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EURASIA Journal of Mathematics Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
2017 13(7):4301-4309
DOI: 10.12973/eurasia.2017.00835a



Training Mode of Innovative Talents of Civil Engineering Education Based on TRIZ Theory in China

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Received 9 November 2016 • Revised 22 March 2017 • Accepted 17 April 2017

ABSTRACT

The key to improve comprehensive national strength is to training more innovative talents. At present, the teaching mode of China's civil engineering focuses on pouring the knowledge, which leads to the dissociation between class and practical case. As an innovation tool, TRIZ theory has been widely used in worldwide enterprises, however, there is scarce analysis on its application in training innovative talents in universities and colleges as a training method of innovative thinking and innovative ability. Regarding the shortage in training civil engineering talents, this paper based on RIZ Theory, proposed training methods of innovative talents of China Civil Engineering; Strengthening the establishment of teaching staff of civil engineering based on TRIZ theory; Initial the course of TRIZ Innovation Theory for civil engineering major; Applying TRIZ theory into civil engineering class; Building TRIZ based platform for practicing innovative method; Building the software platform based on TRIZ theory.

Keywords: TRIZ theory, civil engineering, innovative talent, training mode

INTRODUCTION

For the past few years, with the rapid development of science and technology, improving self-innovation ability and establishing a new innovation nation has become the key to improve the comprehensive national strength and thus enhancing the China's competence under the wave of worldwide economic globalization. To innovate is neither a negative empty talk, even nor a blindness of attempt; however, innovation needs the systematic methods.

So far, innovation scientists from home and abroad have concluded over 300 kinds of innovation methods, over 100 of which are common methods (Duan and Hou 2012). There are many naming ways about innovation methods in different countries including the innovative engineering in the states, innovative engineering technical method or concept-building and ideate technical method in France; innovation engineering science or ideate technical method in Japan; and innovative ability technique or expert technique in Russia(Xu 2009).

In 1942, Zwicky, the Sweden astronomer, formulated the morphological analysis with the application of mathematical permutation and combination theory during the researching process of USA rockets (EDWARD DE BONO 1999). In 1963, an American company named Hortaiwale researched and found the method of Pattern.

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State of the literature

- TRIZ method is once of most representative and influential methods in innovation method study. Currently, this theory has been widely used in various developed countries.
- TRIZ theory has been widely used in worldwide enterprises, however, there is scarce analysis on its application in training innovative talents in universities and colleges as a training method of innovative thinking and innovative ability.
- Aim to promote the basic method of the invention and innovation to civil engineering talents and there isn't detailed exposition of a specific knowledge point of TRIZ theory.

Contribution of this paper to the literature

- This study puts forward the concrete methods to cultivate civil engineering innovative talents with TRIZ theory.
- Based on TRIZ theory, it concluded challenging problems in training innovative talents of civil engineering and proposed a series of suggestions including strengthening the establishment of innovative teaching staff, opening the course of TRIZ theory, establishing the TRIZ-based course teaching method, building platform for practicing innovative thoughts, and building the TRIZ based software platform.
- The results of the study play an important role in training students' innovative quality, innovative thought, and innovative ability.

In Germany, there are also methods such as self-discipline training method by J.H.Schurz, the concept organizing method by F.Hans, the thought meeting method by B. Girij, system innovation method by N.Muriel and the use value analysis method by K. Thomas (RICHEY 2006).

In Russia, TRIZ method is once of most representative and influential methods in innovation method study. Supported by a group of scholars represented by Altshuller, TRIZ method, function with high universality and effectiveness, and was summarized by 40,000 high-level patent literatures selected from millions of invention patents (JUNG-HYEON 2005).

Since the TRIZ theory was founded in 1946 in former Soviet Union, Over 100 colleges and universities have set the TRIZ theory course. Currently, this theory has been widely used in various developed countries. It contributed to the new product development of many big companies including Boeing of USA, general motors, South Korea's Samsung, and help to make considerable economic benefits (Liang and Chen 2012). In 2001, the TRIZ theory training was introduced and gradually generalized in China. In China, TRIZ theory has been used in various fields such as aerospace engineering, military engineering, equipment manufacturing industry and bionics techniques, and helped to make substantial achievements (Wu and Yao 2010; Zhao and Duan 2013; Yan et al. 2014; Jia et al. 2014). In the application of teaching and academic research, Tsinghua university, zhejiang university, sichuan university have set course of TRIZ theory and related approach education, however, it is only explained as a course, which still has a long way to go for the establishment of innovative talents training system based on one particular subject. In this paper, based on TRIZ theory, it concluded challenging problems in training innovative talents of civil engineering and proposed a series of suggestions including strengthening the establishment of innovative teaching staff, opening the course of TRIZ theory, establishing the TRIZ-based course teaching method, building platform for practicing innovative thoughts, and building the TRIZ based software platform, all of which will play an important role in training students' innovative quality, innovative thought, and innovative ability.

THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

Introduction of TRIZ theory

Early in 20th century, people pointed out that the entire civilized society was not thinking. Due to the lack of well organizing the thoughts, people wasted their potential wisdom, not only without thinking, but also without doubting their previous noneffective thinking mode. Therefore a proposition was carried out: Compared with the

basic trial-and-error method, it might be better to extract useful experience from the success and transform it into articulated regulation, and thus develop it into a refined theory for guiding practice. And the proposer of this theory (TRIZ theory) is Altshuller (1926-1988)

The TRIZ theory is short for The Theory of Inventive Problem Solving, which was invented by Genrich Altshuller from former Soviet Union through analyzing over 2.5 million high-level patent materials from various countries, and summarizing the evolution law of technology development. The purpose of this TRIZ theory is to analyze the scientific principle and law in making innovation and creation and solving technical problems. TRIZ theory contains many innovative thoughts methods with scientificity, systematicness and high-operability as well as the method of inventive problem analyzing. The core thought of TRIZ theory is: all scientific developments and progresses are developed and evolved based on objective law, i.e, they should obey the objective evolution law and pattern.

As a qualitative theory, TRIZ theory is a methodology of solving inventive problems and obtaining technical innovation, which was invented by composing effective ideas in order to properly solve problems. Compared with other innovation method, TRIZ possesses one of most out-standing characteristics that is to exert uttermost human wisdom.

Basic Thought of TRIZ

- (1) The developments of all systems (Not just technical system) need to realize some functions, which are so-called "beneficial functions". The system is developed based on certain perceptible law; meanwhile, the law can affect the system development in return.
- (2) All systems try to enhance its efficiency during their lifecycle, and the efficiency can be regarded as a ratio between positive factors brought by benefit functions in the process of system design, use and practical application and the negative factors such as environmental harm.
- (3) The development of all systems and its components are different from the development of systems in environment, which is mainly caused by the disadvantage in development of techniques and system efficiency.
- (4) The incompatibility and needs conflict between systems and its components hinder the realization of beneficial functions, which resulting in the source of technical problems.
- (5) To solve the technical conflicts, the answer is to innovation and creation.
- (6) Since the number of different kinds of conflicts is limited, we can precisely perceive and choose proper computing method for obtaining solutions to practical problems.
- (7) Through research and analysis on big amounts of typical innovation patent materials and technical literatures, we can find the most proper method for conflicts solving.
- (8) Based on memory, attention, imagination, association, the stimulation between all levels of intelligence and psychological feature as well as its development process, we can also find out the solution.
- (9) Following the previous development framework method of other complicated systems in fields of economy, system technique, culture and education, and even the politics, we can apply the solving method any way (Orloff 2010).

TRIZ theory in once of most valuable methods for science and study, which has been widely used in many companies for long. However, as a training method for innovative thought and innovative ability, it has not been practically applied in colleges and universities for training innovative civil engineering talents, which is caused mainly by following reasons: The complicated structure of TRIZ obstacles all beginners; Multi-versions of TRIZ caused by different self-development approaches incomfort beginners; College innovators need too long time for mastering TRIZ; More complication caused by application of various teaching tool; Difficulty of hand computation; Due to the lack of simple procedures for solving medium complicated problems (Ma 2013), it is necessary for us to integrate the TRIZ Promotion with higher education, training the innovative civil engineering talents in undergraduates and graduates.

PROBLEMS IN TRAINING CIVIL ENGINEERING INNOVATIVE TALENTS AT PRESENT CHINA

Training innovative talents can be extended in three aspects: (1) Training innovative quality. We need to train not only the intelligent factors including imagination, observational ability, and practical operation ability, but also train the non-intelligent factors such as passion, curiosity, and hobby. (2) Train innovative thinking. We need to train both non-logical thinking (association, imagination and analogy) and logical thinking (comparison, induction, deduction and reasoning), enabling students to establish thinking habit of agility, profoundness, integrity and innovation. (3) Train innovation ability. Innovation ability is a kind of comprehensive ability, which is reflect in the process of innovation practice. To train innovation ability, we need to adopt the combination of practice and guidance so as to enable students to master innovation method and improve self-study ability.

A survey was conducted among civil engineering professionals who have been graduated for nearly 10 years and diversified in fields of engineering design, construction, supervision and cost. The results shows that over 75% of interviewees think the engineering knowledge learnt from class is seldom used in practical work and less than 5% think the class knowledge is very useful. It can be seen from the snapshot of the results that at current civil engineering class, theory teaching is the only emphasis, leading to a severe disjoints between class knowledge and practical work. Over 90% interviewees argue that civil engineering class should be integrated with practical engineering case and relevant engineering regulations, and meanwhile, it should reflect the cutting-edge and latest knowledge, absorb the new theory and technology related to civil engineering from home and abroad. Due to the shortage of civil engineering development history and most dynamic knowledge, students can only passively accept knowledge instead of conducting innovative and critical study with forward-looking thinking (Ma and Bai 2012; Ning and Bao 2010). There are 3 major reasons resulting in problems in training civil engineering innovative talents at present China: (1) Social factor. The impetuous Atmosphere of entire society focus only on pragmatism, utilitarianism, quickness of success, while ignore the fundamental training; (2) Political Factor. The conventional higher education formed under long-term planned economic condition has disadvantages of independency, coerciveness, unicity and encapsulation; (3) Methodology factor. The problems include over-unitary selection mode, ignorance of individual hobby, emphasis on unified training plan, narrow range of knowledge, force-feeding teaching method with less reflection and practice but over on memorizing, as well as one-sided and unfair estimation standard, which is only based on the proficiency of class knowledge.

The conventional civil engineering teaching mode not only disjoints between students and practical engineering case, but also restricts the technical development and innovation of relevant industries. Therefore, we should reform the current teaching mode, apply the method with more precise target and higher operability, and adopt new civil engineering teaching mode which meet more requirements of training innovative talents under current situation, and promote it in all domestic colleges and universities.

METHOD OF TRAINING CIVIL ENGINEERING TALENTS BASED ON TRIZ THEORY

In order to strength the innovative think and innovative ability of students and teachers majored in civil engineering, in this paper, through combining the subject characteristic and knowledge system of civil engineering, an integral analysis was conducted including TRIZ innovation theory analysis, course establishment, reform of class teaching mode and innovation practice. The specific flow is shown in [Figure 1](#).

Build Innovation-Type Civil Engineering Teaching Staff Based on TRIZ Innovative Theory

The teaching staff with comparatively high innovation quality is the key for cultivation of innovative talents. Only innovative teachers can be more conducive to the implementation of innovative education and better cultivate innovation talents. In recent years, the majority of new young teachers in Chinese institutions of higher learning have doctor's degree. Although they have cultivated their innovation ability through study in the doctoral stage, but without systematic innovation theory training, there is certain limitation in their innovative thinking and innovation ability. Therefore, cultivation of civil engineering professional teachers, especially the young teachers,

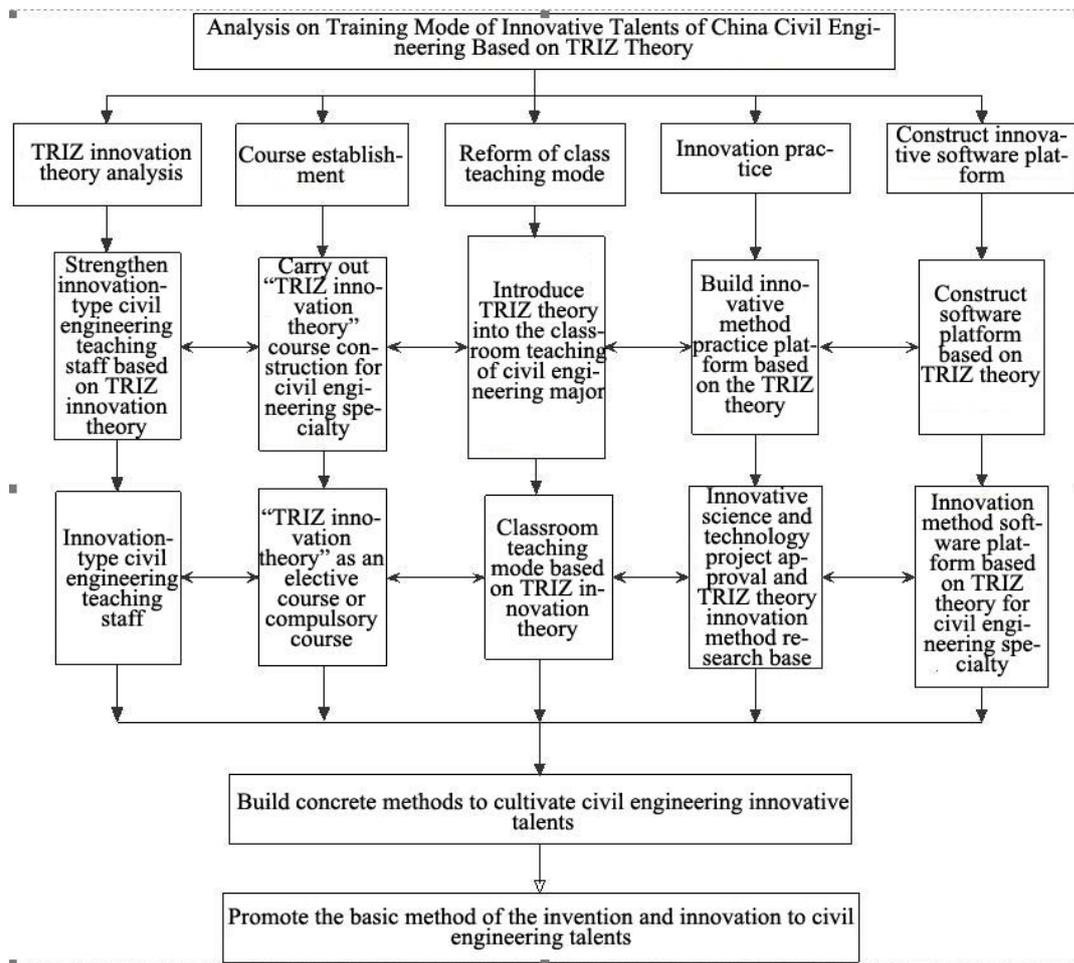


Figure 1. Technology Roadmap to Cultivate Civil Engineering Innovative Talents based on the TRIZ theory

based on the TRIZ innovation theory is needed to strengthen the learning of innovative ways, so that teachers can systematically set up their own innovation system, research the teaching mode and reform the teaching method according to the TRIZ innovation method and build an innovative quality engineering college teachers team.

In the building of innovative teaching staff, teachers must master a set of innovation principle and innovation method, and proficiently apply it in professional classroom teaching. Application of TRIZ innovation theory can enhance the innovation ability of civil engineering professional teachers and can be carried out according to the following points.

- (1) Actively hire domestic and foreign well-known TRIZ theory experts to undertake innovative method lectures, for teachers to understand the basic contents and principles of the TRIZ theory and realize the important significance of learning innovation methods;
- (2) Run TRIZ theory training class for the civil engineering professional teachers. Hire domestic professors with in-depth study of TRIZ theory. In 1 or 2 weeks time and in the intensive teaching mode, let learners systematically study TRIZ theory for a comprehensive grasp of the relevant methods and principles of TRIZ theory. For the relevant examples in the training process, discussion can be carried out by combining the problems that civil engineering professional teachers encounter in their respective study;

- (3) Actively encourage and organize the teachers to participate in the meetings and training courses relevant to domestic and foreign innovation methods, to enable teachers to fully understand the present status of research and application of TRIZ theory or other innovative methods and exchange and learn from each other;
- (4) Organize civil engineering professional teachers to undertake visits, exchange and learning in domestic universities and business units that have been carried out TRIZ theory education, to strengthen cooperation in innovative scientific research projects in civil engineering;
- (5) Encourage teachers to apply the TRIZ theory to their own scientific research projects and carry out subject study with the TRIZ method, enriching their research results while enhancing the innovation ability of the research team at the same time.

Carry Out “TRIZ Innovation Theory” Course Construction in Civil Engineering Specialty

Creative talents must have the innovation thinking, innovation spirit and innovation ability. The cultivation and improvement of their innovation ability is a systematic project, but there exist certain rules. Therefore, it is imperative to systematically carry out innovation method and innovation ability training for the college students and postgraduates.

At present, undertaking of TRIZ theory education has just started in China and most teachers and students know few the relevant innovation method of TRIZ theory. Open “TRIZ innovation theory” as an elective course or compulsory course for the students majored in civil engineering, combine the knowledge background of students majored in civil engineering and systematically cultivate students’ innovative thinking and innovative ability through classroom explanation and training of innovative methods, enabling students to apply the TRIZ innovation method in their learning and study for further invention and creation.

- (1) Open the elective course of “TRIZ innovation theory” for civil engineering undergraduates. Enable students to understand and master the knowledge relevant to TRIZ theory innovation method through classroom learning and learn to apply innovative methods and principles in thinking. In order to ensure the effectiveness of classroom learning, there are no more than 20 students in each class. In addition to explanation of the basic principles of the TRIZ innovation theory, the classroom teaching mainly features discussion on the relevant innovation problems, letting students actively apply innovative method in thinking and problem solving and enhancing students’ innovative thinking and innovation ability;
- (2) Open the compulsory course of “TRIZ innovation theory” for civil engineering innovation class. Run the civil engineering innovation class with training of students’ creative thinking and creative ability as the purpose. Open “TRIZ innovation theory” course as a compulsory course of the innovation class to enable the students more systematically learn the basic knowledge of innovative methods. Only through systematic learning and training of innovative methods can students think about problems with innovative thinking mode in the process of problem solving and can we cultivate innovative talents in the true sense. For the course construction of innovation class “TRIZ innovation theory”, the living examples of invention problems adopted in the classroom should be related to the major of civil engineering, so that the student can deepen the understanding of their professional knowledge while thinking about problems with innovative methods at the same time.

Introduce TRIZ Theory into the Classroom Teaching of Civil Engineering Major

Although China actively advocates cultivation of high-quality talent, but influenced by the traditional examination oriented education system, at present, China’s classroom teaching methods mainly feature direct cramming type teaching. The teaching method tends to make students form a fixed pattern of thinking, lack of creative thinking and innovation ability. The classroom teaching mode based on TRIZ innovation theory can make up for the deficiency in the traditional classroom teaching mode. The teacher can integrate the method and principle of innovation into the civil engineering related classroom teaching and uses the TRIZ theory to find, analyze and solve problems for the teaching course, enabling the students to analyze the direction for possible

development and evolution of future problem solving in addition to mastering the existing solutions in the textbook, thus cultivating students' creative thinking ability.

The teachers combine the specific engineering examples, apply the basic theory of TRIZ and put forward the contradictory demand, to trigger students' thinking on the corresponding environmental model so that they can put forward the creative method to reconcile the contradiction, thus training targeted, systematic creative way of thinking. For example, in explanation of the problem of piling in pile foundation construction, to construct the foundation of bridges and buildings, piles are often piled into the depth of the foundation, and the upper joint of the pile are often broken and damaged, which means that many piles cannot be piled too deep, but that they should be sawed for piling at the top, which reduces the productivity and increases the cost. For this problem, the conflict theory, field model, system ideal degree, 40 inventive principles, thinking set elimination tool and other innovation methods of TRIZ theory can be adopted for explanation and analysis. Next, we use TRIZ theory to consider this problem: when effective function (piling) is achieved, "sensor" -- the hammer -- causes the negative function, i.e. it has negative function on the "receiver" -- pile. The main positive function is to pile the undamaged pile fast into the required depth. Diagnose, narrow the scope, convert, check, further diagnose, further narrow the scope, further convert, verify, gradually eliminate the other method and finally determine that by covering the pile head with a vessel with sand layer with a certain thickness, the pile stress is stable and uniform when hammering so that the pile top will not be damaged and the materials are easy to get, thus greatly saving the cost (Orloff 2010).

For the specific civil engineering examples, use innovative methods to explain and analyze, which avoids the shortcomings of examination oriented education and helps the students enhance creative thinking ability and avoid rote learning. In the civil engineering profession knowledge class, simple engineering example modes can be used to replace complex TRIZ theory for the convenience of beginners' understanding, so that students can have a more in-depth understanding of basis professional knowledge while gradually understanding the TRIZ theory and developing innovative thinking mode at the same time.

Build Innovative Method Practice Platform Based on the TRIZ Theory

As the saying goes, knowledge starts with practice. The most effective way to improve the students' innovative thinking and innovative ability is to practice and apply the innovation method. Only through the practice and application can college students truly transform the innovative thinking and innovative ability into their mode of thinking; only by combining the innovation method and civil engineering practical problems can the students understand in depth the rules and principles of TRIZ innovation method, systematically cultivate their innovation consciousness and work habits, and thus improve their ability to solve professional civil engineering problems with innovative methods.

- (1) Strengthen platform construction of college students' innovative science and technology project approval. To cultivate college students' innovation spirit and innovation ability, colleges and universities should actively encourage college students to participate in the innovative science and technology project approval and carry out the invention creation work with TRIZ innovative methods and principles. The source of science and technology projects can be raised by students on their own or decided by mentor, but the technology project contents should be combined with professional civil engineering problems and with innovation. The students are encouraged to positively declare invention patent for the research results and the research costs should be with maximum support based on the science and technology project content;
- (2) Carry out the research base construction of TRIZ theory innovation method. Set up TRIZ theory innovation method research base. The innovation base can be combined with civil engineering related enterprises so that the students and teachers can actively participate in the enterprise innovation type research and cultivate innovative ability through practice.
- (3) Participate in the domestic and foreign innovation method competition. Organize teachers and students to actively participate in domestically or internationally organized innovation method

competition. Improve students' innovation ability through participation in the competition and also achieve the aim of learning and exchange.

- (4) Participate in the study of teachers' scientific research projects. For civil engineering students, the instruction mode of the tutor responsibility system can be adopted. According to tutor's research projects, students actively join the research team in their scientific research and actively apply TRIZ method to think about problems and solve problems in the process of scientific research, exercising their creative thinking and innovation ability through participation in research projects.

Hegel once said: the method is the highest, unlimited power that anything cannot resist (Zhu and Cao 2002). To teach fishing is better than giving fish, demonstrating the importance of method. The production of invention and innovation results is a process which contains one or more methods. In many civil engineering extra-curricular activities such as structural modeling competition, we often only pay attention to the final outcome of the race, while ignoring the method of invention and innovation adopted in the modeling process, which is not wise. The significance of the extra-curricular activities is to stimulate students' creative thinking, guide them to gradually comprehend the rules in the invention and innovation process and master a method of lifelong benefit, rather than simply a competition of ability. So, while actively constructing the platform of extracurricular activities, we should focus on the process of innovation and invention at the same time, and systemize and standardize the original method through the appropriate use of TRIZ theory for further development and promotion.

Construct Innovative Software Platform Based on TRIZ Theory

The computer system is a kind of tool that cannot replace human creativity, but the computer can free the people from the routine and time-consuming work so as to ensure the effective choice of the fact and extract appropriate necessary knowledge for a new idea. The main principle and procedure of TRIZ is beyond doubt, so it is necessary and feasible to develop innovation software invention machine based on computer technology.

TRIZ experts have developed the invention machine software since the 1980s. After years of development, from the invention machine to Co-Brain and Goldfire software, from the problem formulation designer to innovation work table, there appeared a series of related software. But China's development in this kind of software is still few and it is urgent to await development of innovation method software platform aiming at China civil engineering major.

The scientific research departments should encourage talents from various professions that master TRIZ theory with comparatively strong software development capability to actively develop invention and innovation method software with professional features that target at Chinese people's thinking mode and software operating habits. At the same time, considering the knowledge interpenetration across different industries, establish a seamless connection between the comparatively perfect TRIZ software in different industries, benefit by mutual discussion, learn from each other and build a standardized, systematic TRIZ software platform.

Constructing a software platform based on TRIZ theory, taking advantage of efficient human-machine interactive operation mode, transforming the difficult and complex TRIZ theory into practical tool with easy operation and applying it in innovation and application in the field of civil engineering will have great economic benefits.

CONCLUSION

This paper describes in brief the development of domestic and foreign innovation methods and TRIZ's successful application in different industries, introduces the concepts and basic ideas of TRIZ theory, analyzes China's current deficiency in cultivation of innovative civil engineering professional talents and puts forward the concrete methods to cultivate civil engineering innovative talents with TRIZ theory: (1) strengthen innovation-type civil engineering teaching staff based on TRIZ innovation theory; (2) carry out "TRIZ innovation theory" course construction for civil engineering specialty; (3) introduce TRIZ theory into the classroom teaching of civil

engineering major; (4) build innovative method practice platform based on the TRIZ theory; (5) construct software platform based on TRIZ theory.

This article aims to promote the basic method of the invention and innovation to civil engineering talents and there isn't detailed exposition of a specific knowledge point of TRIZ theory. Civil engineering is a profession with strong theoretical and practical property. Under the new situation, how to improve the quality of education and establish scientific innovative talent training mode is a problem every educator is worth paying attention to and thinking about.

ACKNOWLEDGMENTS

This work is supported by the national natural science foundation of china (NO.51208069), and the State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, (NO.SKLG2016Z010).

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