TRIZ EDUCATION: VICTORIES, DEFEATS, AND CHALLENGES

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The growing pace of change in the 21st Century has significantly reduced the lifetimes of many products and increased the pressure on companies to offer novel and improved products to customers on a perpetual basis. Since introducing its first model of the iPhone in 2007, Apple has been launching newer versions of iPhones at least once a year. Competitors of Apple have offered customers new mobile phones with similar regularity. The need for companies to innovate continuously has intensified the demand for skilful engineers and scientists. This demand has strengthened the expectation that university graduates must be capable of solving complex problems quickly and creatively. To make graduates more creative, academics turned their attention to ideation methods that can help students in enhancing their problem solving skills. As a result, many engineering and science programs became interested in Russian TRIZ (Theory of Inventive Problem Solving). Some of them even decided to introduce their students to TRIZ heuristics, which are commonly known as TRIZ tools.

Unfortunately, neither published nor anecdotal evidence provides many examples of the successes of TRIZ education at university. Some universities that introduced TRIZ at engineering and science schools refrained from teaching it after just a few years. Only a fraction of academics have been able to report on sustainable TRIZ educational successes. This paper examines the defeats and victories of TRIZ education and explores the challenges that are faced by academics who teach TRIZ. It also proposes various ways of facilitating TRIZ university education. The conclusions of this paper are grounded in (i) numerous peer-reviewed papers on TRIZ education that have been published in the last 20 years; and (ii) in discussions that the author has had over the last two decades with academic colleagues from around the world who have shared an interest in TRIZ education.

What makes teaching TRIZ at university challenging?

Teaching TRIZ at university raises many challenges. The following are the most significant obstacles that limit the success of TRIZ education at university. These challenges are intertwined and even influence each other.

- Discipline-specific subjects are considered by engineering and science educators as more important for the future of graduates than subjects related to specific problem solving methodologies;
- Only a small handful of university educators possess sufficient TRIZ expertise to teach it;
- There is an overall shortage of TRIZ textbooks that are suitable for university students;
- There is a lack of reporting on successful university TRIZ teaching which is based on improvements in actual student problem solving performance;
- Some TRIZ tools (including software) appear "easy to learn and teach", but may require significant prior knowledge and extensive practice to comprehend.

Let us consider these obstacles, in turn.

Discipline-specific subjects are already over-represented in Engineering and Science curricula. Academics are often reluctant to replace any of the discipline-specific subjects by a subject that is solely devoted to TRIZ or to any other set of ideation methods [1]. The discipline-specific knowledge is considered more valuable for the future graduates' professional success if compared to their problem solving skills. Moreover, educators mistakenly believe that students acquire adequate problem solving skills by default as a result of undertaking three to five year university degree [1, 2]. Consequently, proposals to introduce TRIZ subjects as part of engineering or science degrees are often rejected by university educators.

There are few universities that have successfully incorporated subjects fully devoted to TRIZ into their degree structure. Brno University of Technology (Czech Republic), Komsomolsk-on-Amur State Technical University (Russia) and the Royal Melbourne Institute of Technology (Australia) are examples of universities that offer separate TRIZ subjects at the undergraduate level [1, 3, 4]. Beuth University of Applied Sciences (Germany), INSA Strasbourg (France) and the Polytechnic University of Milan (Italy) are among the few universities that offer the TRIZ subjects to postgraduate students [5, 6]. Not surprisingly, all the academics behind TRIZ subjects at these universities are TRIZ experts. Each of them has devoted 10 or more years to learning TRIZ and its application. The general extent of TRIZ expertise among university educators is, however, limited.

There are very few academics in the world that possess sufficient TRIZ expertise. Most of the academics who have tried introducing TRIZ to students did not study TRIZ and did not apply its tools to real projects themselves. They became aware of TRIZ from publications on TRIZ industrial successes or as a result of participation in TRIZ workshops and conferences. The foundations of TRIZ seemed sound to them. TRIZ was portrayed as being 'based on the Laws of Evolution of Technical Systems that were established by analysing thousands of patents'. TRIZ tools, like the 40 Innovative Principles and the Contradiction Table, as well as software tools like Innovation Work Bench and TechOptimizer appeared to suit the needs of engineering and science education. Some information on these tools was available (e.g. from the web and software manuals) and the tools looked simple to use and teach. In this sway, academics decided to take them on board. As a result, in the last 20 years engineering and science educators from many countries that were lacking TRIZ expertise have attempted to incorporate one or two TRIZ tools (including TRIZ software) into their subjects hoping to improve students' skills in idea generation. Unfortunately, most of these academics lost enthusiasm for TRIZ after just a year or two of teaching it. Students seemed unable to comprehend the application of TRIZ. TRIZ tools that looked simple to use appeared ambiguous when applied to problems. The freely available TRIZ materials that the academics were able to obtain were insufficient for rectifying learning challenges. Teaching material that could have helped them to fill the gaps in their TRIZ expertise and to improve student learning was simply not available.

Although the number of publications on TRIZ is rapidly growing, there is a lack of textbooks dedicated to TRIZ. Only a small number of publications contain examples and exercises with explanations and instructions that are appropriate for university students [e.g. 7, 8]. The majority of TRIZ books that have been published in Russian and English are 'about TRIZ'. These books contain descriptions of TRIZ tools, present intriguing stories and interesting examples that illustrate TRIZ application and even provide descriptions of some TRIZ heuristic methods [e.g. 9, 10]. Nevertheless, these publications do not offer the most important methodological information on the application of TRIZ tools. In order to learn a heuristic, a novice needs to be given clear instructions on a step-by-step procedure for the novice to emulate. These step-by-step procedures are often missing in TRIZ books. The examples presented in these books are usually solved in a 'magical expert way' – by suggesting the most appropriate solution immediately after presenting the problem. The actual path to the solution that a novice is expected to follow in order to learn a heuristic is not provided and remains hidden from the learner. It seems that the authors of TRIZ books presumed that readers had TRIZ expertise and an inherent ability to "fill in the blanks" behind the solutions presented in the books. In other words, it seems that many authors hoped that educators who were prepared to use their books as educational material would be able to comprehend the 'concealed' solution paths and, on their own volition, to provide the students with appropriate explanations and step-by-step guides to follow. Unfortunately, this is not the case.

Anecdotal evidence suggests that academics, who were interested in teaching TRIZ but lacked TRIZ expertise, realised their own knowledge gaps and chose not to start teaching TRIZ altogether. Other academics attempted to teach TRIZ, but discovered these hidden gaps whilst teaching it. Most of the teachers failed to identify the concealed solution procedures which the students had to model to learn the tool and soon after dropped teaching TRIZ altogether. Regrettably, failed attempts to teach TRIZ heuristics have prevented many academics from publishing on their TRIZ teaching experiences. Instead, they have shared their stories of mishaps in private discussions. Clearly, the negative experiences of these educators could have persuaded some of their colleagues to also avoid teaching TRIZ. Fortunately some academics have reported on their observations of TRIZ education. These publications presented heterogeneous reports of university TRIZ teaching experiences and were usually perception-based. The published results were both qualitative and quantitative. The results frequently depended on positive outcomes recorded in student surveys that focused on students' enjoyment of the TRIZ method studied.

There is lack of reporting on successful university TRIZ teaching that is based on actual improvement in student problem solving performance. It is difficult to measure the practical success of any ideation methodology in a university setting. Special experiments need to be properly planned and carefully executed. Measuring the effectiveness of TRIZ is even more challenging. TRIZ tools are most helpful in solving ill-defined and knowledge-rich problems, but such problems are rarely considered by students during undergraduate studies. Most of the problems students face are well-defined and require a limited amount of specified discipline knowledge that is closely associated with the individual subject studied. Therefore, most of reported successes of TRIZ teaching have been related to improved student perceptions of their problem solving self-efficacy [1, 5, 11]. Although these reports contained statistically significant qualitative evidence, it was insufficient for convincing engineering and science educators. Like most engineering and science professionals, they were seeking practical (and quantitative) evidence to demonstrate improved problem solving skills. The positive changes in student perceptions as a result of learning TRIZ were important, but not sufficient to conclude that TRIZ teaching resulted in enhanced problem solving skills.

Only recently, reports on improved problem solving self-efficacy have been supplemented by actual evidence of the effectiveness of simple TRIZ tools in improving the outcomes of students' idea generation [12]. In their experiment, Belski et al. [12] involved undergraduate students in generating ideas for a real knowledge-rich, ill-defined problem. Students from a control group generated solution ideas in silence for 16 minutes. Students in an experimental group were shown the names of the eight fields of Substance-Field Analysis (MATCEMIB: Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, Biological) for two minutes per field [8]. Exposure to the eight fields of MATCEMIB assisted the students from the experimental group to generate 2.5 times more solution ideas compared to the students from the control group. This experiment also demonstrated that simple TRIZ tools can be learnt by university students in just a few hours.

Some TRIZ tools that were introduced to university students over the last 20 years appeared to be easy to teach, but were difficult to comprehend and use. In order to effectively use these tools the university students required substantial prior knowledge and/or extensive practical experience that they did not possess. One example that reveals the unsuitability of some TRIZ tools for undergraduate teaching is provided by way of illustration. Two academics, who engaged students in learning the TRIZ tools of 40 Innovative Principles and the Contradiction Table reflected on their teaching experiences in the following way [13]:

[student] "… concerns were related to difficulty of understanding the method, and some frustration using the contradiction matrices due to the large number of tables and numbers within the tables, coupled with the tedium of having to look up the corresponding design principles from the suggested numbers. In addition, students felt that more examples beyond those contained in the text provided would have facilitated a better understanding of the design principles."

This reflection summarises the experiences of many academics that the author has met and spoken to. The TRIZ tools taught by these academics looked simple, but could not be taught effectively unless students possessed appropriate prior knowledge and/or relevant practical experience. The following section of this paper will consider aspects of knowledge and experience that TRIZ tools demand from a learner.

The tools of TRIZ: demand for prior knowledge and practical experience

The first publication on TRIZ analysed the psychological side of the inventive process [14]. It suggested a blueprint for an effective ideation heuristic that consisted of three stages and was subdivided into 10 steps. Since 1956, many TRIZ heuristics have been developed. These TRIZ tools require varied knowledge/experience from a problem solver. Simple TRIZ tools can be learnt by practically anyone and require only a few hours to master. Complex TRIZ heuristics require significant prior knowledge and extensive practical experience. They may require weeks and even months to learn. Table 1 depicts the demands for prior knowledge and practical experience for certain TRIZ tools that have been popular amongst educators. Table 1 classifies the TRIZ heuristics into four criteria: (i) demand for prior knowledge; (ii) demand for practical experience; (iii) time that a novice needs to learn the tool; and (iv) heuristic complexity. Each criterion was evaluated on three levels that are self-explanatory (e.g. Low, Medium and Extensive Practical Experience and Prior Knowledge). The TRIZ tools listed in Table 1 are arranged from the simplest (at the top) to the most complex (at the bottom) as per the above-mentioned four criteria. The TRIZ tools are further combined into three groups that classify the suitability of the tools for teaching to learners with different prior knowledge and experience.

The Undergraduate group in Table 1 contains six heuristics that can be effortlessly embedded into undergraduate engineering and science degrees. The Method of Smart Little People, the Size-Time-Cost operator and the notion of the Ideal Ultimate Result (IUR) require the least knowledge/experience and can be taught to practically anyone. Learning Substance-Field Analysis [8] and applying its eight fields of MATCHEMIB, as well as exploiting the notion of Resources, requires a knowledge of science basics. School graduates that choose engineering and science studies at university are expected to possess this knowledge.

The Postgraduate group in Table 1 consists of five heuristics that are suitable to postgraduate students. The effective learning of these tools require prior knowledge and/or practical experience that can rarely be acquired by a high school student before entering university. It is illustrative to consider what kind of prior-knowledge and practical experience is required for the proper comprehension of the most commonly taught TRIZ tool of 40 Innovative Principles. This tool presents a user with 40 sets of reasonably general solution "recipes" that are intended to trigger analogies that the user can map onto the problem in order to solve it. To provide analogies educators offer up the lists of example-analogies that communicate the "recipes" proposed by each particular principle. It is anticipated that once a student can view many analogies, she/he is able to map some of them onto the problem at hand and, as a result, will propose one or more solutions. As can be concluded from the above-mentioned quotation [13], this approach does not work as smoothly as expected. The reasons for its failure are well known to cognitive scientists. Research on analogical transfer, in which the 40 Innovative Principles are grounded, suggests that

Table 1

Classification of TRIZ heuristics
(* — the asterisk indicates the knowledge required by students commencing engineering and science degrees)

Suitability	Tool	Prior Knowledge	Practical Experience	Time to learn	Heuristic Complexity
Undergraduate students	Method of Smart Little People	Low	Low	Hours	Low
	Operator Size-Time-Cost	Low	Low	Hours	Low
	Notion of the Ideal Ultimate Result (IUR)	Low	Low	Hours	Low
	Fields of MATCEMIB	Medium*	Low	Hours	Low
	Substance-Field Analysis	Medium*	Low	Hours	Low
	Notion of Resources	Medium*	Low	Hours	Low
Postgraduate students	Separation Principles	Low	Medium	Hours	Low
	Method of the Ideal Result	Medium	Low	Days	Medium
	Contradiction Table	Medium	Medium	Hours	Medium
	40 Innovative Principles	Medium	Extensive	Hours	Low
	Nine Screens	Medium	Extensive	Hours	Medium
Experienced practitioners	Laws of Evolution	Extensive	Extensive	Weeks	High
	Algorithm of Inventive Problem Solving (ARIZ)	Extensive	Extensive	Weeks	High

a problem solver can only use her/his own analogies effectively [e.g. 15]. A practitioner's own analogies are built up over years of practical experience. This experience is what undergraduate students are lacking. Most of the example-analogies prescribed to them by their teachers may not relate to their own experiences. Consequently, undergraduate students are not likely to evoke their own analogies that match a particular principle, nor are they likely to map the example-analogies attached to this principle onto the target problem.

The Experienced Practitioners group in Table 1 includes two heuristics: the Algorithm of Inventive Problem Solving (ARIZ) and the Laws of Evolution of Technical Systems. Although these tools are also taught at some universities, the requirement of significant prior knowledge and practical experience make them suitable for use by subject matter experts only.

How can you make university TRIZ education successful?

The author's reflections on the challenges of teaching TRIZ at university can be concluded by proposing two key directions to improve the success of TRIZ at university:

- More evidence is required which demonstrates that teaching TRIZ leads to actual improvement in the problem solving skills of students. TRIZ educators need to be able to demonstrate that teaching TRIZ leads to outcomes that are beyond a mere change in student perception. Academics have to prove that teaching TRIZ enhances students' skills in tackling ill-defined and knowledge-rich problems practically; that is, the students become much better at idea generation and problem solving as a result of studying TRIZ subjects. It would also be advantageous to promoting TRIZ education if the success stories from many Russian universities where TRIZ is taught were properly published and became available to the wider academic community. For instance, anecdotal evidence exists that some Russian undergraduates have patented the ideas that they generated after studying TRIZ subjects. Such evidence on the practical efficiency of teaching TRIZ will help to convince engineering and science academics, as well as the professional bodies that accredit degrees, of the need to make TRIZ an essential part of engineering and science curricula.
- Academics, who teach TRIZ, as well as TRIZ experts, need to prepare textbooks and educational materials that can be used by educators with little TRIZ expertise and that suit the knowledge and experience level of university students. This will enable many more academics to effectively teach TRIZ and will ensure that a TRIZ subject is taken on by a colleague after the original teacher retires or leaves the university.

The author has successfully deployed TRIZ in his scientific and engineering practice for over 30 years. The majority of the 24 patents granted to him during nearly 15 years of research and development work in Moscow evolved from the application of TRIZ heuristics. Practical evidence of TRIZ application in industry supports its effectiveness in research and development, design, manufacturing, etc. TRIZ tools are amongst the few alternative problem solving heuristics that fit the needs of technology and science professionals. There is no doubt that future demand for rapid development of novel and improved products will only grow and that engineering and science schools need to seriously consider taking TRIZ on board.

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ТРИЗ ПЕДАГОГИКА: ПОБЕДЫ, ПОРАЖЕНИЯ И ПРОБЛЕМЫ

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Статья обсуждает насущные вопросы преподавания Теории Решения Изобретательских Задач (ТРИЗ) в вузах.

КЛЮЧЕВЫЕ СЛОВА: *ТРИЗ, методы решения изобретательских задач, творческие способности, методы преподавания*