan="2">Problems on receiver side:
- missing trust
- lack of structures capable of knowledge processing
- missing expertise with regard to KT
- problems of language and culture</td><td>Institutional barriers:
- differences concerning nature of work
- different perceptions of the product of R & D processes
- structure and responsibility changes on industrial side</td></tr>
<tr><td>Operational barriers:
- deficient knowledge about knowledge of partner
- insufficient coordination and project management
- lack of acceptance of results of the partner’s processes</td></tr>
</table>

2.2 Existing knowledge transfer approaches

Existing knowledge transfer approaches and tools for their support can be divided into

- Knowledge transfer offices (Porcel et al., 2012)
- Recommender systems (Porcel et al., 2012)
- Semantic analysis tools (Litvin, 2005)
- Methodology for solution modeling and solution transfer (Vincent et al., 2006)

Some of these approaches use TRIZ methodology. All of these approaches feature significant drawbacks: First, knowledge transfer offices, recommender systems and semantic analysis tools are capable of transferring only explicit, codified knowledge. Second, most of the approaches allow the retrieval of information, but they are not capable of interpreting this kind of information. Third, these approaches are designed for unidirectional transfer of solutions only to well identified problems of the industrial domain.

2.3 Group creativity, group diversity and shared mental models

Research in group creativity provides interesting insight in order to understand problems with knowledge processing and KS in face-to-face working groups. Diversity in teams has positive and negative effects on team performance. Ancona and Caldwell (1992) suggest that functional diversity can have a positive effect on problem solving and product development, but they also mention that it negatively influences implementation of innovation due to reduced capability for teamwork. Tajfel *et al.* (1971) show that social group discrimination in heterogeneous working groups can lead to non-optimal group decision processes. Moreover, Stasser et al. (2000) show that indicating a group member’s expertise to the other members does not facilitate the pooling of unshared information among the participants. On the other hand, De Dreu and de Vries (1996) point out that input stemming from a minority group member leads to divergent thinking at other group members. Finally some research (e.g. Mumford et al., 2001) has shown that shared mental models positively affect creative performance in groups when it comes to the extension and elaboration of ideas but not when it comes to the number of generated ideas.

2.4 TRIZ and its derivatives

TRIZ is based on the analysis of nearly two million patents (Savransky, 2000) and has its origins in the work of Altshuller (1996).

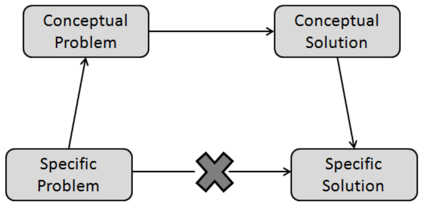

Figure 1: TRIZ problem solving process

The theory states the following: In order to find a solution to an inventive problem, the inventor has two possibilities: (1) He can randomly produce solution concepts and test them in a trial-and-error procedure. (2) He can transform the initial inventive problem into a more generic problem model; then, he can apply specific solution heuristics in order to generate conceptual solutions for the generic problem; and finally, he can transform the conceptual solutions into specific solutions responding to the initial specific problem (Figure 1). According to TRIZ, the second process leads to more adequate results and is less time consuming. In order to support the inventor during this process, TRIZ provides a certain number of heuristics and tools for problem definition, problem analysis, and problem solution. Schöfer et al. (2012) give an overview on examples of TRIZ concepts and tools which have been used by other authors to model and understand scientific reasoning and problem solving in mathematics, physics and life sciences. Two examples for the application of TRIZ are the modeling of the development of methods in numerical mathematics using Inventive Principles (Berdonosov and Redkolis, 2007) and the discovery of the causes of Russell's Effect using Physical Contradictions and Separation Principles (Altshuller, 1983). Schöfer et al. (2012) also present a descriptive model of processes in human physiology which has been inspired by TRIZ analysis tools. Further researchers and engineers have developed several approaches to modify, simplify and adapt TRIZ like Systematic Inventive Thinking (SIT), Advanced Systematic Inventive Thinking (ASIT) (Horowitz, 1999) and Unified Structured Inventive Thinking (USIT) (Sickafus, 1997).

2.5 Conclusions

From the above mentioned findings we infer that there is a need for a methodology which is capable of facilitating KT by face-to-face working sessions of multidisciplinary teams (Roberts, 2009). Here, multidisciplinary explicitly includes domains that are distant not only in terms of knowledge, but also in terms of cognitive style (Jablokow, 2005) and in terms of contexts of knowledge creation (Yakhlef, 2007). More specifically, the methodology should allow joint problem identification, problem analysis, problem modeling, and generation of solutions by the integration of knowledge and technologies which are owned by the team members. Furthermore, the methodology should facilitate the transformation (Autio, 1997; Fontes, 2005) and the mutual exchange of distant and sticky knowledge (Szulanski, 2000). We believe that TRIZ methodology and its derivatives feature concepts and tools that bear potential value for such a methodology. The value of the said methods can be derived from the following features:

- They dispose of several problem analysis tools, e.g. the System Operator Tool (SOT) (Savranksy, 2000) which cannot only be applied on technological systems but also on biological systems (Schöfer et al., 2012) as well as on structures in the domain of physics and chemistry (Altshuller, 1983).
- Other problem analysis and problem modeling tools like the Closed World Algorithm (CWA) (Sickafus, 1997) or Su-Field Modeling are useful for making specific problem settings accessible to non-experts by using generic vocabulary.
- Other concepts and tools, e.g. the Ideal Final Result (IFR) (Altshuller, 1996) or the Particles Algorithm (PA) (Sickafus, 1997) can be used in order to overcome mental inertia and to identify knowledge and technologies which are useful for the solution of problems (both in technological

and non technological domains). The PA, for example, can lead, in combination with the SOT, to the identification of items, effects and technology whose combination requires the knowledge of different scientific domains but which can lead to innovative solutions to a problem at hand.

3 EXPERIMENTATION

In order to test the value of TRIZ methodology and its derivatives for KS and thus mutual KT during interdisciplinary problem solving sessions for problems in non-technical domains, the authors carried out the experiment described below. The problem setting originating in life sciences was chosen because KT between engineering design and this discipline is considered to be of growing industrial importance, e.g. in biotechnology.

3.1 Demographics

The participants were 60 graduate students. 45 of them had a life science background (LS), which means their undergraduate courses focused on topics like biology, chemistry and/or, in the broader sense, life science. 15 participants had a background in mechanical engineering (ME), i.e. their undergraduate courses focused on topics like mathematics, mechanics, thermodynamics, etc.

3.2 Training

At day one, the participants were divided into two groups. One group, consisting of 23 participants with a LS profile and seven participants with a ME profile, obtained a 4.5 h training on classical creativity methods (CC), i.e. Mind Mapping and Brainstorming. The other group, consisting of 22 participants with a LS background and eight participants with ME background obtained a 4.5 h training on the basics of TRIZ and its derivatives (TD). The training of the second group was designed to provide the participants, in very short time, with basic knowledge about significant methods and tools of TRIZ and its derivatives. Examples are overcoming mental inertia (Altshuller, 1996), dialectical principles (Duran-Novoa et al., 2011), and so on. In order to provide methods which cover the whole problem solving process (as described in TRIZ theory), we identified different tools in literature (Nakagawa et al., 2002; Nakagawa et al., 2003) and mapped those tools which have an identical or similar purpose. At day two, the participants were assigned to 20 groups. Half of the groups were composed of participants who attended the training in classical creativity methods and the other half was composed of participants who attended the training on TRIZ and on its derivatives. A second criterion of the group's composition referred to their respective academic background. Nine groups were composed of three participants with LS background (LS-G), another nine groups were composed of two participants with an LS background and one participant with a ME background (LS/ME-G), respectively. Finally, two groups were composed of three participants with ME background (ME-G).

3.3 Procedure

The whole experimentation took two days (with one week distance in between). On day one, the participants received a brief introduction on the problem which would be to solve on day two and then obtained the 4.5 h trainings. On day two, the 20 groups were asked to find solutions to a problem in the medical domain: cancer treatment through radiation and the challenge of not harming or altering healthy tissue next to, or around the cancerous tissue (Duncker,1945 in Gick and Holyoak, 1983). This was done in order to give the participants the possibility to transfer the knowledge acquired during the training. This two hour process will later be referred to as the Pedagogical Case Study (PCS). The participants were asked to document the outcome of each problem solving step on specific documentation sheets. These worksheets should, first, help the participants to structure their problem solving process, and, second, allow a later documentation and analysis of the outcome of the process. The documentation sheets consisted of four different types: one sheet for the identification of the problem, one sheet for problem structuring, one sheet for divergent concept generation and one sheet for the convergent generation of final solutions. Even though the PCS was not sought to be analyzed, it was used to familiarize the participants with the documentation sheets. At the end of each problem solving step, the groups were provided with possible outcomes of the respective problem solving step. The participants were free to base the subsequent problem solving steps on the provided outcomes or on their own ones. They were also allowed to ask questions about the problem setting and the methods and tools they were sought to use. Following the PCS, the participants who attended the TD training were asked to answer to a questionnaire. The latter inquired into their subjective perception on their initial knowledge about the treated problem, their motivation to do so and the perceived value of the concepts and tools acquired during the TD training for problem understanding, problem solution and group communication. Then the groups were reminded the second problem to treat during the experimentation. The task was to find creative solutions to the problem of Adenovirus infection of children who are immune-suppressed due to recent bone marrow transplantation. Three days before day two, each participant had received a certain number of scientific papers in order to better understand the specific problem. The participants were encouraged to use every means and knowledge they wanted in order to find creative solutions to the problem. The participants had 3.5 hours time for the identification of the problem, the generation of solution concepts in a divergent phase and the synthesis of the most interesting concepts into so called final solutions. The participants were asked to document their reasoning, the problem statement, the problem analysis, the concepts, and the final solutions on the documentation sheets. In the end, every participant was asked to answer a second questionnaire with regard to his/her subjective perception on his/her initial knowledge on the treated problem, their motivation to do so and the perceived value of the concepts and tools acquired during the respective training (TD or CC) for problem understanding, problem solution and group communication.

3.4 Evaluation of concepts and solutions

The evaluation of the output of the experimentation, i.e. the generated concepts during the divergent phase and the final solutions during the convergent phase, was executed by domain experts. The experts were asked to evaluate the output on 7-point Likert-type items according to the following five independent criteria: feasibility, applicability, effectiveness, profundity, and originality (profundity being a mixture of implicational explicitness and completeness). These criteria have been selected on the basis of a meta-analysis realized by Dean et al. (2006).

4 RESULTS

In this paragraph we present the results of the analysis of the questionnaires as well as the impact of the training and the group composition on the concepts and solutions which were generated by the groups (Figure 2) and evaluated along the five above mentioned criteria. We also report on the impact of group composition on the usage of problem analysis and modeling tools of TRIZ and its derivatives.

4.1 Knowledge and method value as perceived by the participants

The evaluation of the answers to the questionnaires after the radiation case study and the adenovirus case study revealed some interesting results. The group composition had an effect, even though marginal ($F(1/26) = 3.26$; $p = 0.084$), on whether the participants estimated their knowledge to be high or low with regard to the problem domain. This means that participants with LS background estimated their problem related knowledge to be lower when being in a mono-disciplinary group than when being in a group with participants with ME background. For participants with ME background, this effect was inverted. When comparing the problem relevant knowledge before the preparation of the adenovirus case, a marginal ($F(1/57) = 3.67$; $p = 0.061$) difference between the participants who attended the CC training and those who attended the TD training can be observed. The participants with CC training estimated their problem related knowledge to be higher than the participants with TD did. Not surprisingly the academic background had significant influence on how the participants estimated their knowledge related to the adenovirus case, both before the preparation of the case ($F(1/57) = 62.53$; $p < 0.001$) and in general ($F(1/57) = 21.58$; $p < 0.001$). The participants with LS background estimated their knowledge in this respect to be significantly higher than the participants with ME background. Finally, we remarked a significant difference between the taught methods when it comes to their value for problem understanding as perceived by the participants ($F(1/54) = 4.7$; $p = 0.035$). The TD training was perceived to have improved problem understanding significantly in comparison to the CC training. The other questionnaire variables (e.g. motivation) showed no significant difference according to the group composition or the kind of attended training.

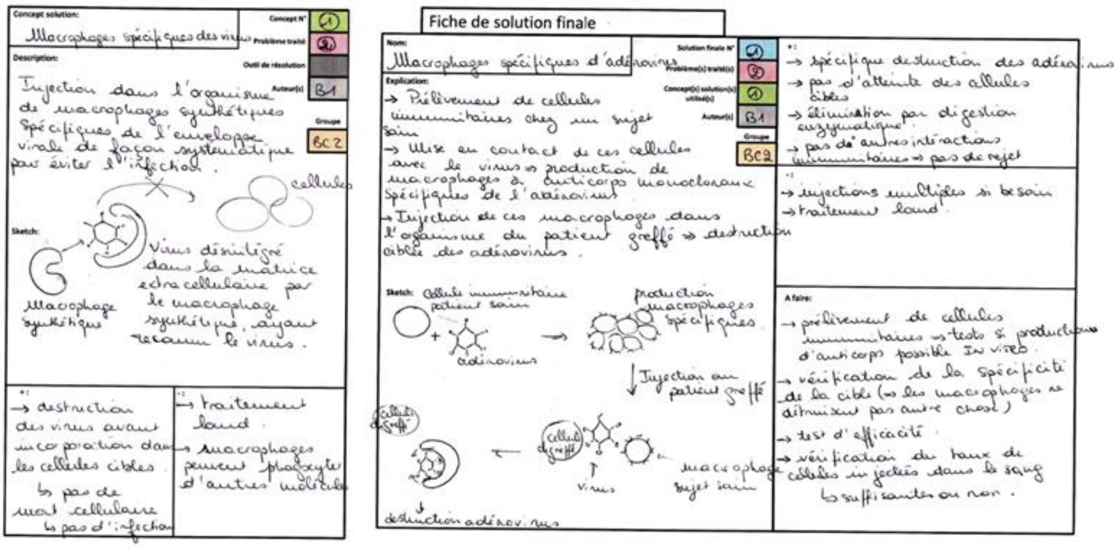

Figure 2: Example of concept and final solution as generated by a group

4.2 Effects of training and domain background on concepts and solutions

The evaluation of more than 200 concepts and solutions has been carried out by two independent experts. The overall interrater-reliability for the evaluation of the generated concepts (divergent phase) and generated solutions (convergent phase) amounts to Cronbach's alpha = 0.728, which is considered an acceptable value. Regarding the products of the divergent creativity phase, a significant positive effect ($F(1/159) = 11.77$; $p = 0.001$) of CC training compared to TD training on the profundity of the generated concepts can be observed. In terms of originality of the generated concepts however we could measure a significant interaction effect between the attended training and the group composition ($F(1/159) = 4.83$; $p = 0.029$): Homogeneous groups consisting of either participants with LS or ME background produced more original concepts when they had previously attended the CC training whereas heterogeneous groups consisting of participants with mixed background produced more original concepts when they had previously attended the TD training. The same significant interaction effect between attended training and group composition could be observed for the products of the convergent creativity phase ($F(1/45) = 7.83$; $p = 0.008$) (Figure 3). The other evaluation criteria (feasibility, applicability, effectiveness) showed no significant difference according to group composition or the attended training.

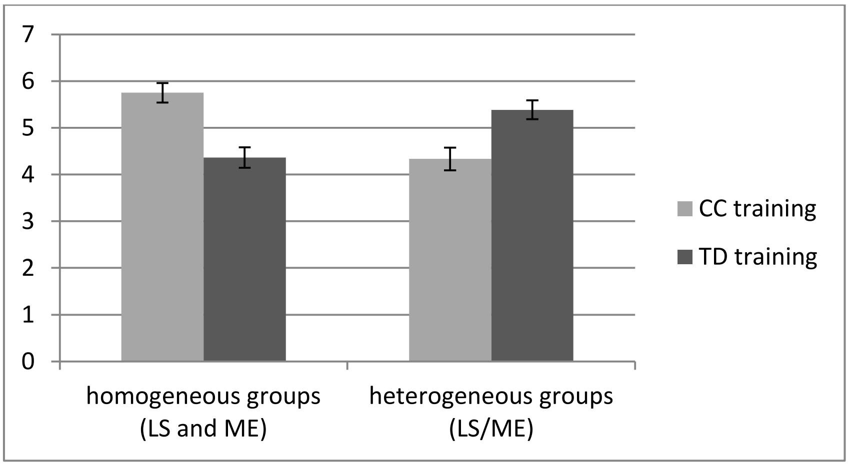

Figure 3 : Influence of attended training and group composition on originality of products of convergent creativity phase (solutions)

4.3 Influence on group composition on usage of problem analysis tools

Quantitatively comparing LS groups to LS/ME groups in terms of usage of problem analysis and problem modeling tools of the TRIZ complex reveals that group composition has a, even though marginal effect ($F(1/8) = 4.6$; $p = 0.069$) on the number of these tools used during the problem analysis and problem modeling stage. Multidisciplinary groups with at least one participant with ME background tend to use these tools more extensively. The number and type of tools used by the respective mono or multidisciplinary groups can be taken form Table 4.

Table 3: Problem analysis and problem modeling tools used by groups taught in TD methodology. An (X) indicates rather rudimentary usage.

		Groups									
		LS				LS/ME					
Tools		BI1	BI2	BI3	BI4	II1	II2	II3	II4	II5	Σ
Problem Analysis	Reform + Sketch			X		X		X		X	4
	SOT + Resources			X	X	X	(X)	X		X	5 (6)
	Ideality	X	X	X	X	X	X	X	X	X	9
	Law of System Completeness		X			X		X	X	X	5
Problem Modeling	Magic Particles	X		X		X	X	X			5
	Closed World	X	X		(X)	X	X	X	X	X	7 (8)
	Space/Time An. + Contradict.				X	X	X	X			4
	Σ	3	3	4	3 (4)	7	4 (5)	7	3	5	
	ΣΣ	13 (14)				26 (27)					
	Average Σ	3,25 (3,5)				5,2 (5,4)					

5 DISCUSSION AND IMPLICATIONS OF FURTHER RESEARCH

The findings have some interesting implications for multidisciplinary group creativity and problem solving, which are crucial for KS and KT (cf. e.g. Wang and Noe, 2010).

5.1 Discussion of results and limitations

The marginal effect of team composition on the estimation of the quality of personal problem related knowledge can be interpreted as a complementary aspect to theories explaining performance differences in cross-functional groups (Randel and Jaussi, 2003). It could indicate that group members which represent a functional or a domain minority in a group - in our case the participants with a ME background - could not only contribute less to group performance, because they fear for being considered as weak performers, but also because their subjective problem-related knowledge perception is reduced when being in a group with members whose problem related knowledge seems to be higher. Further, the experiment shows that problem analysis tools of the TRIZ complex are, at least when compared to classical creativity methods, valuable for problem definition and problem structuring in non-technical problem settings. The finding that the presence of participants with a ME background in groups has a, even though marginal, positive impact on the usage of those tools supports the hypothesis that engineering design expertise in groups has a positive impact on the problem identification phase of a creativity process in non technical domains. Finally, there is evidence that training in TRIZ and its derivatives has a positive impact on the originality of the products resulting from creative problem solving processes of multidisciplinary teams in life sciences. The question that still has to be answered is if the presence of participants with ME background lead to creative solutions which make, explicitly or implicitly use of technical knowledge. The answer to this question requires in depth analysis of 163 solution concepts and 46 solutions, which is still ongoing.

5.1 Implications for further research

It is important to stress that the training which the participants obtained previous to the problem solving sessions was very short. It is well known that mastering a complex methodology like TRIZ takes many days of training. Thus it could be interesting to carry out a similar experimentation but giving the participants more time for acquisition of the methodology. Another interesting aspect to investigate would be the effects of disciplinary group composition and methodological training on KS and KT for the solution of technical problems. This is impelling before the background of the increased importance of biotechnology and nanotechnology industry, where sharing and transfer of previously not connected knowledge is crucial for the design of future products and processes. Further, the authors plan to apply a modified version of Gero’s (1990) Function-Behavior-Structure framework in combination with TRIZ concepts for system modeling in order to systematically analyze a chosen set of the concepts generated during this experimentation. This analysis shall serve as input for the design of a new solution for the problem of Adenovirus infection which will be carried out with the evaluating domain experts.

6 CONCLUSION

In this article we gave an overview on current problems of KT. It appears that a lot of those problems are linked to problems of the transformation and translation of knowledge. As information and communication technologies have limits in solving these problems, we argue for a framework capable of facilitating KT and KS during face-to-face problem solving sessions with participants possessing knowledge of distant domains., We tested the value of TRIZ and its derivatives for such a framework in an experiment. 60 participants with LS or ME academic background were divided in 20 mono- and multidisciplinary groups which were asked to generate solutions to a problem originating in life sciences. The analysis of the participant's subjective perception of the methodology and the analysis of the products of the problem solving process stress the value of the said methods for the understanding of problems of distant knowledge domains and for the generation of original ideas in multidisciplinary groups. The experimentation shows that TRIZ and its derivatives are useful not only for the solution of technological problems but also for the understanding and solving of problems in science. These qualities make the methods interesting for mutual transfer of knowledge allowing all participating partners to profit from and thus enhancing KT.

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