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Impact of TRIZ Learning on Performance in Biologically Inspired Design*

WEI LIU[1,2] RUNHUA TAN[1,2,3]** QINGJIN PENG[4] HUI LI[2,3] ZIBIAO LI[1] and BOJUN YANG[2,3]

[1] School of Economics and Management, Hebei University of Technology, Tianjin 300401, China. E-mail: lwofhebut@126.com

[2] National Engineering Research Center for Technological Innovation Method and Tool, Hebei University of Technology, Tianjin 300401, China.

[3] School of Mechanical Engineering, Hebei University of Technology, Tianjin 300401, China.

[4] Department of Mechanical Engineering, University of Manitoba, Winnipeg, MB, R3T 5V6, Canada. E-mail: lwofhebut@126.com, rhtan@hebut.edu.cn, Lihui2009@hebut.edu.cn, Lizibiao@hebut.edu.cn, ybj@hebut.edu.cn

Biologically inspired design (BID) is a complicated cognitive process that largely depends on designers' capability to transfer biological inspirations into design solutions. It usually requires special training for engineering designers to gain this capacity. As a systematic invention approach, TRIZ, the abbreviation of Russian Theory of Inventive Problem Solving, is suggested to help improve designers' innovative capabilities. An experimental research is conducted by this paper to investigate the impact of TRIZ learning on performances of 20 engineering postgraduates in BID. The outcomes show that participants with TRIZ learning experience generated more novel design solutions. In addition, the relation between experience of TRIZ learning and students' BID performance is also analyzed. The result suggests the positive influence of TRIZ learning on BID and reveals several insights for upgrading education approaches of BID.

Keywords: TRIZ learning; BID; Knowledge representing; Design experiment

1. Introduction

BID has attracted growing interests in the scientific community as its potential in applying nature phenomena to solve innovative design problems [1]. However, BID is a complex cognitive process that requires designers to transform biological knowledge into solutions to engineering problems [2] and also demands capabilities of analogical reasoning and creative thinking [3]. Therefore, it is worth an in-depth study to explore and understand factors influencing BID design performances of designers before thinking out effective teaching strategies.

TRIZ has the ability to inspire inventive designs at very early phase of BID [4]. For example, Bio-TRIZ [5] investigated methods to enrich the TRIZ-based design using biological principles. TRIZ requires a long-lasting training [6] before its users can fully master its rich principles, methods and tools. In TRIZ, a rigorous training program involving teaching and practicing is necessary for cultivating competitive TRIZ users [7]. A previous study [8] demonstrates designers' performances on invention problem solving were improved after they had taken a systematic training.

The main purpose of this paper is to investigate relations between TRIZ learning experience and BID performance for refining educating technique for new practitioners of BID. This research uses two specific measures: a two-task design experiment for measuring performances and a questionnaire collecting information required. In the design experiment, 20 postgraduates distinguished by their TRIZ learning experiences are recruited to compete in a BID design challenge assisted by experimental stimuli. All of participants know few about BID. Subsequently, a questionnaire is used to collect participants' comments on provided stimuli and self-judgments of innovation capabilities. The paper is organized as follows: Section2 briefly reviews related studies. Section3 explains design approaches and evaluation methods used by this study. Section4 shows analysis results. Section5 discusses findings and implications. Section 6 summarizes limitations and provides some opportunities for the future study, followed by the conclusion in Section 7.

2. Related Studies

2.1 Methods to Facilitate BID

BID is an analogical design process during which novel design ideas are created by drawing upon biologcial prototypes [9]. In past decades, various methods have been developed to facilitate using biological knowledge in engineering design [10]. These methods involve keyword-based search engines for biological prototypes [11, 12] , categroy techniques of biological prototypes by their potential engineering applications [3, 13] and database of biomimetic innovations [14]. When represent and

** Corresponding author.

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reveal functional features of biological prototypes, functional diagrammatic models such as design analogy nature engine (DANE) [15] and substance-action-parameter-physics-input-organ-effect (SAPPhIRE) [16] are proposed by former studies. A study found that biological knowledge represented by diagrammatic models can inspire better outcomes of BID [17], since the function structure is widely used by engineering designers, which is also a diagrammatic model [18]. Along studies in proposing and upgrading BID methods, verification studies through design experiments are also used to validate practical workability of BID methods [15, 19, 20]. Using validation metrics, several studies [10, 19] found that after taking a BID course, students' design results achieved higher novelty scores. Findings in another study [20] indicated that the exposure to biological prototypes is also helpful for generating innovative design ideas.

2.2 *Studies on Potential Influcing Factors of BID*

The knowledge gap between designers and biologists and the unawareness of analogical biological systems are two main obstacles for the adoption of biological knowledge in engineering [21]. Design is a wide-ranging and open-ended cognitive activity [15], designers therefore have to deal with complicated cognitive process such as knowledge transferring from different domains [2]. Nevertheless, there are evidences revealed by studies [10, 19, 20] manifest required design capacities for facilitating BID, since nature does not always bring "hands-on" solutions to engineering problems [22]. Moreover, BID is also usually interpreted as an analogical process between biology and engineering [3, 18, 23], so designers' capabilities of analogical reasoning can be a influencing factor to their BID performances.

Besides the analogical reasoning, creative thinking is another positive influencing factor since it is also help to overcome the psychological inertia that may discourage designers to use biological prototypes for solving their professional problems. Designers who incline to think and develop "out-of-the-box" ideas [24] may have better performance in BID since they are more likely to generate unconventional thoughts.

Emotional factors such as more positive attitudes towards the BID stimuli may also motivate designers to work harder since they have more interests in provided stimuli. As a personal characteristic, the curiosity with a high degree during a design process is the original trigger of imagination, which is a relatively strong motivation for innovation [25]. Moreover, another study suggests that positive emotions improve performance for creative and learning activities [26]. "Optimistic" students who have more positive emotions can face more difficulties and challenges than "Pessimistic" students. Meanwhile, optimistic students usually believe that they possess greater capabilities with more successful rate in fulfilling some design tasks [27].

2.3 *Impacts of TRIZ Learning on Innovation*

Compared with brainstorming, mind mapping, lateral thinking and others, TRIZ is able to not only uncover design problems but also offer direct solutions [8].TRIZ has gained a good reputation for being an effective problem-solving, analysis and forecasting tool [6] A former research [28] reveals that TRIZ is very well suited to solve complex design tasks owing to its systematic methodology. Another study addresses TRIZ can benefit the creative problems solving by providing a structured approach other than the erratic brainstorming for generating innovative ideas even in a very short time [8]. It is reported by another research [29] that almost 80% of engineers think TRIZ is very helpful for triggering novel solutions by minimizing the detrimental effect of expertise on creativity. It is also indicated by the study [30] that TRIZ trained employee report higher qualities of idea generations at work with more submitted patents than their coworkers. There are also positive impacts of TRIZ training observed on emotional factors concerning innovation of engineering designers such as motivations for innovation [30, 31]. Findings in the Ref [32] suggest that learning experience of TRIZ gives learners faiths to face up and solve problems in the future, in turns their problem-solving abilities are improved. Another study [33] also shows that engineering students have improved capacities of thinking and problem-solving after they studied TRIZ courses.

Based on the aforementioned review, it is naturally to consider the integration of BID and TRIZ to train engineering designers since the TRIZ learning experience can help designers to gain skills required to facilitate and enhance BID. Therefore, the main purpose of this research is to investigate to what extend TRIZ learning experience impact on designers' BID performances.

3. Research Design

3.1 *Research Questions*

As BID is a very broad topic, this study only focuses on designers' performances in forms of design challenges inspired by biological knowledge. Therefore, this study uses several biological prototypes that are represented in forms of DANE and SAPPhIRE models by referring to previous studies. The research consists of two sections. The first section is a two-task design experiment involving two specific design problems with their detailed information as follows.

Problem 1: A personal alarm
Alarm is an important time reminder for everyday life. However, the usage of alarm in public places such as dormitories or libraries annoys others around. Therefore, an ideally personal alarm is expected to remind its user without disturbances to other people especially at public places.

Its main design requirements include: (1) remind time; (2) work only on the user without producing disturbances on other persons; (3) portable; (4) low cost to build.

Problem 2: A grabbing device for the disabled
A grabbing device is of great help for disabled persons on the wheelchair to get objects such as bottle or cup beyond their reach especially when it has a certain degree of adaptabilities to different shapes or sizes of objects.

Its main design requirements include: (1) grab objects such as bottles or cups; (2) a certain degree of adaptabilities to various sizes and shapes; (3) adjustable reach range; (4) easy to use; (5) low cost to build.

In the second section, a questionnaire is used to collect designers' responses. The questionnaire includes questions on three aspects for responses of participants to formulate a reliable study. The first part investigates TRIZ learning experience of participants by questions 1.1–1.3 listed in the appendix A. The second part surveys participants' attitudes on the provided stimuli by four questions from 2.1 to 2.4. As the third part, questions 3.1 to 3.4 gather information of participants' remarks of their abilities and experience of innovation.

3.2 Participants

This research firstly invited 26 postgraduates at the third year of Mechanical Engineering in Hebei University of Technology (PRC). None of them has attended courses or conducted studies related to BID. In order to ensure that all the participants have acquired the basic skill for using provided BID materials in the experiment afterwards, they have attended a brief training program about the provided BID stimuli a week before the experiment. After the course, students should pass simple tests that assess the basic level of using the provided BID stimuli. At last, 20 of 26 participants (17 males, 3 females, and aging from 25 to 27 years old) had passed the test and were recruited as participants for the experiment.

A half of 20 participants come from the department of "National Engineering Research Center for Technological Innovation Methods and Tools" and they had taken a systematic TRIZ training course. Meanwhile, others came from other departments without any TRIZ learning experience. Participants are evenly separated into four groups, groups 1 and 2 are made up of participants coming from other departments are used as control samples. Groups 3 and 4 are consisted of students with systematic TRIZ training and labeled as "skilled TRIZ learners". Besides differences regarding TRIZ learning, all the participants are believed to hold the same level of common knowledge and skills for engineering design.

3.3 Experimental Procedure

In the design experiment, the first round is the baseline study that requires participants to design personal alarms, which verifies whether there are differences of innovative capabilities among groups. The second round investigates how the participants perform in developing a grabbing device for people with the disabled with experimental stimuli.

Experimental stimuli used by this study involve key information abstracted from three biological prototypes: "Mantis' limbs", "Butterfly's mouth" and "Leaf of the flytrap". The DANE model of "Mantis' limbs" used as the exemplar stimuli is shown in appendix B. These biological prototypes can facilitate the main functional requirement of the grabbing device. Another reason of using two different representing methods is to investigate whether there is any difference in design outcomes when the same stimuli are in different forms. In the second round, groups 1 and 3 use stimuli in forms of SAPPhIRE model [16], while groups 2 and 4 are assisted by the DANE model [9].

The whole experiment involves three phases as shown in Table 1. In the first phase, participants are required to complete the first task in 30 minutes. Then 50 minutes are assigned to participants for accomplishing the second task. Lastly, participants are asked to answer the questionnaire in 15 minutes.

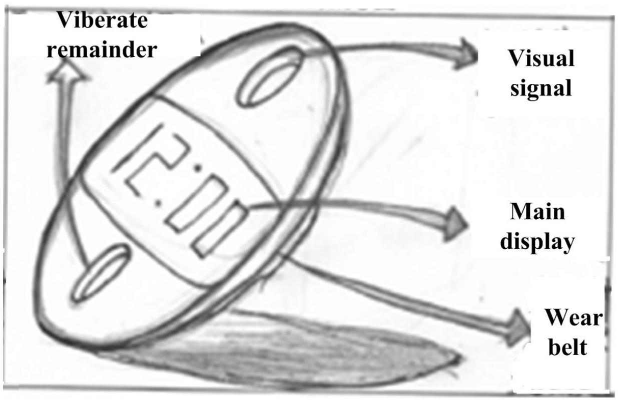
The experiment is held in a classroom. During the experiment, mutual communication and usages of the Smartphone or computer are banned for preventing potential interferences. Moreover, participants are informed that good ideas generated in experiments will be awarded bonus for encouraging them work hard.

3.4 Analytical Methods

This research applies the validation metrics to evaluate design outcomes from four specific dimensions: quantity, quality, novelty and variety. Exemplar design results of the first and second design tasks are shown in Fig.1(a) and Fig.1(b). Validation metrics defined in the research [34] have been widely

Table 1. The outline of the experiment

Timeline	Time	Group 1	Group 2	Group 3	Group 4
	Begin (0)	Instruction of experiment			
	30 minutes	First-round design (generating the concepts of personal alarm)			
		No stimuli provided for all the participants			
	50 minutes	Second round design (providing the conceptual solutions to machinery)			
		Provide and pass on the BID material			
		SAPPhIRE	DANE	SAPPhIRE	DANE
	15 minutes	Participants are required to answer questionnaires			
	END	Collect questionnaires			



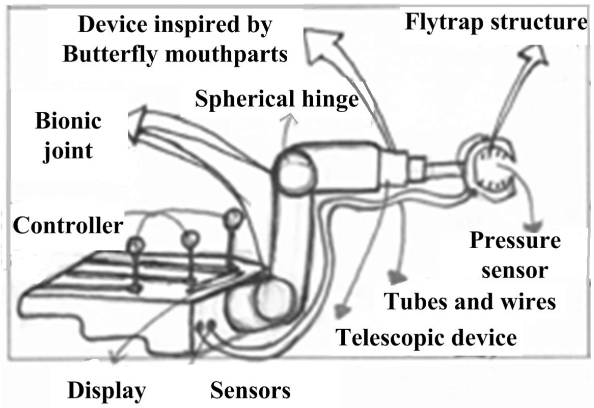


Fig. 1. Exemplar design results.

used in validations of BID methods especially in outcome-based studies [10, 19, 20, 35].

Quantity is an important indicator [34], which is determined by amount of validated design ideas from participants. By following guidance in previous studies [10, 36], raters assessed experimental outcomes and normalized their evaluation results.

Quality is determined by design solutions' feasibilities and relevance to design requirements. This study applied a five-point rating technique as shown in Table 2, which is adapted from the former study [36]. This new assessing technique is built by implementing the basic principles of Stanine [37, 38] since very limited design concepts are generated in the design experiment. Therefore, this proposed method can address differences related to design solutions' qualities. If there is more than one design concept is generated by one participant, the quality of his/her experimental outcome is scored by the means of all the generated concepts.

Novelty reflects how unusual or unique a concept is different from other solutions generated in the same task [35]. The novelty measuring has two specific steps: defining collections of all the ideas generated, and calculating the degree of novelty by using Formula (1) [34]. In Formula (1), M_1 denotes the overall score for novelty of the concept for in total m functions on the nth abstraction level in the genealogy tree [34]. Weights of function and abstraction levels denote as f_i and P_k respectively, while S_{1jk} is the novelty value for ideas on the different abstractive level, calculated by Formula (2).In Formula (2), T_{jk} expresses the total amount of ideas produced to meet the jth functional requirement on the kth abstraction level, while C_{jk} represents the number of the existing solutions or those originated from the common senses on the corresponding level,it is then multiplied by 10 for normalization [32].

$$M_1 = \sum_{j=1}^{m} f_j \sum_{k=1}^{n} S_{1jk} \cdot p_k \quad (1)$$

$$S_{1jk} = 10 \times \frac{T_{jk} - C_{jk}}{T_{jk}} \quad (2)$$

Variety indicates the diversity of a set of solutions, which reflects the region of participants' solutions. A prerequisite for a variety calculation is positioning concepts in a genealogy tree consisting of four

Table 2. Guidance for evaluating the quality of design concepts

Score	Grading guidance
9	Perfect: Solution has very high relevance, workability and clear descriptions in forms of both illustrators and texts.
7	Good: Solution has high relevance and good workability with both picture and textual description.
5	Medium: Solution is well relevant to design task with enough feasibility and simple description of the scheme.
3	Relative poor: Solution is relevant to design requirements and mediate practicality depicted by pictures and texts.
1	Very poor: Relevant concept has no clear enough description, or the ideas are irrelevant.

hieracies,each of which is scored as 10,6,3,1, respectively [19]. The variety score can be calculated through Formula (3), in which V denotes the final variety score, S_1 stands for the value of physical principles in the first hieracy, S_i for ith level in the tree; b_i is the amount of nodes on ith level while d_l is the number of differentiation.

$$V = \sum_{j=1}^{m} f_j \left(S_1(b_1 - 1) + \sum_{k=2}^{4} S_k \sum_{l=1}^{b_{k-1}} d_l \right) \quad (3)$$

In this study, quantity and quality scores of generated ideas are assessed by two raters, correlations of ratting are essential to conduct the statistical analysis. Therefore, Pearson's correlation coefficient is applied to testify the agreement between two raters' evaluations. There are two indicators: r and p in Pearson's correlation coefficient test. Specifically, r indicates the strength of correlation ranging from –1 to 1, p suggests the statistical significance of correlation test and its standard threshold value is 0.05.

Analysis of variance (ANOVA) is applied to measure the statistical significance of variance among performances of all experimental groups. For this study the null hypothesis is that all groups in experiment show no difference in their BID performances measured by the validation metrics. In ANOVA, *p_value* indicates the statistical significance among tested samples, its threshold is normally set as 0.05. If the *p_value* is lower than the threshold, it indicates the rejection of the null hypothesis and manifests a statistic difference.

4. Result Analysis

4.1 Results of the Baseline Task

Correlations of raters' quality assessments are firstly tested by Pearson's correlation coefficient. The result of analysis (r = 0.830) which indicates a high correlation of two raters' quality evaluations. Performances of four groups in the first design task are illustrated in Fig. 2 with bars indicating 95 percentages of the confidence interval (With 95% CL).

In Fig. 2, higher quality means scores are observed in groups 3 and 4 compared with groups 1 and 2, while scores of other dimensions are almost at the same level. It is reasonable to conclude that all the groups show almost the same performances in

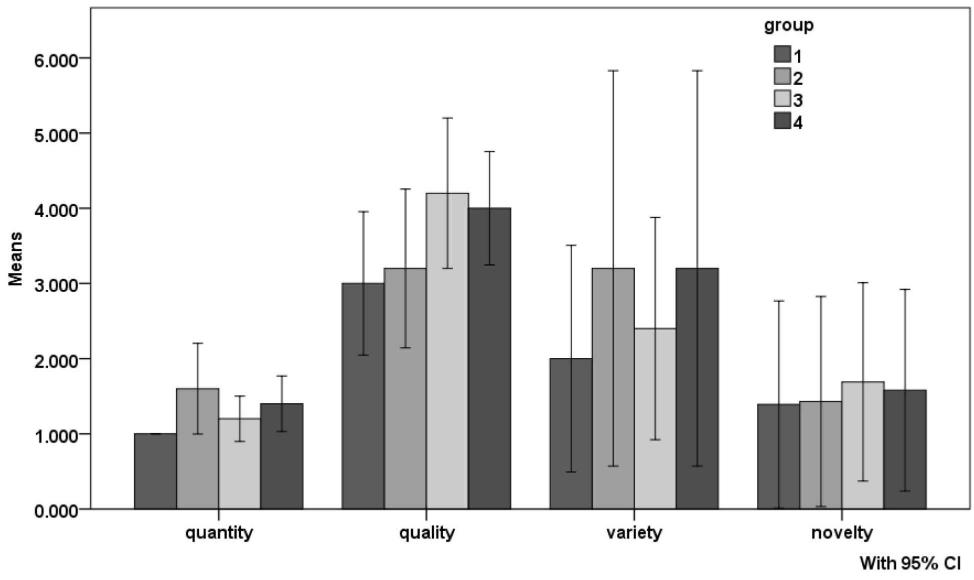


Fig. 2. Performances of all the 20 participants in the baseline task.

Table 3. ANOVA tests for the factor of TRIZ learning in the first task

Structure	Quantity	Quality	Variety	Novelty
Control samples	1.300	3.100	2.600	1.410
Standard error means (SEM)	0.147	0.307	0.666	0.422
Skilled TRIZ learners	1.300	4.100	2.800	1.635
SEM	0.105	0.275	0.655	0.405
P-value	1.000	0.019*	0.832	0.703

* Indicates p_value is at the level <0.05.

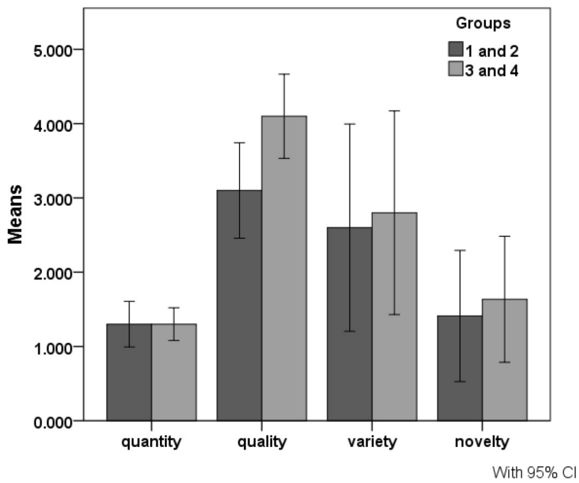


Fig. 3. Comparison of TRIZ learning impact on the baseline task.

the first round, though groups 3 and 4 are the "skilled TRIZ learners" participants, there is no evidence showing any better performance measured by variety or novelty scores.

In the first round, participants in groups 1 and 2 are used as the control sample, which are compared with all the "skilled TRIZ learners" from groups 3 and 4. The comparison result is shown in Fig. 3, which shows that quality scores in "skilled TRIZ learners" are higher than control groups, and ANOVA test results in Table 3 also indicate there is a higher quality score with the statistical significance in "skilled TRIZ learners". The finding indicates that TRIZ learning experience can improve the quality of baseline design outcomes.

4.2 Analysis of the Second Task

Results of four groups in the second task are shown in Fig 4. There are higher novelty scores are observed in both groups 3 and 4 in comparison with groups 1 and 2. Group 3 has a significantly higher quality score than group 4 and a higher variety score than groups 1 and 2. Results of ANOVA tests in Table 4 also demonstrate statistic significances in four groups' design performances. According to Table 4, both groups 3 and 4 have achieved statistically higher novelty scores than groups 1 and 2.

4.3 Comparison of Two Representation Techniques

Two BID representations is also investigated by conducting two comparisons. The first comparison is made between group 1 and 2 to investigate whether two representations act differently among

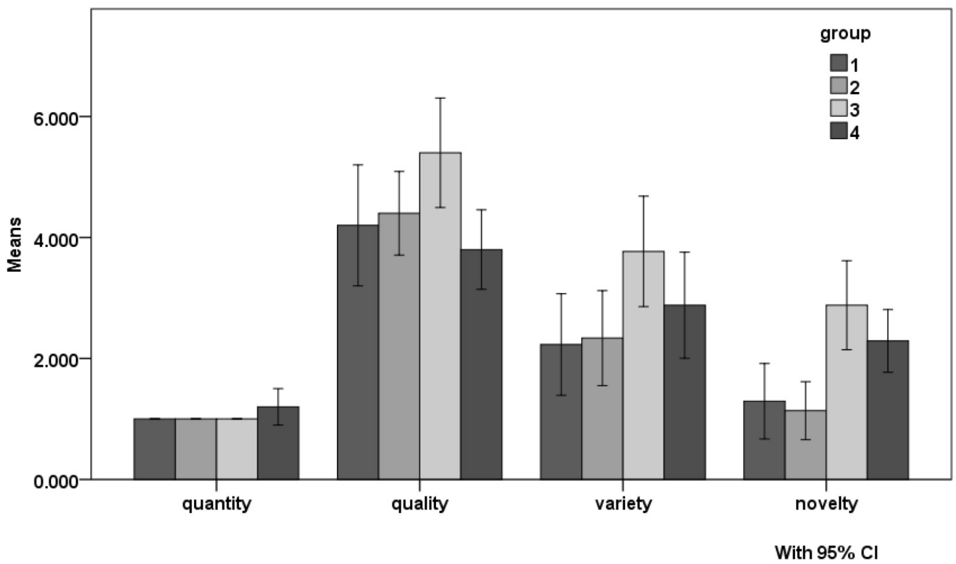


Fig. 4. Results of four groups' performances in the second task.

Table 4. Results of ANOVA tests for the means metrics scores for comparisons of each group in task 2

Structure	Quantity	SEM	Quality	SEM	Variety	SEM	Novelty	SEM
Group1	1.000	0.000	4.200	0.442	2.230	0.371	1.293	0.276
Group 2	1.000	0.000	4.400	0.306	2.337	0.347	1.137	0.212
Group 3	1.000	0.000	5.400	0.400	3.770	0.404	2.880	0.325
Group 4	1.200	0.133	3.800	0.291	2.880	0.388	2.290	0.230
P-value	0.099		0.026*		0.026*		0.000**	

* Indicates p_value is at the level <0.05 ; ** indicates p_value is at the level <0.01.

participants without TRIZ learning experience and its result is Fig. 5(a). Meanwhile, another comparison is made between group 3 and 4 to reveal whether the difference of representation techniques can influence outcomes of participants of "skilled TRIZ learners", its results is shown in Fig. 5(b). Refers to Fig. 5(a), there is no evident finding to suggest which models is better than the other. For "skilled TRIZ learners", ANOVA tests only indicate statistically better quality in group 3 (*p_value* = 0.005).

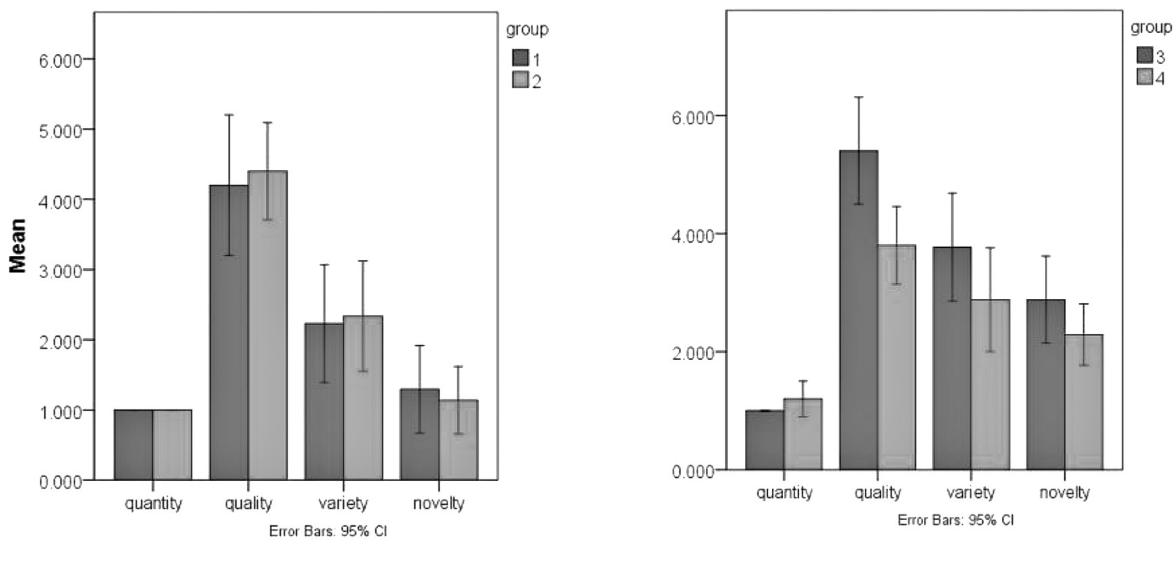
4.4 Impact of TRIZ Learning on BID Performance

To investigate the impact of TRIZ learning on BID performance, a series of comparisons are made. Results of the comparison between control samples and "skilled TRIZ learners" are shown in Fig. 6(a). Meanwhile, the comparison between users of SAPPhIRE is shown in Fig. 6(b), and the result between users of DANE is shown in Fig. 6(c). Fig. 6(a) shows that "skilled TRIZ learners" have much higher variety and novelty scores than control samples.Have acquired the TRIZ learning experience, both users of SAPPhIRE and DANE show much higher novelty scores than control samples, moreover, skilled TRIZ learners who use SAPPhIRE even have much better performene measured by variety and quality. Meanwhile, higher variety and novelty scores are observed in skilled TRIZ learners who use SAPPhIRE, and higher novelty score is also seen in skilled TRIZ users who use DANE. ANOVA tests' results in Table 5 indicate statistical significances.

5. Discussion about Findings

5.1 Impacts of TRIZ Learning on Design Performances

Results of the baseline task have revealed that "skilled TRIZ learners" only show better quality scores than participants without TRIZ learning, which supports findings in the previous study [30] where design ideas with higher qualities were reported by TRIZ learners. However, skilled TRIZ learners in the baseline task do not show any superiority on aspects of variety or novelty. This finding is inconsistent with the previous study



(a) (b)

Fig. 5. Comparison of two representations in the second task.

Table 5. ANOVA tests for the impact of TRIZ learning on the second task

Structure		**Quantity**	**SEM**	**Quality**	**SEM**	**Variety**	**SEM**	**Novelty**	**SEM**
Total comparison	Groups 1&2	1.000	0.000	4.300	0.263	2.283	0.248	1.215	0.170
	Groups 3&4	1.100	0.069	4.600	0.303	3.325	0.291	2.585	0.205
	P-value	0.154		0.459		0.010*		0.000**	
Users of SAPPhIRE	Group 1	1.000	0.000	4.200	0.442	2.230	0.371	1.293	0.276
	Group 3	1.000	0.000	5.400	0.400	3.770	0.404	2.880	0.325
	P-value	–		0.059		0.012*		0.002**	
Users of DANE	Group 2	1.000	0.000	4.400	0.306	2.336	0.347	1.137	0.212
	Group 4	1.200	0.133	3.800	0.291	2.880	0.388	2.290	0.230
	P-value	0.151		0.172		0.310		0.002*	

* Indicates p_value is at the level <0.05 ; ** indicates p_value is at the level <0.01.

[34] in which more novel ideas were generated by TRIZ learners. One possible reason may lie in that previous studies usually focus on comparing performances of long-terms design projects. Another reason may be previous studies have not excluded interference from other knowledge sources. In this study,the first round is a brainstorm, since 30 minutes are enough for participants to saturated brainstorm [39], however, it may be not enough for skilled TRIZ learners to apply TRIZ methods to solve design problems.

Analysis results of the second round indicate a

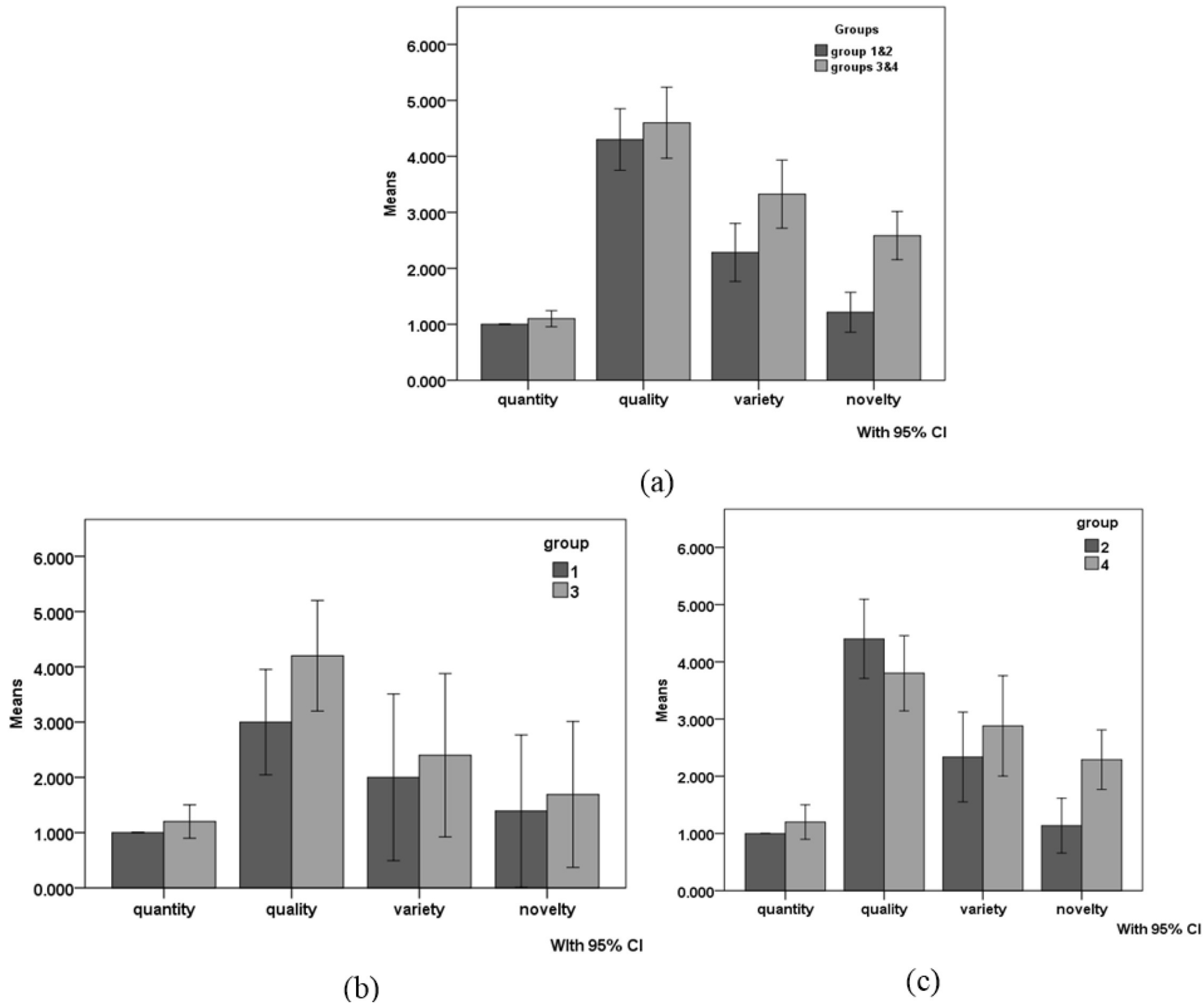


Fig. 6. Comparisons of impact of TRIZ learning on BID performances.

Table 6. Correlation analysis between novelty and factors in the questionnaire

Structure		Ever-TRIZ	Triz-degree	Patent-apply	Num-Patent	Easy-bid	Feasible-bid	E-evaluate	F-evaluate
Novelty	r	0.640**	0.633**	0.539**	0.435**	–0.006	0.044	0.223	0.197
	p_value	0.000	0.000	0.000	0.005	0.970	0.789	0.166	0.224

** Indicates p_value is at the level <0.01.

statistically better novelty in performances of "skilled TRIZ learners". In addition, this superiority is observed in both groups 3 and 4 who are supported by different forms of BID stimuli. We can conclude that the TRIZ learning has the positive impact on improving the novelty of outcomes in BID.

5.2 Evidences for Comparing Two BID Representations

This study also investigates whether there is a difference in outcomes of BID when using different biological knowledge representation techniques. In this study, methods of SAPPhIRE and DANE are respectively used by groups 1, 3 and groups 2, 4 in the second round. The comparing result of groups 1 and 2 is used to find the two techniques influence of BID performances in participants without TRIZ training experience. Meanwhile, the comparison between groups 3 and 4 is applied to investigate whether there is any difference in performance of "skilled TRIZ learners". However, there is no significant difference in both comparisons. Specifically, two groups in control samples have very close performances in the second task. For "skilled TRIZ learners", group 3 shows clearly higher scores in quality, variety, and novelty than group 4. Built on data analysis, we can make an unsoiled conclusion that for users without TRIZ learning experience there is no apparent difference between two BID representations. However, for users having acquired systematic TRIZ learning experience, SAPPhIRE has shown some superiority than DANE under experimental conditions in this study.

5.3 Factors Analysis for Influences of TRIZ Learning

Based on data collected by the questionnaire, the novelty of design performance is investigated in the second-round task. Firstly, the correlation analysis is used to reveal correlations between novelty scores and potential factors, and results are shown in Table 6. In Table 6, there are four factors having significant correlations with the novelty score of BID performances. Component analysis only indicates one principal component among these five items with eigenvalues is shown in Fig. 7.

In the component matrix of Fig. 7, the item of Ever-TRIZ, the indicator for participants having TRIZ learning experience, has the highest correlation with single chief undefined component. Therefore, it is reasonable to testify this primary factor by a partial correlation. If the item of Ever-TRIZ is removed, correlations between novelty and the other three items do no longer exist, as shown in Table 7. Therefore, this factor analysis has revealed

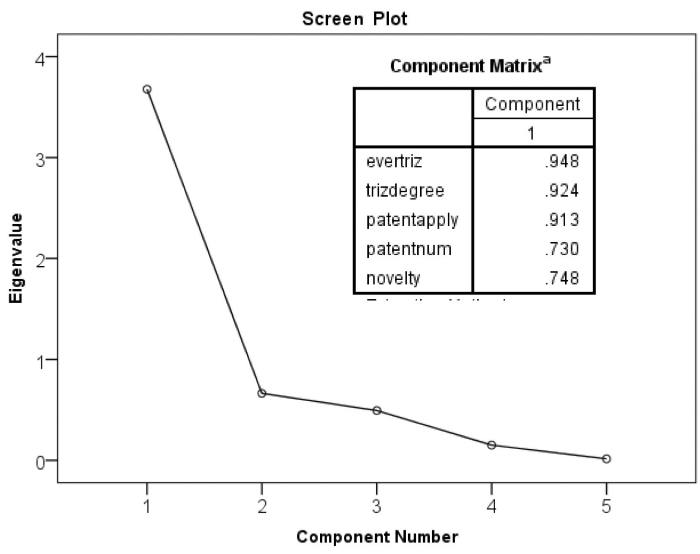


Fig. 7. Component analysis of factors correlated to the novelty.

Table 7. Partial correlation analysis with Ever_TRIZ as the control variable

Items	Index	Triz-degree	Patent-apply	Num-Patent
Novelty	r	0.039	0.037	0.120
	p_value	0.816	0.825	0.466

that the TRIZ learning experience is the single main factor that influences the novelty score of BID performances.

5.4 Attitudes of Designers Influence on BID

Correlations are also analyzed between outcomes of BID and other factors such as attitudes towards the provided stimuli and participants' self-evaluation of innovative capacities. Results of analysis are shown in Table 8. Refers to Table 8, participants who thought the provided BID stimuli are easier to be used have generated solutions with higher quality. Other correlations are also revealed in Table 8, for example, the item of "Ever-TRIZ" has indicated participants who have systematic TRIZ training experience show more positive attitudes towards their abilities in solving innovation problems, which is consistent with findings in former studies [30, 31].

6. Limitations and Opportunities for the Future Work

6.1 Main Limitations

Although this study has revealed some evidences to support that the TRIZ learning experience has positive impact on improving performances of BID. However, there are some limitations in this study.

Firstly, this study uses a very small size of samples involving only 20 participants which weaken statistic significances of results. Moreover, it is another reason for the limitation of this study is the imbalance of gender ratio.

Secondly, this study is organized in forms of a short-term design challenge. When the design period can be extended to a long-term design forms such as a week-long design project its results can be compared with findings in this paper.

Thirdly, this study mainly considers backgrounds of participants by their majors which is another limitation of this study since more careful and rigid measures can be applied to differentiate their backgrounds related to the research.

6.2 Insights for the Future Work

There are several insights from findings and limitations in this research to inspire studies in the future.

Firstly, if the design condition is changed from short-period classroom design challenges to long-term innovation projects, some new findings may appear to foster new discussions about relevant topics and formulate an overall picture about impacts of TRIZ training on participants' performances in BID.

There is some difference in comparisons of SAPPhIRE and DANE used by skilled TRIZ learners in BID tasks. Based on the similar principle and approach, after a series of comparisons, a better BID representation can be developed for skilled TRIZ learners with the most useful information.

Another possible opportunity for the future study is to develop a novel effective BID education program by incorporating with TRIZ training sessions. In order to testify which TRIZ methods are helpful

Table 8. Correlation analysis between design outcomes and other factors

Items	Index	Existed-Efficacy	Future-Efficacy	Easy-bid	Feasible-bid	Ever_TRIZ
Quantity	*r*	0.140	0.096	–0.171	0.037	0.229
	p_value	0.391	0.554	0.293	0.822	0.154
Quality	*r*	0.057	–0.298	0.492*	–0.135	0.121
	p_value	0.727	0.062	0.001	0.406	0.459
Variety	*r*	–0.016	–0.205	0.284	0.010	0.405*
	p_value	0.924	0.204	0.076	0.952	0.010
Novelty	*r*	–0.006	0.044	0.223	0.197	0.640**
	p_value	0.970	0.789	0.166	0.224	0.000
Ever-TRIZ	*r*	0.473**	0.420**	–0.068	0.000	1.000
	p_value	0.002	0.007	0.679	1.000	0.000

** Indicates p_value is at the level <0.01.

for improving the design novelty, a series of comparisons can be applied to train participants with certain TRIZ knowledge then compare their performance in BID. Results of comparison help decide which part of TRIZ training program is appropriate to be incorporated into BID education program.

To explain the improvement observed in BID performance of skilled TRIZ learners, one possible reason is that learners' abilities on transferring and implementing knowledge have been enhanced by TRIZ learning. However, this hypothesis needs to be further investigated for the innovative knowledge from the biological domain that can be replaced by other forms such as the patent documents, successful innovation design cases, etc. Comparisons can be made between the skilled TRIZ learners and their peers with no TRIZ knowledge by applying the methods and evaluation techniques used in this study.

7. Conclusions

This paper was investigated impacts of TRIZ learning experience on designers' performances in BID. The result has shown more novel ideas generated by participants who have systematic TRIZ learning experience. Besides the main finding, the comparison of practical usability between SAPPhIRE and DANE is also testified in both control samples and "skilled TRIZ learners". Results also indicate that skilled TRIZ learners using SAPPhIRE performs better than their peers using DANE in BID. This study also investigates factors that benefit the novelty improvement of BID solutions in skilled TRIZ learners and finds TRIZ learning is the main influencing factor. Factors involving participants' attitudes towards provided BID stimuli and self-evaluations of innovation capacities are also investigated, whilst analysis results show significant correlations between designers' self-evaluation on innovation and their TRIZ learning experience. However, there is no direct finding to support the TRIZ learning can improve designers'attitudes towards BID stimuli. Finally, this paper summarizes its limitations and discusses several oppotunities to foster new studies in the future.

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Appendix A: Questionnaire

1.1 Have you ever attend a TRIZ oriented lesson or a training program?

○Yes ○No

1.1 (2) If your answer is Yes, please remark the corresponding bar to represent the degree of TRIZ training you have received.

☐ 0 very limited, only know some basic knowledge about TRIZ.

☐ 1 average, familiar with the principal methodology of TRIZ.

☐ 2 medium, familiar with the principal method of TRIZ and capable of using some TRIZ tools solve design problems.

☐ 3 good, know well about the methodology of TRIZ and capable of use most TRIZ methods and tools with successful experience for solving problems.

☐ 4 excellent, a very good TRIZ users and has been accustomed to using TRIZ proficiently.

1.2 Have you ever try to use the TRIZ to solve the practical problem in your experience?

○Yes ○No

1.2 (2) If the answer is Yes, please remark the corresponding bar to comment the help you got from TRIZ by your experience?

☐ 0 no help ☐ 1 very limited ☐ 2 medium ☐ 3 helpful ☐ 4 very helpful

1.3 Have you ever authorized by certain kind of TRIZ certification?

◯Yes ◯No

1.3 (2) If the answer is Yes, what is the level of your certification?

☐ level-1 ☐ level-2 ☐ level-3

2.1 To what degree do you think about the proposed BID stimulus are understandable?

☐ 0 very hard ☐ 1 a little hard ☐ 2 medium ☐ 3 averagely easy ☐ 4 very easy

2.2 To what degree do you think about the proposed BID stimulus are helpful for problem-solving?

☐ 0 not at all ☐ 1 limited usage ☐ 2 medium ☐ 3 a little helpful ☐ 4 very helpful

2.3 What do you think is the most useful part in the provided BID stimulus?

2.4 What is the difficulty you meet in the design task to implement the biological knowledge to solve your problem in the task?

3.1 Have you ever successfully resolve the innovative design problem?

◯Yes ◯No

3.2 How to you think about your ability to solve the innovative design problem based on your previous experience?

☐ 0 very poor ☐ 1 limited ☐ 2 average ☐ 3 good ☐ 4 excellent

3.3 How do you evaluate your ability to solve the innovative design problem will be meet in future?

☐ 0 very poor ☐ 1 limited ☐ 2 average ☐ 3 good ☐ 4 excellent

3.4 Have you ever apply for patents? If the answer is Yes, how many patents have you applied and please list amounts by their types?

◯Yes ◯No

Total number of patents applied:____________________, including _________inventions______ New Utility ________Appearance patents.

Appendix B: Experimental stimuli

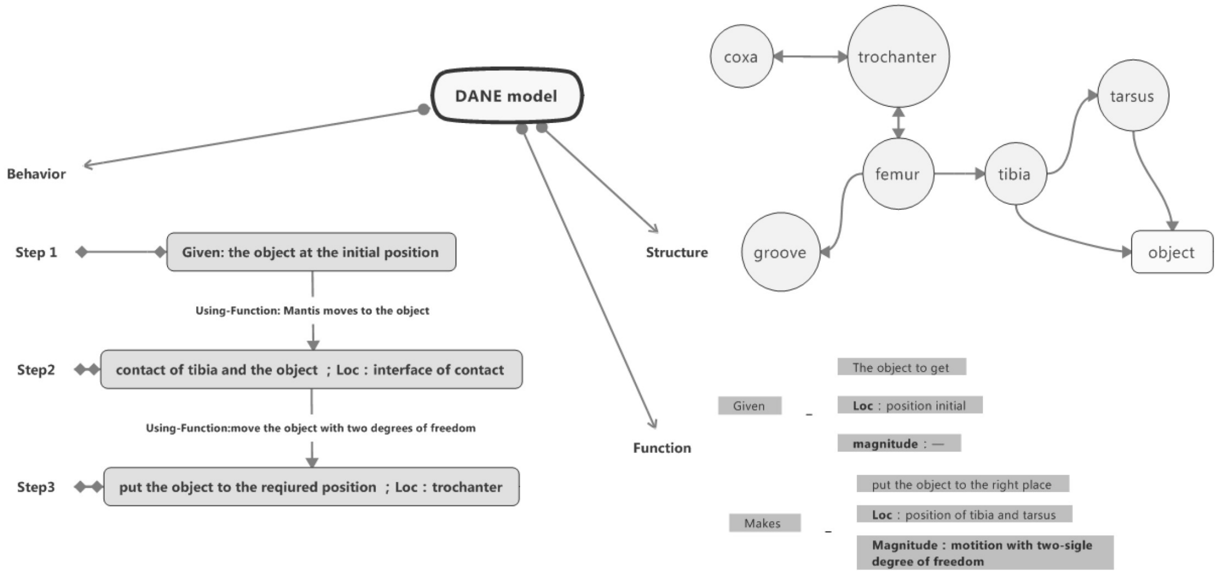
An exemplar stimulus in forms of DANE model used by this experiment has three subsections:

Main characteristics:

Joints of arthropod such as mantis usually have two degrees of freedom (to achieve deflection in up, down, left and right directions respectively). This characteristic is due to the special structure of joints, which is achieved by two joints with a single degree of freedom arranged at right angles.

Illustrator:

DANE model:



Wei Liu, is currently a postdoctoral researcher at School of Economic and Management and a research associate at National Technological Innovation Method and Tool Engineering Research Center, Hebei University of Technology, China. His primary research interests include innovative design, technological innovation.

Runhua Tan, is currently a professor, a Ph.D. candidate supervisor, the president at National Technological Innovation Method and Tool Engineering Research Center, China. His primary research interests include product design, innovative design, inventive problem-solving and engineering education.

Qingjin Peng, is a Professor in the Department of Mechanical Engineering at University of Manitoba, Canada. His research areas include digital manufacturing, product design for personalization and sustainability, reverse engineering, system modeling and simulation.

Hui Li, is currently an associate professor at National Technological Method and Tool Engineering Research Center, Hebei University of Technology, China. Her primary research interests include patent around design, technological innovation.

Zibiao Li, is currently a professor, a Ph.D. candidate supervisor in School of Economic and Management, Hebei University of Technology, China. His primary research interests include technology innovation management, S&T innovation policy design.

Bojun Yang, is an associate professor and a deputy president at National Technological Innovation Method and Tool Engineering Research Center, China. His primary research interests include product design, innovative design, inventive problem-solving and engineering education.