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# A PBL-Based TRIZ Training Approach for Improving Inventive Competency of Engineers in Workplace*

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How to improve inventive competency of engineers in workplace plays a significant role in competitive advantages of companies. This paper presented and validated a PBL-based TRIZ training approach for engineers in workplace aiming at enhancing their inventive competency using the integration of TRIZ and PBL-based educational techniques. To do so, after a systematic review of related studies, a new TRIZ training approach is fabricated with seven specific steps built on the framework of PBL. Subsequently, research data collected from 95 participants is used to validate the practical proposed TRIZ training approach. Statistical analysis is conducted based on pre-training, during-training and post-train inventive outcomes of the research sample that are measured by a set of patent-based indicators. Comparing analysis results have indicated that the proposed TRIZ training approach has evidently increased the inventive outcomes of participating engineers. Moreover, regression results revealed that the position closeness to the new product development and the patent applying experience are two most significant positive influencing impactors on the effectiveness of the proposed approach. Lastly, this paper also highlights several implications for educating TRIZ to engineers in workplace and limitations to initialize studies in the future.

**Keywords:** TRIZ; PBL; inventive competency training; engineers training; training in workplace

## 1. Introduction

Nowadays, how to improve the inventive competency of engineers plays an essential role in development of innovative performance of companies, which is important for companies to gain and maintain advantages in the fierce marketing competition [1]. Therefore, educating engineers in workplace to acquire necessary knowledge and skills to invent has attract widespread interests in the domain the engineering education [2]. However, the recent educational system does not have the feasible technique to train such advanced professional person in the current educational institutions [3]. To cultivate inventive competency, many strategies are applied by scholars in engineering education, among which TRIZ has proven itself as a powerful tool for conceiving engineering design concepts and solving inventive problems [4].

TRIZ, the acronym in Russian for the phrase "Teoriya Resheniya Izobreatatelskikh Zadatch", means the Theory of Inventive Problems Solving. Developed by Genrich Altshuller and his colleague, TRIZ is built on the analysis of over 2.5 million high-level patent materials from various countries and has developed into a well-established knowledge-based systematic methodology for understanding, exploring, analyzing, defining and finding solutions to technical problems and innovating technical systems [5]. TRIZ is often seen as a powerful toolkit involving the 40 Inventive Principles, the Contradiction Matrix, the Ideal Final Result, the Algorithm of Inventive Problem Solving, and the Patterns of Evolution of Technical Systems for designers and inventors to avoid trials and errors in solving inventive problems [6, 7]. Currently, TRIZ has been spread to various developed countries and widely used in many noted companies including Boeing of USA, General Motors, South Korea's Samsung, and help to make considerable economic benefits [8]. Findings reveal that participation in TRIZ training led to improvements in the creative problem-solving skills of participants in both the workplace and the university curriculum settings [2, 9]. However, as a systematical innovative methodology, TRIZ is somewhat too rigid and difficult to be understood and applied by ordinary users in a variety of situations, which has become the main challenge in the promotion of TRIZ [10].

Several previous researches have adopted tools and methods from TRIZ in engineering design courses in universities by asking students to resolve inventive problems in design challenges to help develop their inventive competency [8, 9, 11]. As the core of those TRIZ-based curriculums, the cultivation of inventive competency usually requires the higher-order thinking skill which is hard to be acquired through a set of theoretical courses and traditional pedagogies [12]. Therefore,

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researchers in TRIZ advocation have turned to the strategy of problem/project-based learning (PBL) and attempted to put the education of TRIZ in the framework of the PBL [13–15].

As the latest developing trend of engineering education, PBL has shown its potential of cultivating higher-order thinking skills of students by requiring them to solve problems that are complex and ill-structured [16, 17]. Compared with engineering students in universities, engineers in workplace have much less time to participate in continuous educational programs particular for TRIZ training programs which are usually in forms of comprehensive structures with a long learning duration [18]. Moreover, a previous study ever found that problems faced by engineers in the real workplace are significantly different from those used by engineering design curriculums in the university sitting [19]. TRIZ training approach firstly designed for teaching engineering students in the university needs to adapt itself to different requirements of engineers in workplace. However, there are very few studies attempted to develop PBL-based TRIZ training programs for engineers in workplace to improve their inventive competency. Moreover, a commonly accepted standard of the organization of TRIZ training programs is still absent [11], which arises skeptics about the practical effectiveness of TRIZ training programs in improving engineers' inventive performances [11, 20].

This study presents and validates a PBL-based TRIZ training approach aiming at improving inventive competency of engineers in workplace. To do so, a systematic review about studies on TRIZ training programs designed for engineers in workplace and practical integrations of TRIZ and PBL educational techniques in engineering education to address the research focus of this paper. Subsequently, a new PBL-based TRIZ training approach is described in detail as a result of several years self-develop and refining followed by the validation of its practical effectiveness through the analysis of inventive performances of sample participants. Regression analysis is also applied to reveal further findings on factors that influence the performance of the proposed TRIZ training approach. The rest of paper is organized as follows: Section 2 is a systematic review of relevant studies; Sect. 3 is the description about the proposed PBL-based TRIZ training approach; Sect.4 presents the validation of the proposed TRIZ training approach through analysis of inventive performances of the sample participants; Sect.5 discusses contributions and implementations of this study and highlights opportunities for the future study, Sect. 6 is the conclusion of the whole paper.

## 2. Literature Review

### *2.1 TRIZ Training Programs Designed for Engineering Education*

As a knowledge-based systematic methodology and toolkit, TRIZ has been spread to over 35 countries around the world [11]. To adopt TRIZ in the engineering education, various TRIZ training approaches have been developed and applied in various specific forms [9, 21]. The early application of TRIZ training approach can be traced back to 1980s, a simplified version of TRIZ methodology was taught in engineering courses in several universities and has also been applied successfully in industry [22]. TRIZ training approaches applied by universities usually pick up several tools from the TRIZ toolkit, for examples the situation analysis [18], substance-field analysis [23], ideal result [24], even the advanced TRIZ tool such as the algorithm of TRIZ (ARIZ) [25] and the OTSM (the Russian acronym for "General Theory of Powerful Thinking") –TRIZ [26] are applied by courses designed for training engineering students in universities for cultivating their creativity and inventive competency.

Even though there are significant differences between university settings and the real workplace, TRIZ training approaches designed for real engineers are also mainly in forms of lectures and problem-solving tasks. However, without a commonly accepted standard [11], TRIZ training approaches are varies, for example, periods of training program range from 2 to 3 hours in forms of brief introductions [18] to several mouths in comprehensive courses consisting of informational lectures, coaching for project-based learning and representations of final solutions [27, 28]. The inconsistence of organizations of TRIZ training also raises arguments and doubts [11, 29] about insufficient performances of several short-term TRIZ projects that are welcomed by companies since they have low cost of time and funds. However, previous studies [28, 30] have found that the deeper explanation of basic TRIZ, the more positive the responses from learners. Therefore, the existing TRIZ training programs need to strike a balance between the cost of time and efficiency by choosing appropriate forms to adapt to the requirements of engineers in industry.

Many previous studies have reported that effectiveness of TRIZ training on improving the inventive competency of trainee. To be specific, it has been addressed that the TRIZ training experience has increased the self-efficacy which is vital for the long-term development of the inventive capability [31]. Moreover, TRIZ training can enhance students' capabilities of problem solving significantly more than all the units incorporated in four years of engineering degree added together [32].

However, without a commonly agreeable standard for organization of TRIZ training approaches, it often arouses arguments about the practical effectiveness of various approaches for genuine engineering implementation in workplace [20, 33]. It still needs further efforts to design a validated TRIZ training programs for engineers in workplace to improve their inventive competency.

### *2.2 Integration of TRIZ and PBL-Based Techniques in Training Innovative Engineers*

Originates in the health education to prepare students better for their later professional practices, PBL has been commonly and successfully used by many medical schools in different countries [34]. Since its very beginning stage, PBL has been introduced as an educational strategy to other areas, such as business administration, science and engineering studies [35, 36]. After about 40 years' development, PBL has been widely adopted in engineering education because of its justified effectiveness in developing students' professional knowledge and transferable skills through the generation of unique and valuable solutions to open-ended problems [37]. PBL implementations take various forms including course levels, cross-course levels, curriculum levels and projects levels [38]. Unlike the medical education mostly used practice-case based PBL whereas PBL programs in engineering education mostly belong to the project-based level [38]. Moreover, the project-based PBL programs are designed not only for educating students in school but also for training engineering faculty or staff in workplace [38, 39]. PBL allows its trainee to learn about knowledge and skills required to solve problems that are similar to those will arise in their later professional lives [40]. Evidence from previous studies has suggested a structural PBL implementation plan is helping to improve long-term development of engineering faculty and students [38].

Within a pro-active and flexible learning environment, PBL integrates knowledge acquisition in a practical way and provides significant benefits to students by enhancing their capabilities of handling inventive problems, since problems used by PBL are usually complex and ill-structure ones that require inventive solutions [41, 42]. Training inventive competency of engineers covers a wide range of knowledge and requires sophisticated experiences, which is extremely difficult to be achieved through a set of theoretical courses and traditional pedagogies applied by engineering curriculums in university settings [43]. Through PBL, learners make use of the high order of thinking skills instead of memorizing information [16]. Moreover, the using of free-choice open-ended projects benefits better to participants than pre-defined topics as challenging problem since more difficult inventive problems can motivate learners work more pro-active during training processes [44].

With its systematic toolset, TRIZ is one of the most applicable methodologies for technical problem solving and innovations, which focuses on identifying, formulating, analyzing and solving inventive problems [6, 11, 21]. In general, TRIZ training programs are mostly problems or projects aiming to strengthen the creativity of trainee through solutions of problems or execution of projects [45]. Therefore, attempts to integrate of using TRIZ and PBL are widespread in educational approaches designed for training TRIZ users in engineering design courses in university [6, 9, 14]. A typical TRIZ courses built on the framework of PBL usually requires students to accomplish a design project that involves tasks of problem defining, problem analyzing and resolution with the assistance of TRIZ tools during the TRIZ training programs.

With the development of technologies, engineers should obtain relevant and timely technical knowledge for maintain or develop their inventive competency as an emerging branch of the continuing professional education [46, 47]. However, there is very limit studies on development of structural PBL-based TRIZ training programs for engineers in workplace [45]. Therefore, it of significant practical value to develop the structural PBL-based TRIZ training approach to meet the ever-growing requirements of engineers in workplaces to upgrade their inventive competency.

### *2.3 Summary of the Literature Review*

Aforementioned researches have indicated that there is a growing need for training approaches to enhance inventive competency of engineers in workplace to keep up with the technological advance. The integration of PBL and TRIZ therefore become an important trend in the development of engineering education. However, existing practices of PBL-based TRIZ training programs mainly focus on the education of students in university. Further efforts are still needed to propose and validate new PBL-based TRIZ training approaches particularly for engineers in workplace to meet their growing requirements for continuous development of inventive performances.

Moreover, the absence of commonly accepted standard of organization of TRIZ training approaches raises numerous arguments about practical effectiveness of TRIZ training on improving long-term inventive performances of trainee. From this viewpoint, a new TRIZ training approach should be validated its effectiveness before it can be accepted as a feasible way to educate engineers' inventive competency.

Influencing factors that impact performance of TRIZ training approach is also very obscure since there are very limited studies ever tried to validate TRIZ training approach in industrial implementation. With more evidences revealed from further studies on influencing factors of TRIZ training performance, TRIZ training practices can be refined based on more reasonable insights.

To solve aforementioned problems, this paper firstly presents a new PBL-based TRIZ training approach aiming at improving inventive competency of engineers as the conclusion of more than ten years' field research. Then, the proposed TRIZ training approach is validated by analysis of sampling participants' inventive performances. Moreover, influencing factors that impact the practical performance of the proposed TRIZ training approach are found through the statistical analysis.

## 3. The Proposed PBL-Based TRIZ Training Approach

### *3.1 Organization of the Proposed Training Approach*

In the implementation of the classic TRIZ, sophisticated TRIZ users have capabilities to integrate TRIZ with their invention processes in workplace. But for ordinary engineers who have no knowledge nor experience related the application of TRIZ in inventive problems in new product development. As a result, it is too difficult for ordinary engineers to acquire the required knowledge and skills from some existing TRIZ training programs that only last a few days. Therefore, it is more appropriate for train engineers to use TRIZ by formulating a PBL-based approach to solve inventive problems found in real projects of their companies.

Built on the PBL framework, a new TRIZ training programs is developed as the Fig. 1. In the proposed TRIZ training program, there are three subsections: the training strategy which involves several specific steps to educate TRIZ to engineers in workplace, which will be explained in detail in subsection of 3.2; the set of knowledge and skills which is the main body of methods and tools to be transferred to engineers during TRIZ training programs; auxiliaries mainly involve methods and process besides those from TRIZ to facilitate the integration of TRIZ and other methods for improving engineers performances in solving inventive problems.

In Fig. 1, there are four levels of specific knowledge and skills to adapt to various engineers' requirements for improving their inventive competency, which makes up the main body of the whole training program. To be specific, the first level consists of several principal TRIZ methods and tools such as the analogy, extended effects and extended afore failure diagnose (AFD) to educate engineers the basic ideas in implementation of TRIZ. The second level mainly involves integrations of TRIZ methods with other product design methods such as the axiomatic design (AD), the Pahl and Beitz systematic design (PB) and incremental innovation (II) to help engineers solve inventive problems in their workplace. The third level involves more advanced integration of TRIZ and other innovative theories such as the product lifecycle (PL), the radical innovation (RI) and the disruptive innovation (DI) to extend solutions space. The fourth level consists of the redesign process, the six sigma($6\sigma$) and the radical process to facilitate more advanced applications of TRIZ in solving interdisciplinary inventive problems in management and business domains. Engineers with various requirements for developing their inventive competency can choose the most suitable level to inventive processes in their workplaces.

Auxiliaries are supportive subsections to help trainee in the proposed TRIZ training approach

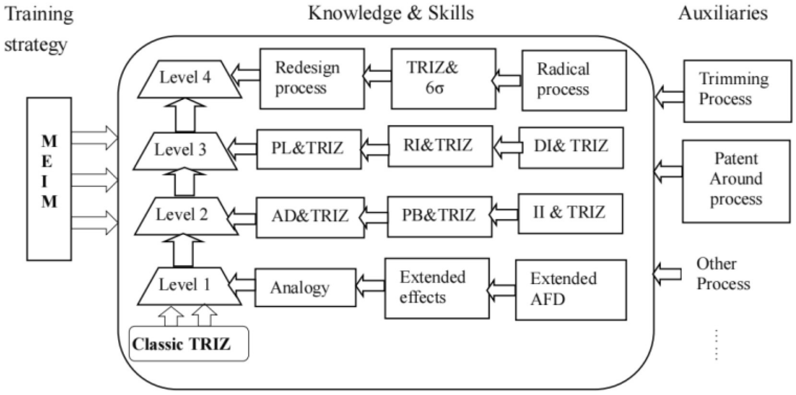

**Fig. 1.** Organization of the PBL-based TRIZ training program.

to apply the main body of the set of knowledge and skills to solve their own inventive problems. Engineers can choose auxiliaries to learn as supplements to TRIZ methodology depending on their specific requirements. Specific methods in auxiliaries involve the trimming, the patent around process and other processes since both these methods are frequently used in industrial to generate new inventions.

### *3.2 The MEIM Training Strategy in the Proposed Approach*

The training strategy used by the proposed approach is named as a massive-engineers-inventions-method (MEIM) since it aims to achieve multiple goals including the cultivation of inventive engineers, the generation of inventions and the improvement of innovative capabilities of companies. In the MEIM training strategy, different stakeholders related to the TRIZ training approach work collaboratively to achieve aforementioned multiple goals. Detailed information about how the MEIM strategy is organized is shown as Fig. 2.

In the MEIM training strategies, there are three roles played by different stakeholders in educating TRIZ methodology to engineers in workplace. The first role is the source institution which mainly includes universities, research agencies or consultancies have capabilities to conduct the proposed PBL-based TRIZ training approach. The second role is usually played by the local government or intermediary agencies which work as bridges to connect the source institutions and companies have willingness to improve their engineers' innovative competences. The third roles in the MEIM strategy are targeting companies who hold responsibilities to choose their engineers to participate in TRIZ training programs.

In Fig. 2, the arrow flows indicate the transferring of knowledge and skills in the flexible TRIZ training program shown in Fig. 1 from sources institutions to targeting companies through the bridge provided the intermediary agencies. Engineers chosen from targeted companies are required to define and resolve inventive problems through a PBL-based TRIZ approach training strategy by acquiring TRIZ knowledge and skills, meanwhile their inventive competency can be improved. The outcomes of the proposed MEIM training strategy are not limited to training of inventive engineers for companies but also solutions to inventive problems related to companies' practical projects such as new technologies, new products prototypes and new processes.

### *3.3 Framework of the PBL-Based TRIZ Training Approach*

All the elements of the proposed PBL-based TRIZ training approach combine and formulate the framework that is shown in Fig. 3.

There are four sections in the framework of the proposed approach: an innovation process, a training process, an interface between the two processes, and companies to participate in the program. The innovation process includes three specific stages: the fuzzy front end, the new product development and the commercialization. The training process have seven steps: selecting companies, selecting engineers, training stage-1, finding problems, training stage-2, finding solutions and summing up. The interface includes opportunities for innovations, defined inventive problems and solutions to defined inventive problems. Practically, engineers from different companies can be selected to participate in training programs that are based on the proposed TRIZ training approach. The duration of a complete training can last from 8 to 10 months. Table 1 shows specific information about seven steps to facilitate integrating of TRIZ training with the principal framework of PBL.

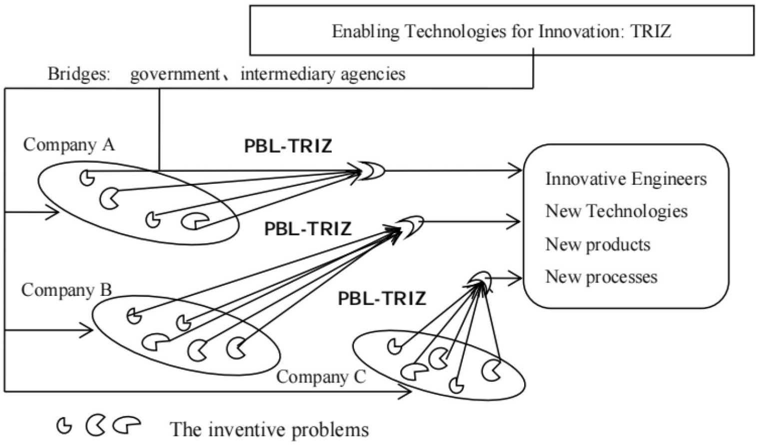

**Fig. 2.** Organization of the MEIM training strategy.

**Table 1.** Seven steps with specific information in the proposed PBL-based TRIZ training approach

| Serial | Name | PBL-tasks | Activities |
|---|---|---|---|
| 1 | Selecting companies | Preparation | The companies to attend the training programs are selected.<br>• Some institution of a local government, or an organizer, is responsible for the selection of appropriate companies to attend the training programs.<br>• Sources institutions also hold the responsibilities to help organizers to locate and select suitable participating companies for the training programs. |
| 2 | Selecting engineers | Select participants | The engineers to attend the class are selected.<br>• The companies selected make recommendation for a list of engineers to join the class.<br>• The organizer needs to decide the name list of participating engineers. |
| 3 | Training stage-1 | Basic knowledge learning | TRIZ experts from sources institutions teach engineers the basic TRIZ methods.<br>• The basic concepts, methods of TRIZ will be taught.<br>• Many cases applying these methods are also demonstrated. |
| 4 | Finding a problem | Problem definition | Each engineer of the class must identify an inventive problem from his or her workplace.<br>• Engineer finds an inventive problem from a stage of innovation processes of their companies.<br>• Engineer constructs an inventive problem for the situation of his/her workplace. |
| 5 | Training stage-2 | Problem analyzing | TRIZ experts from sources institutions teach engineers advanced TRIZ methods.<br>• The systematic methods, such as problem-oriented inventive process, are the contents.<br>• A systematic process model for finding and solving inventive problems are demonstrated. |
| 6 | Solving problem | Problem resolving | Every engineer is required to resolve inventive problems defined and analyzed.<br>• Every engineer generates new ideas.<br>• Every engineer develops the ideas and transform them into at least one solution. |
| 7 | Summing up | Solution evaluation | Evaluation of the overall learning performances of participating engineers.<br>• The final oral examination is made and engineers will present their results with slides.<br>• An evaluation is made and a certificate is presented to some qualified engineers who are innovative. |

At the beginning of the proposed TRIZ training approach, a group of engineers with the numbers ranging from 60 to 80 come from different companies are chosen as participants. During the training program, local government takes the responsibility to provide financial support to facilitate intermediary agencies direct the whole training progress. Meanwhile, source institutions are required to provide technological support to intermediary agencies and hold responsibility to train, guide and coach the participating engineers.

As the results of the training program, a group of innovative engineers are direct fruits together with new technologies, new processes, and new products, all of which are solutions to inventive problems defined by engineers from their workplace. Among these outcomes, the improvement of engineers' inventive competency is the main purpose of the organizations of TRIZ training programs since engineers will contribute to their companies with promising innovative performances for a long time in the future. New technologies and new patents are created by participating engineers during the training programs, which are derived purposes. Within a PBL framework, new products projects are also initialized by participating engineers defining inven-

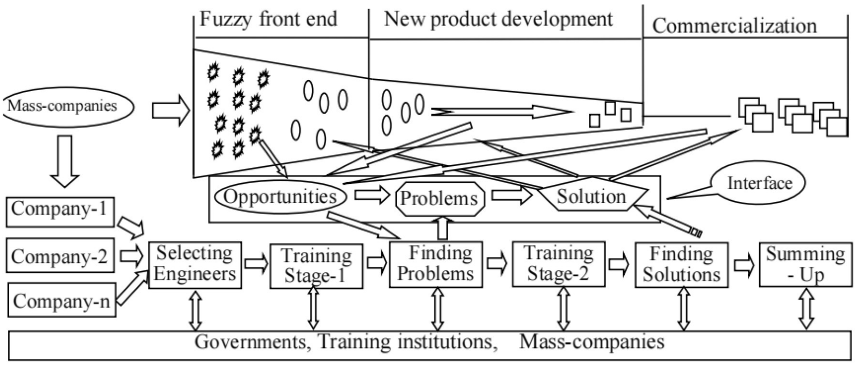

**Fig. 3.** Framework of the PBL-based TRIZ training approach.

tive problems to be solve, which are lucky results of training programs built on the proposed training approach.

After more than ten years of practical applications, the proposed PBL-based TRIZ training approach has gradually developed into a mature version with two distinguished features:

The proposed approach has high flexibility to meet various requirements of participants engineers from various backgrounds, as engineers from different companies with different professional fields can attend the same training program.

The proposed approach is able to be incorporated in the current innovation process being implemented by participating engineers' companies with a rich set of methods and tools, which helps participating engineers acquire both knowledge and skills to enable effective TRIZ applications in their real workplaces afterwards and formulate a long-term inventive competency.

## 4. Validation of the Proposed Training Approach

### *4.1 Research Design*

#### *4.1.1 Participants*

The proposed PBL-based TRIZ training approach have been applied in organizations of TRIZ training programs since its complete version had been developed in the late of 2012. From the year of 2013 to 2016, the aforementioned training approach has been implemented in more than 40 TRIZ training programs to train more than one thousand engineers from hundreds of companies located in various provinces around China. There are in total 1471engineers participate in the whole training programs and passed the final solution evaluations. These authorized innovative engineers have applied 1218 patents including 648 items of inventions.

To validate the effectiveness of the proposed training approach, the research sample is made up of participating engineers from training programs in the year of 2013 since it is the first year to apply the mature version of the proposed training approach with the longest available periods to observe long-terms afterwards performance. In 2013, there were five TRIZ training programs organized in different regions of China with 241 participating engineers from 42 different companies. All the participating engineers from companies with the most participants in each training programs are chosen as the research sample. As a results, the 95 engineers (70 male and 25 female) from five different companies hold bachelor degree in engineering fields. Their ages ranged from 28 to 43 with working experience as full-time engineers from five to eighteen years when participated in the TRIZ training programs, all of them had reported no previous knowledge or experience about TRIZ learning.

#### *4.1.2 Dependent Variables*

Dependent variables in the validation of the proposed training approach are inventive performances of participating engineers. To measure their inventive performance before, during and after training programs, patent-based indicators are implemented as measuring variables. Patent-based indicators such as the patent applications provide discrete measures of inventive solutions generated at work by engineers to innovative [48]. Patent-based indicators have been widely used as measures of both individual and organizational inventive performances [49, 50]. Even in the field of the engineering education, students having outstanding performances are encouraged to submit patents in some courses on innovation and invention [51].

Patent submissions at workplace are usually collaborations results of efforts from multiple engineers. Therefore, a new set of adapted patent-based indicators are proposed based on methods in the previous study [52] to calculate individual contributions in patent applications with multiple inventors. Specifically, two dimensions of patent-based indicators adapted from widely used in creativity measurements [53, 54]: the weighed patent amounts (WPA) to measure engineers' inventive fluency and the weighed patent values (WPV) to measure engineers' inventive originality based on types of patent applications.

Formulas 1 and 2 correspondingly illustrate how to calculate indicators of WPA and WPV. Both the WPA and the WPV have considered differences in contributions by according to the order of inventors, which represents a more reasonable measure of individual engineer's contribution in patents containing multiple inventors.

$$WPA=\sum_{i=1}^{n}\left(\frac{m_i+1-j_i}{m_i(\mathrm{m}_i+1)/2}\right) \tag{1}$$

$$WPV=\sum_{i=1}^{n}\left(\frac{m_i+1-j_i}{m_i(\mathrm{m}_i+1)/2}V_i\right) \tag{2}$$

In formula (1), there are in total n(n>=1) patents applied by engineers to be assessed, $\mathrm{m}_\mathrm{i}$ indicates there are m(m>=1) inventors who have contributed to the $\mathrm{i}^{\mathrm{th}}$ patent. The $\mathrm{j}_\mathrm{i}$ indicates the engineer to be assessed has ranked the $\mathrm{j}^{\mathrm{th}}$ place in the inventors list of the $\mathrm{i}^{\mathrm{th}}$ patent. In formula (2), $\mathrm{V}_\mathrm{i}$ indicates the value of the $\mathrm{i}^{\mathrm{th}}$ patent. Values of patent are assigned by their specific categories, the authorized invention is assigned as 3, while the invention applied without authorization or under investigation is scored as 2, patents of new utilities get 1 point for their values.

For example, there is an engineer has contributed to two different patents during the observing window, one of them is an authorized invention the other one is a new utility. In the authorized invention, the engineer ranked in the second place in the name list of five inventors and ranked as the third out of six contributors in the new utility. Results of WPA and WPV are 0.457 and 0.991 correspondingly calculated through formula (1) and formula (2).

Observing windows for assessing engineers' innovative performances before and after training programs are as long as three years based on the previous study to measure engineers' patent application activities [55]. WPA and WPV indicators of all engineers' inventive outcomes before, during and after TRIZ training programs are calculated through formulas (1) and (2). Specifically, the before WPA(BWPA) and the before WPV(BWPV) indicate engineers' inventive performance before they participated in PBL-based TRIZ training programs, correspondingly the during WPA(DWPA) and during WPV(DWPV) measure performances during training programs, and the after WPA(AWPA) and the after WPV(AWPV) measure inventive performances of engineers after training programs.

### *4.1.3 Independent and Explanatory Variables*

The main independent variable in validation of the proposed PBL-based TRIZ training approach is the participation in training programs, which has been differentiated by using the AWPA(V) and the BWPA(V). Besides this main independent variable, there are several explanatory variables used to reveal potential influencing factors of the proposed TRIZ training approach based on previous studies.

The first one is the working departments of participating engineers, in other words, this binary indicator DRPshows whether the participating engineer work in the R&D departments or not (1 for working in R&D departments, 0 stands for working in other departments). As revealed by the previous study [55] that the departmental support is important for employee innovation performance. Moreover, R&D departments are major determinants of firms' innovative performance [56], R&D departments can provide more positive departmental supports to engineers to innovate. Hypothesis 1 therefore can be proposed as the working in R&D department positive impact the performance of the proposed TRIZ training approach.

The second explanatory variable is the former experience of patent applications since the successful experience is positive related to the self-efficacy of participants which play crucial roles in their creativity and inventive performances [32, 57]. Binary indicator of FPE (1 for have applied patents before and 0 for no experience of patents application) stands for the former experience of patent application of participants. Hypothesis 2 is proposed as the former experience of patent application has positive impact on the performance of the proposed approach in improving the inventive competency of engineers.

The third variable DoT stands for evaluation results of overall learning performance of participating engineers in the proposed training approach. To be specific, there are two levels of examination results: the qualified level (DoT = 0) and the good level (DoT = 1). The qualified level means the learner has the fulfilled all the tasks with average performance, while the good level means learners have achieved better performance. Since TRIZ is a knowledge-based methodology, it is reasonable to propose the hypothesis 3 that is the participants have archived good levels can performance better in the post-training stage.

The fourth variable PRT (1 means correlated patents have been applied, 0 means no correlated patents) indicates the binary results of whether patent applied by participants during and after training programs are correlated to inventive problems raised in their training programs. This indicator can measure the performance of the implementation of the PBL framework in enhancing TRIZ training approach. Therefore, hypothesis 4 is proposed as the participating engineers who have applied correlated patents can perform better during and after the training programs.

### *4.1.4 Statistic Analysis Methods*

At first, in the validation of the proposed training approach, the paired sample T-test is applied to verify whether there is any statistically significant improvement of research samples' inventive performances by comparing their pre-training and post-training dependent variables. Secondly, the testify of all the four hypotheses firstly applied the paired sample T-test to reveal supportive or rejective findings then uses the Pearson correlation analysis to discriminate most important influencing factors followed by using the multiple regression analysis on explanatory variables impact on the performance of the proposed PBL-based TRIZ training approach.

## *4.2 Results Analysis*

### *4.2.1 Validation of the Practical Effectiveness of the Proposed Training Approach*

The paired-sample T-test is applied to compare indicators of the BWPA and the AWPA as well as the BWPV and the AWPV to verify whether the proposed training program have improved the inventive competency of participating engineers measured by their patent submission activities. Comparation results of the BWPA and the AWPA are shown in the Fig. 4 and the comparison results of the BWPV and the AWPV are shown in the Fig. 5. Moreover, the statistical data about means, standard deviations of these indicators and statistic significances of the paired-sample T test are shown in the Table 2.

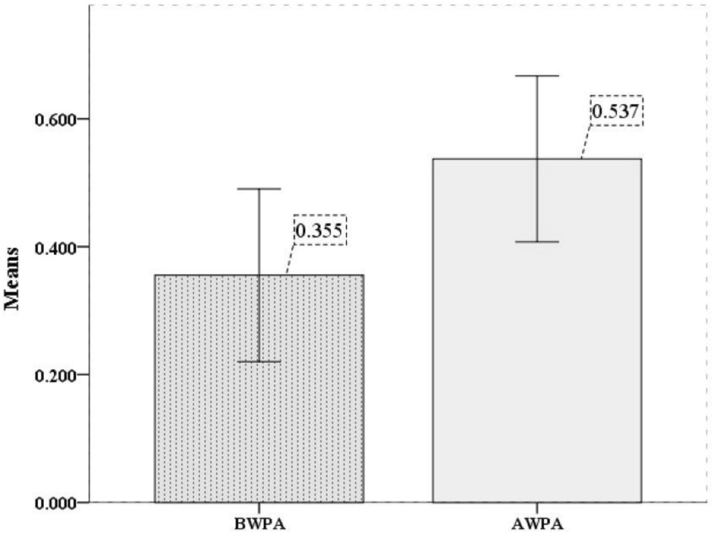

**Fig. 4.** Comparison results of the BWPA and AWPA indicators of sampling engineers.

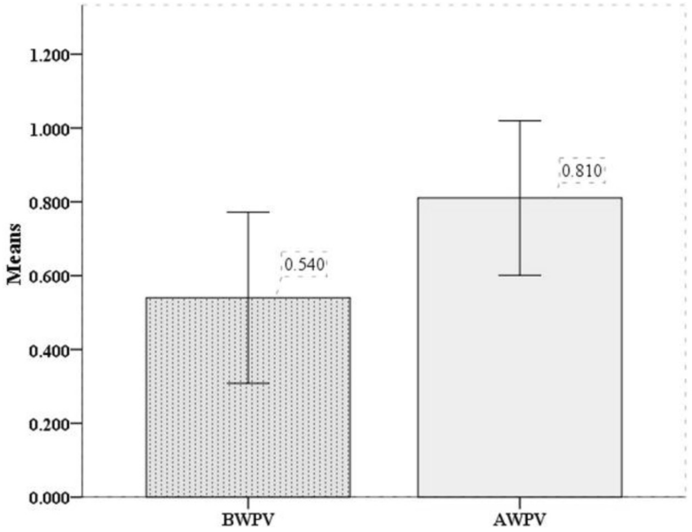

**Fig. 5.** Comparison results of the BWPV and AWPV indicators of sampling engineers.

**Table 2.** Paired-sample T testes results of innovative performances

| | | **Means** | **Std. deviation** | **P-value** |
|---|---|---|---|---|
| Pair 1 | BWPA | 0.355 | 0.663 | – |
| | AWPA | 0.537 | 0.637 | – |
| | BWPA-AWPA | –0.182 | 0.739 | 0.018* |
| Pair 2 | BWPV | 0.540 | 1.138 | |
| | AWPV | 0.810 | 1.028 | |
| | BWPV-AWPV | –0.270 | 1.105 | 0.019* |

Note: ** $p < 0.01$,* $p < 0.05$.

**Table 3.** Results of the paired T-test for the impact of the DRP

| | Group (DRP) | Means | Std. deviation | F | P-value |
|---|---|---|---|---|---|
| BWPA | 0 | 0.315 | 0.643 | 0.127 | 0.722 |
| | 1 | 0.389 | 0.684 | | |
| BWPV | 0 | 0.431 | 0.839 | 0.521 | 0.472 |
| | 1 | 0.631 | 1.338 | | |
| DWPA | 0 | 0.097 | 0.195 | 3.555 | 0.063 |
| | 1 | 0.167 | 0.355 | | |
| DWPV | 0 | 0.127 | 0.256 | 2.933 | 0.090 |
| | 1 | 0.240 | 0.632 | | |
| AWPA | 0 | 0.125 | 0.222 | 18.912 | 0.000** |
| | 1 | 0.878 | 0.668 | | |
| AWPV | 0 | 0.145 | 0.264 | 29.099 | 0.000** |
| | 1 | 1.360 | 1.099 | | |

Note: ** $p < 0.01$, * $p < 0.05$.

Refers to Fig. 4 and Fig. 5, means of the AWPA and the AWPV are evidently higher than means of the BWPA and the BWPV, which indicate inventive competency of sampling engineers have significantly improved after they participated in the proposed training programs. Moreover, P-values in Table 2 even indicate that there are h statistic significances of paired-sample T tests for both comparisons. In other words, the proposed training model has evidently improved the inventive performances of participants, which are measured by both the number of patents and the value of patents.

### 4.2.2 *Testify Hypotheses about Influencing Factors of the Proposed Training Approach*

All the hypotheses about influencing factors of the proposed training approach are testified through the paired T-test comparing. At the first, the hypothesis 1 is testified by the results of paired T-test comparing in Table 3. Refers to Table 3, although better inventive performance of participating engineers from the R&D departments are observed in pre-training and during-training indicators, there is not any statistic significances represented by P-values. But their post-training inventive performances of participating engineers from the R&D departments evidently better than participants from other departments with statistic significances. The result has evidently indicated that the positive impact of the working in R&D departments on the performances of the proposed training approach. Therefore, the hypothesis is supported.

Secondly, the FPE, the indicator of engineers' former patent applying experience, is verified by the paired T-test comparing analysis with results shown in Table 4. Refers to Table 4, the hypothesis is partly supported since only the inventive originality indicator i.e., AWPV of participants who have previous patent application experience is significantly higher than others have not applied patents previously, whilst the higher inventive fluency indicator i.e., APWA does not indicate statistical significance.

Thirdly, results of the paired T-test for the impact of the DoT are shown in Table 5. Refers to Table 5, the hypothesis 3 is rejected because of there is no better performances of participating engineers with

**Table 4.** Results of the T-test for the impact of the FPE

| | Group (FPE) | Means | Std. deviation | F | P-value |
|---|---|---|---|---|---|
| BWPA | 0 | 0.000 | 0.000 | 43.994 | 0.000** |
| | 1 | 0.689 | 0.792 | | |
| BWPV | 0 | 0.000 | 0.000 | 25.114 | 0.000** |
| | 1 | 1.047 | 1.412 | | |
| DWPA | 0 | 0.044 | 0.163 | 14.836 | 0.000** |
| | 1 | 0.221 | 0.360 | | |
| DWPV | 0 | 0.050 | 0.172 | 13.301 | 0.000** |
| | 1 | 0.319 | 0.652 | | |
| AWPA | 0 | 0.379 | 0.513 | 0.795 | 0.375 |
| | 1 | 0.686 | 0.708 | | |
| AWPV | 0 | 0.485 | 0.685 | 8.136 | 0.005** |
| | 1 | 1.116 | 1.197 | | |

Note: ** $p < 0.01$, * $p < 0.05$.

Table 5. Results of the T-test for the impact of the DoT

| | Group (DoT) | Means | Std. deviation | F | P-value |
|---|---|---|---|---|---|
| BWPA | 0 | 0.312 | 0.696 | 0.281 | 0.597 |
| | 1 | 0.413 | 0.622 | | |
| BWPV | 0 | 0.486 | 1.313 | 0.037 | 0.848 |
| | 1 | 0.611 | 0.865 | | |
| DWPA | 0 | 0.044 | 0.113 | 28.367 | 0.000** |
| | 1 | 0.256 | 0.401 | | |
| DWPV | 0 | 0.060 | 0.156 | 18.369 | 0.000** |
| | 1 | 0.359 | 0.708 | | |
| AWPA | 0 | 0.409 | 0.540 | 2.651 | 0.107 |
| | 1 | 0.707 | 0.717 | | |
| AWPV | 0 | 0.653 | 0.952 | 0.830 | 0.365 |
| | 1 | 1.018 | 1.097 | | |

Note: ** $p < 0.01$, * $p < 0.05$.

good levels of learning evaluations observed in neither the AWPA nor the AWPV indicator.

Fourthly, results of the paired T-test for the impact of the PRT are shown in Table 6. Refers to Table 6, the hypothesis 4 is supported as participating engineers' who have applied patents that are correlated to problems defined in training programs have significantly better during and post-training inventive performance.

### *4.2.3 Regression Analysis to Reveal Influencing Factors to the Performance of the Proposed Approach*

Possible impactors on the feasibility of the proposed training approach are revealed by the Pearson correlation analysis with its analysis results shown in Table 7. Refers to Table 7, the most obvious correlations are observed in pairs of the

Table 6. Results of the T-test for the impact of the PRT

| | Group (PRT) | Means | Std. deviation | F | P-value |
|---|---|---|---|---|---|
| BWPA | 0 | 0.314 | 0.677 | 0.049 | 0.826 |
| | 1 | 0.388 | 0.657 | | |
| BWPV | 0 | 0.393 | 0.790 | 0.845 | 0.360 |
| | 1 | 0.657 | 1.348 | | |
| DWPA | 0 | 0.045 | 0.121 | 17.125 | 0.000** |
| | 1 | 0.207 | 0.365 | | |
| DWPV | 0 | 0.069 | 0.204 | 8.192 | 0.005** |
| | 1 | 0.283 | 0.630 | | |
| AWPA | 0 | 0.137 | 0.260 | 16.337 | 0.000** |
| | 1 | 0.854 | 0.670 | | |
| AWPV | 0 | 0.181 | 0.354 | 24.210 | 0.000** |
| | 1 | 1.309 | 1.112 | | |

Note: ** $p < 0.01$, * $p < 0.05$.

Table 7. Analysis results of Pearson correlations among all the research indicators

| Pearson Correlation | DWPA | AWPA | DRP | FPE | DoT | PRT | BWPV | DWPV | AWPV |
|---|---|---|---|---|---|---|---|---|---|
| BWPA | 0.092 | 0.355** | 0.056 | 0.522** | 0.076 | 0.055 | 0.936** | 0.119 | 0.406** |
| DWPA | | 0.287** | 0.120 | 0.303** | 0.357** | 0.276** | 0.065 | 0.939** | 0.277** |
| AWPA | | | 0.591** | 0.242* | 0.233* | 0.562** | 0.397** | 0.318** | 0.958** |
| DRP | | | | 0.219* | 0.067 | 0.681** | 0.088 | 0.113 | 0.592** |
| FPE | | | | | 0.164 | 0.325** | 0.462** | 0.270** | 0.309** |
| DoT | | | | | | 0.305** | 0.055 | 0.298** | 0.177 |
| PRT | | | | | | | 0.116 | 0.214* | 0.548** |
| BWPV | | | | | | | | 0.096 | 0.483** |
| DWPV | | | | | | | | | 0.313** |

Note: ** $p < 0.01$, * $p < 0.05$.

**Table 8.** Regression results of impactors on performances of the proposed training model

| **Regression model** | | | **DRP** | **FPE** | **BWPA** | **BWPV** | **DoT** | **PRT** | **DWPA** | **DWPV** | **Constant** | **$R^2$** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWPA | Model 1 | B | 0.753 | – | – | – | – | – | – | – | 0.125 | 0.349 |
| | | Beta | 0.591 | – | – | – | – | – | – | – | – | |
| | | P-value | 0.000 | – | – | – | – | – | – | – | 0.115 | |
| | Model 2 | B | 0.747 | –0.094 | 0.346 | – | – | – | – | – | 0.054 | 0.457 |
| | | Beta | 0.587 | –0.074 | 0.360 | – | | | | | – | |
| | | P-value | 0.000 | 0.426 | 0.000 | – | | | | | 0.518 | |
| | Model 3 | B | 0.527 | –0.259 | 0.387 | – | 0.091 | 0.627 | 0.360 | – | –0.116 | 0.547 |
| | | Beta | 0.414 | –0.204 | 0.403 | – | 0.071 | 0.257 | 0.166 | | – | |
| | | P-value | 0.000 | 0.030 | 0.000 | | 0.381 | 0.021 | 0.042 | | 0.449 | |
| AWPV | Model 1 | B | 1.215 | – | – | – | – | – | – | – | 0.145 | 0.350 |
| | | Beta | 0.592 | – | – | – | – | – | – | — | – | |
| | | P-value | 0.000 | – | – | – | – | – | – | – | 0.256 | |
| | Model 2 | B | 1.143 | –0.037 | – | 0.399 | – | – | – | – | –0.012 | 0.537 |
| | | Beta | 0.557 | –0.018 | – | 0.442 | – | – | – | – | – | |
| | | P-value | 0.000 | 0.828 | – | 0.000 | – | – | – | – | 0.920 | |
| | Model 3 | B | 0.856 | –0.241 | | 0.413 | 0.044 | 0.410 | | 0.423 | –0.128 | 0.608 |
| | | Beta | 0.417 | –0.118 | – | 0.457 | 0.021 | 0.199 | | 0.205 | – | |
| | | P-value | 0.000 | 0.149 | | 0.000 | 0.774 | 0.049 | | 0.005 | 0.574 | |

xWPA and the xWPV since the number of patents is the basis for the value of patents. Except for these naturally correlations among two types of patent-based indicators, other correlations are also revealed by analysis results. Built on the correlation analysis, the multiple regression approach is used to discriminate the most significant influencing factors on the performance of the proposed training approach.

In the regression analysis, both the AWPA and the AWPV indicators are used as dependent variables respectively to test the strength of explanatory variables on the performance of the proposed training approach. Results in Table 8 have indicated influencing factors mainly come from three aspects: the working in R&D departments of participating engineers measured by the DRP; Former patent application experience indicated by the FPE together with BWPA/BWPV; Overall learning performances in training programs measured by the DoT with the DWPA and the patent application correlated to problems defined and solved in the training programs measured by the PRT

In the process of the multiple regression, three steps of factors entered the model one by one, in turns these factors have formulated three different models. The first model only includes the factor of the DRP, the second model adds factors indicating former patent applying activities and the third model consists of factors on all the three aspects. Regressions' results are shown in Table 8 with the information about how the goodness of fitting (R-square) of the regressions of the AWPA and the AWPV increase gradually with more factors put into the regression model.

Refers to regression results in Table 8, influencing factors on three aspects are tested. Among these factors, the DRP has the highest standardised coefficient in all the three models of the AWPA regression and first two models of the AWPV regression, in other words, engineers working in R&D departments will permit better inventive performances after they participated in the proposed training programs. Among the second types of factors, indicators of the BWPA and the BWPV play the second important roles in determinations of the AWPA and the AWPV respectively. However, the indicator of FPE has shown negative impact on both the AWAPA and the AWPV but is not strength enough to obtain statistic significances. In other words, the former patent applications experience is also important to inventive performance of participating engineers. Factors of the third type have shown positive impacts on the proposed training model, only the indicator of DoT did not reach the statistical significance, which indicates that even the participating engineers have archived good overall performance of training programs do not permit higher inventive performance afterwards.

### 4.3 Summary of Main Findings

There findings provide insights for practices of TRIZ education for engineers in workplace, which will be explained specifically as follows.

(1) Among explanatory factors, the DRP has the most positive correlation with the improvement of inventive performance of engineers by referring to Table 3 and 8, which indicates that participating engineers who work in R&D departments have gained more obvious

improvements of their inventive competency than their peers from other departments in companies.

(2) The former experience of successful patent application also plays a positive role in the improvement of innovative performances of participating engineers, which is indicated by statistic significances in analysis data in Tables 4 and 8. However, the impact of FPE is smaller than the DRP by referring to its values in regression models in Table 8.

(3) It is unexpected to note that overall learning performances of participants do not permit more significant improvements of inventive performances revealed by analysis results in Table 5 and 8. One of possible explanations is the DoT indicator is mainly decided by learning performances of participants other than the tracking their long-term post-training innovative performances. Therefore, a more reasonable evaluation method is needed to assess participants' training performances.

(4) Analysis results also indicated that engineers who have applied patents that are related to problems raised and solved in training programs have achieved better inventive performances in both the during-training and the post-training periods based on analysis results shown in Tables 6 and 8.

## 5. Discussions

### *5.1 Main Contributions*

There are three major contributions of this paper to both the PBL and TRIZ fields.

In the first place, this paper has enriched the implementation of PBL in engineering education by providing a novel systematic PBL-based TRIZ training approach particularly for educating engineers in workplace. The proposed method is different from existing PBL-based TRIZ courses [6, 9, 14] in universities since it begins with definition of problems explored by participating engineers from workplaces, which makes it flexible to adapt to various requirements of engineers from different backgrounds.

Secondly, this study contributes to the TRIZ research domain with a feasible way to educate TRIZ for engineers by organizing TRIZ teaching & learning into a PBL framework. Moreover, the proposed approach has been validated by evident improvement of inventive performance in 95 participating engineers from five different companies measured by a set of patent-based indicators. Therefore, the integration with the PBL can be seen as a preliminary step towards the commonly agreeable standard of TRIZ training for engineers.

Thirdly, several findings on influencing factors that impact the performance of the integration of PBL and TRIZ are revealed by analysis results of paired T-tests and the multiple regression. Among those impactors, participants' positions in R&D departments and former experience of patent applications have positive influences on their learning performance. Therefore, trainee's knowledge and experience about R&D activities may help improve the performance of the implementation of PBL-based TRIZ training for engineering in workplace. Moreover, this proposed TRIZ training approach is characterized by its PBL-based feature, its workability has been addressed by positive influences of the PRT on participating engineers' inventive performances during and after training programs. Therefore, the integration of the PBL framework with the TRIZ education is validated as a feasible way to improve inventive competency of engineers in workplace. The validation result also indicates that the PBL framework is feasible to educate the comprehensive ability to tackle with complex tasks such as the inventive competency that depends on handling a systematic integration of various knowledge and skills throughout the TRIZ training program.

### *5.2 Implications for Practical TRIZ Education*

There are several implications for practices of educate TRIZ to both engineers in workplace and students in universities can be summarized based on aforementioned findings.

On the first aspect, owing to their very limit resources for employee training, companies are suggested to choose engineers from R&D departments as candidates for TRIZ training to make best of training opportunities since there are more significant improvements of inventive competency of sampling engineers from R&D departments.

Secondly, participating engineers with experiences of patent applications also have evidently higher improvements of their innovative performances during and post the TRIZ training programs. Therefore, the experience of patent applying is another positive indicator in the determination of participating engineers for TRIZ training programs.

Thirdly, the transferability of the proposed approach is able to enrich TRIZ courses for engineering students in universities since problems defined by participating engineers in the proposed training approach can be collected and transformed into typical problems set for engineering students to learn practical engineering problems. In addition, the typical problems set can also be applied in other training sessions for engineers in workplace to help participants define their own problems by providing important references.

### *5.3 Limitations and Opportunities for the Future Study*

Although there are several findings and implications raised by this study, limitations of this paper are also obvious requiring in-depth considerations in the future.

Firstly, this study is an early attempt to validate the workability of the proposed TRIZ training approach. More solid researches can be initialized with more approaches to reasonably evaluate inventive performances of participating engineers. Moreover, good overall evaluation of participants' learning performances is not so decisive to permit better post-training performances of participating engineers. Therefore, more reasonable evaluation methods need to be developed to assess participants' learning performances.

Secondly, the integration of the PBL framework and TRIZ as a training approach to educate engineers has been validated by participants' practical inventive performance measured by a set of patent-based indicators. Subjective information such as comments and suggestions from both educators' and learners' sides are also important for refining the proposed approach. Therefore, studies in the future will collect feedbacks from both TRIZ experts and participating engineers to formulate a comprehensive assessment on the effectiveness of the integration of the PBL approach and the TRIZ training program.

Thirdly, several confounding variables such as gender, age and education degree may impact the inventive performance of participating engineers, which may affect the validation of the proposed training approach. However, these control variables are only considered by companies to choose participants without any further analysis and discussions, which mainly due to sample size of the research sample. Therefore, a more solid comparing analysis study can be conducted to testify these variables in the future by collecting data from a large research sample.

In additions, the development of information technology has shown its significant influence on the reforming of engineers training as well as PBL-based leaning techniques by providing advanced technologies and tools such as the digital twin and the augmented reality to enable remote the engineering education. Therefore, it requires more in-depth thinking and studies to apply these enabling technologies to facilitate practices of educating TRIZ to engineers in industrial settings.

## 6. Conclusions

This paper has presented and validated a PBL-based TRIZ training approach aiming at improving inventive competency of engineers in engineers. Built on the PBL framework, the proposed TRIZ training approach is capable to achieve multiple goals involving the cultivation of inventive engineers, the generation of innovations and the improvement of innovative competences of participating companies, which is a new practice to integrate PBL and TRIZ in engineering education particularly for engineers in workplace. In the validation of the proposed training approach, in total 95 engineers who have participated in training programs built on the proposed training approach are used as the research sample. Their inventive performances of pre-training, during training and post-training stages are measured by a set of patent-based indicators. Analysis results have indicated that the proposed training approach has evidently improve inventive performance of participating engineers, thus, to verify the practical effectiveness of the proposed approach. Moreover, statistical analysis also testified several influencing factors that impact the performance of the proposed training approach. Among these factors, the working in R&D departments and former patent application experience and patent applied related to defined problems in training programs have positive influence on the performance of the proposed approach. There are several implications for practices of educating TRIZ to engineers based on main findings. Lastly, limitations of this study are summarized to highlight several opportunities for the future study.

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