Sustainable Education in Inventive Problem Solving with TRIZ and Knowledge-Based Innovation at Universities

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Abstract. Accelerated transformation of the society and industry through digitalization, artificial intelligence and other emerging technologies has intensified the need for university graduates that are capable of rapidly finding breakthrough solutions to complex problems, and can successfully implement innovation concepts. However, there are only few universities making significant efforts to comprehensively incorporate creative and systematic tools of TRIZ (theory of inventive problem solving) and KBI (knowledge-based innovation) into their degree structure. Engineering curricula offer little room for enhancing creativity and inventiveness by means of discipline-specific subjects. Moreover, many educators mistakenly believe that students are either inherently creative, or will inevitably obtain adequate problem-solving skills as a result of their university study. This paper discusses challenges of intelligent integration of TRIZ and KBI into university curricula. It advocates the need for development of standard guidelines and best-practice recommendations in order to facilitate sustainable education of ambitious, talented, and inventive specialists. Reflections of educators that teach TRIZ and KBI to students from mechanical, electrical, process engineering, and business administration are presented.

Keywords: Education, TRIZ, Knowledge-based Innovation

1 Introduction

Accelerated transformation of the society and industry through digitalization, artificial intelligence and other emerging technologies has intensified the need for university graduates capable to rapidly find non-trivial breakthrough solutions for complex problems, and to successfully implement innovation concepts. The qualification of future

R&D specialists and managers in using efficient techniques for effectively running an innovation process becomes very important for the competitiveness of enterprises, which resides in the ability of companies to produce new products continuously and profitably. The theory of inventive problem solving TRIZ developed by Altshuller and his co-workers [1] is today considered as one of the most organized and comprehensive methodologies for invention knowledge and creative thinking [2], as confirmed by the analysis of the top cited scientific publications on innovative design performed in 2016 by Chechurin and Borgianni [3]. Already in 1985 two comprehensive educational programs for students (Icarus program, 160 academic hours) and educators (Daedalus program, 144 academic hours) in creative thinking, inventive problem solving and technological forecast with TRIZ, and in basics of value and patent engineering were established by Altshuller [4].

In the last two decades numerous universities and educational institutions gathered considerable experience in different education approaches in innovation, new product development and inventive problem solving with TRIZ, as exemplarily reported by Oget and Sonntag [5] - France (2002), Belski [6] - Australia (2007), Nakagawa [7] - Japan (2007), Cascini et al. [8] - Italy (2008), Domb et al. [9] - USA (2010), Jirman and Busov [10] - Czech Republic (2010), Ryynänen and Riitahuhta [11] - Finland (2010), Wits et al. [12] - The Netherlands (2010), Berdonosov [13] - Russia (2015) and others.

However, in general engineering curricula offer less room for enhancing creativity or inventiveness in the discipline-specific subjects. As innovation is an interdisciplinary knowledge area, the full scope of innovation theory is seldom taught at universities [14]. Moreover, many educators mistakenly believe that students are inherently creative and obtain proper problem-solving skills automatically during the university study period. There are only few universities making significant efforts to comprehensively incorporate creative and systematic tools of TRIZ into their degree structure. The academic educators from 9 universities in Australia, Germany, France and New Zealand share in this paper their teaching experience in the fields of mechanical, electrical, process engineering, and business administration. The authors discuss challenges of intelligent integration of TRIZ and knowledge-based innovation in university curricula and give best-practice recommendations which could facilitate sustainable education of ambitious, talented, and inventive specialists.

2 Teaching Creativity by Embedding Simple Thinking Heuristics into Existing Discipline Subjects at the Royal Melbourne Institute of Technology (RMIT)

2.1 Enrichment and Infusion Approaches to teach Creativity

From the first semester of 1998, TRIZ basics have been introduced to RMIT undergraduate and postgraduate students in numerous subjects that are devoted to various aspects of electrical/electronic engineering. In 2006, RMIT started offering a university-wide elective fully devoted to TRIZ heuristics. This subject introduced students to heuristics of Situation Analysis, Method of the Ideal Result, Substance-Field Analysis, 40 Innovative Principles and the Contradiction Table [6]. Comparing the outcomes of this subject, which was explicitly devoted to teaching TRIZ heuristics, with the outcomes of nearly a thousand of discipline-based engineering subjects, Belski, Baglin and Harlim [15] concluded that a stand-alone creativity subject (the "enrichment" approach) is likely to be more effective in nurturing students' creativity than embedding creativity heuristics into existing discipline-based subjects (the "infusion" approach). Belski et al. [15] compared the opinions of 93 students that took the TRIZ subject with the opinions of over 22,000 students that were enrolled to other RMIT engineering subjects between 2006 and 2010. It was established that the TRIZ subject influenced problem-solving self-efficacy of students much more not only than any other engineering subject, but also "boosted students' problem solving self-efficacy to the level significantly exceeding that achieved during four years of a traditional engineering degree" [15].

The "enrichment approach" in teaching TRIZ had been successful at some other universities [66]. Nonetheless, due to significant volume of discipline knowledge to be taught, it is challenging for many engineering schools to change their engineering curriculum and to devote a separate subject exclusively to creativity and TRIZ. Therefore, the "enrichment" approach may not be suitable for many engineering schools. Recent experiments that investigated suitability of a simple TRIZ heuristics of the Eight Fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular and Biological) indicated that effective idea generation heuristics can be taught in just one or two hours [16, 17]. This result suggests that academics can effectively use the "infusion" approach to teach creativity and to embed teaching creativity heuristics into their existing discipline subjects.

The outcomes of two recent studies from Australia and New Zealand discussed below offer first evidence of a success of such teaching approach. Subject coordinators that participated in these two studies used the educational materials of the TRIZ Repository [18] that was developed with the support of the Australian Government Department of Education and Training. TRIZ Repository provided four kinds of resources: educational materials for self-learning, educational materials for academic use, research papers and case studies on the application of TRIZ heuristics [19]. TRIZ Repository was developed for academics that have little expertise in thinking heuristics. It allows a subject coordinator to embed TRIZ heuristics into existing subjects with minimal effort and time expenditure. Each heuristic is introduced by a 10 to 20 minutes video. Also, students are offered simple solution templates and cheat sheets that can be used by them in and out of class.

2.2 Australian study

One hundred and ten students who were enrolled in the first year subject of Engineering Materials at Swinburne University of Technology participated in the study conducted by Blicblau and Ang in 2017 [20]. One laboratory session devoted to properties of construction materials was modified to engage students in learning a simple TRIZ heuristic. During this laboratory session students had to select materials to build a bridges, a house a hand tool, etc. After students made their decisions on the materials for manufacturing the structures, they were asked to learn a TRIZ heuristic of Size-Time-Cost (STC) Operator and to select appropriate construction materials once again.

Blicblau and Ang [20] reported significant differences in choices made by the students after applying the Size-Time-Cost Operator heuristic. They discovered that the STC Operator heuristic helped students to remove the constraints related to traditional engineering techniques and to consider novel materials and novel manufacturing techniques:

> When students responded to the first engineering activity for realistic solutions to the materials selection problems, they all selected either one of two classes of materials for the engineering components, i.e. metals (e.g. varieties of steel, aluminium, or composites)…
>
> When students were asked to… [use] the TRIZ (STC) approach… a variety of traditional (steel, aluminium and wood) and non-traditional materials (titanium, carbon nanotubes, graphene, diamond, ceramics, and gold) were selected for the various constraints.

In other words, a heuristic of Size-Time-Cost Operator that was ‘embedded’ into an existing laboratory exercise, helped students to expand their view on the materials available to manufacture various structures.

2.3 New Zealand study

Shukhmin and Belski [21] conducted in 2017 a study that engaged 60 students enrolled in various diploma programs at the Toi-Ohomai Institute of Technology (TOIT). The authors introduced students to three TRIZ heuristics: the Eight Fields of MATCEMIB, the Ideal Ultimate Result (IUR) and Size-Time-Cost Operator from the TRIZ Repository [19]. Shukhmin and Belski [21] reported a positive influence of TRIZ heuristics on the outcomes of idea generation that was conducted during tutorial sessions:

> After watching the video on the 8 Fields of MATCEMIB heuristic, participants of the first and the third sessions proposed many more ideas for building protection against termites. In essence the number of solution ideas doubled as a result of them watching the video… ([21], p. 233).

A few months after introduction of TRIZ heuristics in class, TOIT students were asked to participate in a web-based survey. Most of the 21 survey participants stated that they had devoted time outside of university face-to-face hours to studying more TRIZ heuristics from the TRIZ Repository. Furthermore, students evaluated the utility of the TRIZ Repository materials as fully suitable for self-learning and useful in their future career [21]. Table 1 presents student opinions on the usefulness of materials in general and on the effectiveness of each of the components of educational materials available at the TRIZ Repository: a short Video, a Solution Template, a Web Tool and a Cheat Sheet. All questions used the Likert scale of 5 (1 – strongly disagree; 5 – strongly agree).

Table 1. Students' opinions on the usefulness of educational materials offered by the TRIZ Repository.

	Educational materials for self-learning TRIZ heuristics made it easy for me to learn thinking heuristics	A short **Video** that explained the way to apply a heuristic was very helpful in learning the heuristic	A **Solution Template** that guided me in applying a heuristic for the first time was very helpful in learning the heuristic	A **Web Tool** that guided me in applying a heuristic for the first time was very helpful in learning the heuristic	A **Cheat Sheet** was very helpful in applying the heuristic
Mean	4.00	4.07	4.07	3.69	4.00
SD	0.365	0.594	0.458	0.751	0.816

The outcomes of the studies published in 2017 by Blicblau and Ang [20] and by Shukhmin and Belski [21] imply that appropriately embedding thinking heuristics in existing discipline-based subjects academics can enhance creativity skill of engineering students. Therefore, the "infusion" strategy needs to be seriously considered by academics as the means of nurturing students' creativity skills.

3 From TRIZ to Inventive design and systematic invention at INSA Strasbourg

3.1 TRIZ at INSA Graduate School of Science and Technology

Teaching TRIZ has always been considered time-consuming and complex by businesses and universities. A large part of this observation does not lie in its intrinsic complexity, but rather from a lack of formalization or axiomatization. When something is expressed in a confusing manner, this thing can appear complex in the eyes of those who observe it. If TRIZ was so long (it still is) shunned by major universities and large businesses, this is due to the blur that surrounds his vocabulary, worse the perimeter of this vocabulary or the variability of vocabularies which surround TRIZ. Another reason comes from its oldness and so his lack of ergonomics in face of the contemporary ergonomics in which evolve businesses and learners in general. By extension, we can also consider that current course syllabuses are overloaded, preventing any new initiative to obtain a place as large as necessary for a decent TRIZ education. TRIZ still appears today, as out of the mainstream of conventional disciplines. Sentences that return the most when we talk about the learning of TRIZ is "blood and tears" or learning "the hard way". In parallel, TRIZ is felt as a transversal competence therefore a student can wait to specialize in it when he will be in industry and only if there is a need in his everyday job.

It was necessary to change this state of affairs both in industry and academia, to rethink TRIZ to build a disciplinary field in which everyone would be able to contribute both scientifically or methodologically. But before that, there was a need to decline all of its concepts in a formal way as a basis for a set of teaching modules. Let's add to this the need to use up-to-date learning means, the use of web-based platforms and remote servers, all this could fill the time-consuming side of its learning curve through asynchronous learning. As to the vagueness that surrounded TRIZ of the early times, the use of ontologies as a formal way to clarify the field of inventive design turns out be a track that pays off like in many other scientific areas. We truly believe this way is more scientific than compiling the commonly agreed set of expressions by group of experts.

INSA Graduate school of science and technology has been known in its early years of activities around TRIZ (1995) to be concerned by the need to understand its basics. The presence in our team of successively Nikolai Khomenko and Dmitry Kucharavy permitted at various degrees, not only to better understand the original corpus of TRIZ, but also to initiate relevant research directions. Our teachings, our research, in contact with them, were placed on the right track. Then comes the need to legitimize the corpus associated to TRIZ compared to its supersystems. For this, we had to broaden the scope of TRIZ to something more generic and less charged by its original image while allowing by this development to absorb research that have contributed to take TRIZ beyond its limits. OTSM-TRIZ [22] was an intermediary state since the leader of this field of research was in our group for a decade. But still over attached to TRIZ community and not to its already existing and active supersystems. We then decide to engage our researches in the use of Ontologies, borrowed from the field of information sciences, as formal way to represent the new field of Inventive design. This choice has been proven to be decisive in the highlighting of the limits of TRIZ while giving us a strategy to produce new knowledge.

3.2 Inventive Design and Inventive Design Learning System

Among the elements that led us to inventive design, several of them deserve to be detailed. First of all, the need to better limit its scope. If Altshuller has well developed a strategy to formulate and solve a contradiction obstructing the follow-up of a law, it has less formalized upstream of this: from an original, complex, multidisciplinary situation before engaging a contradiction in resolution. Even the inventive algorithm ARIZ's upstream phases and their ancient digressions are only scratching the answer. As the downstream; in the Altshuller books [1], it's a little magic to observe the inventor finding suddenly the right solution. We know that the process of management of solution concepts is very important for the emergence of a solution that makes consensus. We therefore reviewed the perimeter of inventive design, it begins where the necessity to model knowledge arises and must be the subject of a comprehensive synthesis that becomes digitally usable in the phases of resolution. It ends at the point where a solution concept emerges, is revised (or clustered with others if necessary) and its effect on the initial situation is measured so that the decision to go further in the innovation pipeline can be appropriately taken.

Between these two ends of inventive design, everything must be done so that there is no obscure area. Each step must be studied, its shortcomings highlighted and everything that will work towards a total computerization of the process will bring us closer, a little more, to a new form of artificial creativity. Because it is to this that we tend when digitizing and processing information by artificial intelligence: a form of multidisciplinary digital tank where side by side, problems and solutions from various areas, are all the time connected to channels that absorb new knowledge found via deep/machine learning. The dream to solve systematically then becomes possible, at least until level 4, so to say for 99% of technology issues on Earth.

This new process of Inventive design has been a project of building a web application (PICC: **P**rivate **I**nnovation **C**ompetence **C**enter) associated with its ontology declined in a customizable database architecture. To orchestrate its use in academic and lifelong learning education, we have developed an environment (IDEAS: **I**nventive **D**esign l**EA**rning **S**ystem) for the management of schools, sessions, teachers, students and projects. The idea is to teach massively inventive design using a teaching method known as "pedagogy by project" by facilitating the creation in autonomy of teams mentored or not by an expert and specially to ensure the opportunity for this team newly formed to act remotely, real time, in collaborative, synchronous or asynchronous mode.

3.3 Towards Systematic Invention Engine

For the part of the inventive process and its total computerization, we have reached 70% of this goal using upstream coupled Machine Learning techniques in a hybrid way to chunking morphosyntaxic techniques. Our results as to the relevance of the extractions and their ability to populate the ontology of Inventive design progress each month. At the other end of the process, our case base reasoning (CBR) that compare problem and solution couples is already settled and associated with algorithms of semantic proximity. We operate comparisons that make sense between problems from a field and solutions of another. There, at the end of the 3rd PhD thesis on the subject, our results become more relevant as the basis of cases expands and the terms of our algorithms become more refined. Between these two extremes (what we can name conventional parts of TRIZ) the process is already digitized since 2006 and a few new but necessary items have been added to its corpus: the notion of problem and solution (and their interrelationships), the concept of evolution hypothesis, the concept of polycontradiction, the notion of hierarchy between the contradictions, the notion of solution concept. New representations have also emerged, the problem graph (transforming tacit knowledge into usable data); the bubble diagram (which order the populations of contradictions along 3 axes) or even the SUN diagram (which offers an overview of inventive opportunities to resolve by creating links between Market-Strategy and R&D).

We do not today measure accurately "when" our two axes of research which border upstream and downstream of inventive design process will succeed completely. But once this stage will be reached, we will be able to talk about systematic creativity (or artificial creativity). Therefore, we will be in position to confront our algorithms with human brainstorming. We look forward to these first experiences even though results may not look in favor of artificial intelligence at the beginning. But the effectiveness of what is produced by human brainstorming declines over time while artificial intelligence is winning over human in many fields.

What remains of TRIZ in all this? Altshuller's theory will have laid the first milestone of a building which starts with the axiomatic decomposition of inventive thinking. For years, its usage will have helped thousands of companies to test its potential. For researchers, they will surely continue to expand it through their work in various directions. But now, with the notion of industry 4.0 and the renewal of artificial intelligence through deep learning or machine learning, we have never been as close to build a systematic invention engine.

4 TRIZ Education at HTW Berlin

4.1 Bachelor and Master Courses at HTW Berlin

HTW Berlin is a relatively young University, founded in 1994. HTW Berlin offers over 70 study programs in the areas of technology, computing, business, culture and design. It is the largest university of applied sciences in Berlin with 14.000 students, 280 professors, about 800 associate lecturers and 350 persons as technical, service and administrative staff.

Subjects are considered as the most "colorful" within Berlin's University landscape, as they range from classical disciplines such as mechanical engineering, automotive engineering, energy, information and business administration to design and culture, computing and communication and also to new and innovative study programs such as facility management, economic policy and game design, split into 5 departments. Within the 5 faculties of the University, the author is associated to Faculty 3 "Berlin Business School" and teaches mainly in the field of "Bachelor of Business Administration" (BA BWL) and "Master of Industrial Sales and Innovation Management" (M ISIM), where TRIZ has become an important part.

Bachelor BWL, Course SB 8: "Innovation and Technology Management" (4 weekly hours per semester, 4 credits). The course "Innovation and Technology Management" aims to cover theoretical basics and competencies within the Bachelor of "Business Administration" (BWL) program. The subject is obligatory for all BA BWL students. The author feels challenged to convey the importance of innovation and technology management to 50 students per course (the author usually covers 2-3 courses, i.e. 100 – 150 students) and from various fields of specializations, ranging from finance and accounting, taxation, controlling and/or production and logistics management, as the course is situated at the end of the entire program.

This is achieved by first taking examples from their own everyday background (like smartphones or sports equipment), and from their specialization field (difficult with e.g. taxation and law, though!), nevertheless the author highlights the importance of getting to know companies that develop and offer products that are (or seem) far from the students' perspective: Products like sealing rings (Freudenberg Sealing Technologies), bone nails (Wittenstein AG), and/or passenger restraint systems (TAKATA) may also make their day, but are usually not considered when being asked for improvements – and are even less in their focus when thinking about their own careers.

To make sure, that students realize the importance of applying structured thinking methods, the author deliberately introduces the above named new terrains of technical applications and far-away product categories - in order to make them overcome thinking barriers (“Why should I be interested in improving sealing rings? I am specialized in taxation…”). The author also introduces classical creativity methods, such as brainstorming techniques, 6-3-5 and many others before turning to more outstanding structured Innovation Methods (SI) like TRIZ, all to highlight that the methods can be applied anywhere – even in improving taxation and law! During the semester, the author takes about 4 to 5 times 3 hours (of 60 min) to introduce and convey first understanding of TRIZ and other SI concepts.

To put it briefly, the author spares no effort to subliminally convince the students that they are better off with structured thinking and methodological innovation methods than without. She does not even hesitate to introduce problem types and their expected shift to complexity [23] and addresses (in the students’ perspective) far-fetched technical fields to show that no matter what problem is at hand, they have and will be able to tackle it.

Master ISIM, Course M8: “Product Development and Innovation” (4 weekly hours per semester, 6 credits). The Master Industrial Sales and Innovation Management (MISIM) has first started in Winter 2009/2010 and was re-accredited in the beginning of 2018. Applications regularly exceed the yearly number of provided places – sometimes by four times. Applicants’ scientific and sometimes business background covers Industrial Informatics, Industrial Engineering and BWL from all kinds of Universities, national and international. The author has co-initiated a Double Master Degree Program with the French Burgundy School of Business, ESC Dijon, so exchange students from France also enrich the course and add to the intake of 45 persons a year, split into two groups, both lead by the author and one after the other.

The qualification for Structured Innovation and especially TRIZ among the students is diverse: some students know about innovation issues and have basic TRIZ knowledge (mostly form the authors’ BA course), some have never heard about it. This may be considered a disadvantage, but very often the students bring other interesting knowledge from other lecturers - be it from HTW or other universities, and this is considered very fruitful for an intense discussion with multiple perspectives.

4.2 Challenges or Problems in BA and MA Education

To make it clear, the various cultural, theoretical and technical backgrounds and knowledge students bring along to any lecture – BA or Master alike – *seem* to be a problem, but the author rather observed (to her opinion) more severe limitations to overcome:

1. Students equal their level of creativity to their ability to draw (and admit almost in unison that “I cannot draw, so I am not creative.”).

2. Students have internalized to categorize a problem as quickly as they can instead of making a detour to new solution fields, providing inventions and innovation.
3. Students lack self-confidence when asked to acknowledge their own problem solving capabilities (and refrain from making “in-field” experience to gain important insights).
4. Students neglect playfulness as important issue to do “serious” work.
5. Rising numbers of participants make it more and more difficult to work individually.

This does not apply to all students and all classes, but still a majority… The author’s main challenges thus remain to make students

- acknowledge that creativity and inventiveness can and should be learned,
- think differently and change perspective, especially when a difficult problem is at hand that cannot be solved in the usual, direct way,
- thrive on foreign fields of knowledge and thinking in analogies is worthwhile and
- follow a rather structured way of learning and thinking as a way to foster creativity and inventiveness AND have fun and being playful at the same time.
- individualize their learning approach (with class or group mates but also, if preferred by themselves), even with the ever-rising numbers of participants.

4.3 Proposed or Used Teaching Methods to Counteract these Challenges in Educational Process

The proposed way to overcome the limitations in teaching TRIZ in the BA course is introducing contradictions as the core to foster one’s own inventiveness, without even mentioning TRIZ at this point. Only later, when students have understood the idea of contradictions being a part of everybody’s life, the author plunges into Altshuller’s investigations of patents and his findings.

In the Master course, the author has made best experiences by introducing other Structured Innovation (SI) methods, such as Design Thinking (DT) and/or TrenDNA, *before* starting with TRIZ [24]. When going into the SI procedures, the students are rather concerned to follow – as to them structured thinking feels contradictory to any form of creativity and inventiveness. They seem to have internalized the funny idea about the flash of inspiration that occurs during leisure time and rather do not see it as an objective to be attainable by work.

Nevertheless, the author experienced that especially DT and TrenDNA open their minds for structured thinking in general and that following a process eases cooperation with colleagues. DT, as TrenDNA, comes along with a rather playful background and is easy to learn.

DT allows for times for focusing (convergent, analytical thinking) and times for imagining (divergent, creative thinking), each when actually needed. Being able to move between the two modes (or being able to make others move) is considered an important skill in the future [25]. Also, DT highlights more than any other method that building prototypes fosters ideas and makes people talk about their needs in a much more potent way. TrenDNA, among other aspects, applies a set of cards that students are supposed to discuss and organize according to the task given, both for getting hints for possible future developments in a structured way [26].

These methods smoothen the path towards following a procedure and applying tools rather than thinking arbitrarily and endlessly in a brainstorming session. This has proven to prepare for more, even harder procedures, as by then students have usually recognized that their first ideas are not sufficient – at least when it comes to “difficult” problems. Only by then, the author moves on to TRIZ details – but then plunges right into and sticks to that method and its tools covering at least 70% of the entire semester.

Each single lecture is split into two parts: one half or one third of the three hours are reserved for theoretical introduction into the TRIZ (or other) tool(s), the remaining time is reserved for group and/or individual work. As this takes place in the classroom, the author is sparring partner to all questions that may come up during their exercises and easy transferable, every-day examples. Usually, this example is a little more difficult than any example provided in the theoretical part, but in case students are struggling, the author is never far and ready for questions and guidance.

As hard nut to crack remains the industrial example the students are confronted with from the very beginning of the semester. Usually, a cooperation with an industrial partner situated in Berlin is established before the start of the semester, who delivers insight and the problem to be solved by the students (though little refined by the author). The students’ final grade will be derived by 50% of what they will have developed in a group of 4-5 people, the other 50% of their grade comes from an individual written exam, both at the end of the term.

One such industrial example was the cooperation contract with the company TAKATA in Berlin: Students were asked to develop a new kind of restraint safety system for passengers in 3 given types of autonomously driving vehicles (Google self-driving pod, Daimler F015 and Rinspeed microMAX). Another was to develop a new assembly station for the half-automated line of optical fiber assemblies at Nokia Siemens Networks NSN, Berlin. A third example was the development of a new software sales model for ORACLE, Potsdam, which constituted a non-physical service for the first time. All projects start with a company visit in the second or third week of the term and the company’s introduction and explanation of what is considered the problem and challenge for the future. The students are supposed to apply all learned SI methods and tools and apply them to the given complex “real-life” problem – very often finding out, that the problem is not exactly where the company mentioned it to be.

Starting with the DT and TrenDNA methods and tools, they also concentrate on special user groups, an issue that is more or less neglected by TRIZ. Only after defining their point-of-view (POV), they are supposed to focus on their newly and self-defined problem and then apply all TRIZ tools learned to the given system. When having defined a solution in the end, they are supposed to build prototypes and make a presentation of their ideas in format of a “Pecha Kucha”, together with an exhibition of the prototypes visited by the company’s staff.

4.4 Evaluation of Experience

The companies regularly highly appreciate the results generated by the students and some even stated, that they represent about 2-3 years of own development, that were developed within a time frame of 16 weeks here (not entirely dedicated to this course only, as the students have other preoccupations during the term). The students are flattered that higher management and steering committee members attend the final presentations, which vice-versa rises pressure and underlines the level of seriousness.

For the students, the “far-away” examples in the BA course, and the industrial part of the MA course are regularly considered as huge challenges in the beginning of the semester, some students even feel fear of the task as they see no way to tackle such a “strange” or “big, fuzzy” problem situation. Later, when they realize that ideas generated with SI methods are better and exceed initial “quick” ideas that have come to mind in the beginning – if any – they get more keen to learn new tools and gain more self-confidence in their problem solving capabilities. When the course is over, they even confirm their ability to lead own project partners to an outcome, all within a given time frame.

A drawback may be seen in the high amount of group work in the MA program. With the author being more of an introvert herself, she is skeptic to enlarge teamwork at infinitum. Students are less and less asked to intensively think about a problem all by themselves (which they usually are supposed to do in their Master thesis). Even with the ever rising complexity of emerging problems, meetings and teamwork alone is not to considered as only solution [27], as it neglects the one third to half of the population that are scientifically to be considered introverts and prefer individual thinking and working before exchanging with others [28]. Especially, when it comes to evaluating group results from project work [29], the author is not always sure, if all group members have equally contributed to the final results. This is why she sticks to the 50% individual exam part, even if it is sometimes considered out-dated.

Rankings and evaluations by HTW Berlin regularly confirm the high level of education provided in the Bachelor and Master programs described here. The students suggested the author “Awardee for good teaching of HTW Berlin” in 2017, mainly because of the impact SI Methods had on students and industrial partners alike [30].

4.5 Outlook and recommendations

The author already sees some of the points covered above, but still questions herself about how to convince more students of TRIZ and make its concepts to stick more sustainably – in less time. The trend towards gamification in all aspects of life [25] lead to the idea to integrate more playful elements also in TRIZ education and to use game-like approaches and cases to do so.

As games, cases and simulations have shown highly advantageous in the author’s teaching of lean management and production issues, and can also be considered a kernel of the entire DT method, her plan is to gamify TRIZ teaching and provide TRIZ cases, for either group work and/or individual exercise. The author has co-edited a new collection of TRIZ games and cases [31] and has started to develop own games and cases.

This will hopefully clear a space to integrate more bionic thinking into all courses [32], which the author has already started with great success and appreciation (not only) in her Master course 2016/17. She is looking forward to the first application of TRIZ games and cases during winter term 2018/19 and will surely intensify bionic issues in the future.

5 Tools for Creativity, TRIZ, and KBI in Engineering Programs at Coburg University of Applied Sciences

5.1 Programs

Coburg University of Applied Sciences and Arts is located in northern Bavaria, Germany. The school was founded in 1814 as a school for architects, turned into a polytechnic school with programs of mechanical and electrical engineering in 1959, and became one of seven Universities of Applied Science in the federal country of Bavaria in 1971 [33].

The school now offers a multitude of studying programs in the areas of engineering, natural and social sciences, business, and design [34]. Traditionally, all studying programs use to be run by their respective faculties and without considerable interaction. Coburg UAS however believes that modern society requires academics who are conscious of the fact that scientific disciplines other that their own exist, have their respective competences, and use to address problems in different ways. This is why besides voluntary general studies "*studium generale*", interdisciplinary subjects are offered which are attended by students of various faculties.

5.2 Mechanical Engineering: Challenges

Coursework in education is largely similar worldwide as outlined in [35]. Engineering design uses to comprise engineering drawing, mechanics, and selecting and dimensioning machine components. Systematic design as described in [36] and in standard VDI 2221 [37] is considered a mandatory subject in education especially in Germany. Its basic idea is that the designer must not stick to and realize the first idea that comes to his mind, but find and compare alternatives and select the best. Systematic design therefore is intrinsically knowledge-based. It recommends the use of design catalogues but also of patent literature and creativity techniques. Accordingly, these methods have to be taught in engineering education along with TRIZ, which must be considered state of the art at least since standard VDI 4521 [38] has appeared.

5.3 Used Teaching Methods

Engineering design classes in mechanical engineering (B.Eng.) in Coburg comprise engineering drawing in 1st term (2,5 credit points, CP) and systematic design in 2nd term (2,5 CP): as an exercise, an exemplary mechanical assembly is reengineered. Machine elements follow in 3rd and 4th term with the 5th being spent outside of school.

In 6th term, an elective course “product definition and conceptual design” (5 CP) treats the following subjects that are applied on a problem from industry:

- identification of customer requests (Voice of the Customer)
- assessment, selection and derivation of engineering features (Voice of Engineer) using Quality Function Deployment [39]
- designation of specifications
- conception of solutions using catalogues, known solutions, patent literature, creativity tools, TRIZ contradiction solving, and Pugh’s method of Concept Selection [40]

The compulsory master program class “innovative product development” (5 CP) gives an overview of innovation management and treats the early phases of product identification and definition in more detail. It uses a TRIZ-based approach for identification of customer requests (VoC), incorporating various TRIZ tools [38] such as analysis of system levels, system operator, multiple S-Curve analyses, and trend extrapolation incl. “laws of engineering systems evolution”, LESE. Ideas for customer requests are taken as input for contradiction solving. Use of patent literature and QFD are taught in greater depth.
A problem is taken from cooperating companies; the goal of the class is definition of a product development project, sometimes concepts for solution are devised.
The format of the course is lecture plus project using agile project management.

An elective master class TRIZ Level 1+2 (5 CP) is scheduled for autumn term 2018. It will treat concepts of TRIZ, primary solutions by TRIZ creativity tools and effects, solving contradictions, problem formulation, system operator, and function analysis [38] (ETRIA Level 1) and LESE, Su-Field analysis, and ARIZ (Level 2).

In *studium generale* for students from all disciplines, TRIZ L1 and creativity techniques are offered. The latter comprises concepts of creativity, intuitive and analytic techniques, the scheme of defining, amassing, condensing, screening and selecting, and the Idea Machine by Brainstore [41, 42].

5.4 Experience

Generally, the reception of systematic work methods strongly varies; the majority of students prefer *ad-hoc* working processes. In industry, however, quality standards have become mandatory, systematic working is thus required. Engineers who have not been taught systematic design may then happen to reinvent process schemes on their own, failing to comply with the state of the art. Even though enthusiasm among students is limited, we therefore consider training in engineering systematics to be important. At least, remembering the basic outlines of methodology will hopefully be sufficient to look up and apply the art when needed.

The situation with TRIZ is similar, as TRIZ is also a systematic problem solving method – after all, TRIZ was conceived in the same situation of post-WWII engineering that has produced the Western schools of systematic engineering. So, TRIZ, too, is mainly appreciated by that minority of characters who are inclined to systematic working and the systematics of knowledge.

5.5 Outlook

Systematic engineering including TRIZ is based on a plan-driven working culture. At this moment, mechanical engineers are with some time delay following the trend to agile methods set earlier by computer scientists. Agile culture focuses on doing, not on organising and structuring. This causes conflicts in regulated areas of business, and research is being done on the relation of plan-driven vs. agile methods [43]. From a dialectic perspective, the individual agile way of engineering prevalent until WWII was negated by systematics and is negated again by standardized agile methods at the time being.

In the field of ideation, Mettler and Schnetzler [41, 42] have developed a highly effective and efficient process which seems to be thoroughly structured and basically plan-driven. Nevertheless, the process features strong similarities to Design Thinking [44] and uses a Scrum-like [43] procedure. It strictly separates two teams one of which steers the activity while the other produces ideas. To the author's opinion, this process offers an intriguing model for TRIZ and it will be worthwhile to examine more practice-oriented and agile forms of TRIZ.

6 Innovation and Creativity in Solving Technical Problems at the Weihenstephan-Triesdorf University

At the Weihenstephan-Triesdorf University of Applied Sciences at the Campus Triesdorf two Master of Engineering Programs are offered (in German): Energie-Management and Technologie (together with HS Ansbach and TH Nürnberg) and Umweltingenieurwesen. Both programs are studied by Bachelors from various Universities of Applied Sciences mainly in the fields of Life sciences, Energy, and Industrial Technology and Management. Students know only little about Invention, Innovation and Intellectual Properties. Ideas for technical innovations are thought to come by chance. Goal of the course 'Innovation und Kreativität in der Technik' is to make the ongoing Master Engineers fit in Innovation management and enable them to be an inventor in their later jobs.

6.1 Challenges Addressed in the Lectures and Seminar

Engineering students without any experience in the innovation process of a company tend to have the following opinions

- Invention is the same as Innovation
- Patents are only filed by very privileged engineers
- Inventions are made by exceptional people (like Disney's 'Gyro Gearloose')
- Inventive ideas happen by chance

However, first ideas need to be worked out to working inventions. Inventions need market diffusion for an innovation success: Innovation = Idea + Invention + Diffusion. Companies need intellectual property rights to protect their developments. In case that an invention is made, both parties, employers and employees have their rights. Everyone can be an inventor and ideas can be created by methods like TRIZ. Having this knowledge in mind and being able to understand and apply TRIZ methods make the young engineers be very valuable partners of the industry.

6.2 Proposed Teaching Methods

The course which is offered with 4 hours per week for one semester (15 weeks) comprises a lecture part of 4 weeks and a seminar part of 2 full days and 3 half days . Additionally, students have work at home.

The lecture part comprises 4 lecture units each 4 teaching hours in which mainly information is given to the students on:

- Innovation (What it is, different kinds, innovation funnel, innovation management, S-curve cycle, innovation strategies)
- Inventions (What it is, who is inventor, situation of inventors in a company – the German ‘Arbeitnehmererfindergesetz’ (rights of inventors as an employee), report of an invention)
- Patents (What it is, other IP rights, patent process, patent research, structure of a patent)
- Creativity (What it is, creativity methods, convergent vs divergent thinking, TRIZ)

Along these 4 lecture units exercises are made where the students experience important issues in the context of innovation. Here practical trainings are made on market space (Blue Ocean Strategy, [45]), invention report on egg drop contest ideas, patent statistics from an own Depatis patent research in expert mode [46], technical solution through individual thinking, unmoderated brainstorm, moderated brainstorm (De Bono).

The seminar part consists of group work where TRIZ tools are explained and used to either solve technical problems or to locate spots of weakness and find improved technical solutions. The various TRIZ tools are used in groups of about 20 students and are moderated by the lecturer.

So, in a first step an up-to-date technical problem is given or suggested by the students. Typically, the TRIZ starting action to work on the problem is to work through the innovation checklist as given by [47] and generate first ideas and to locate technical and physical contradictions. At this step TRIZ basics like ideal final result, resource analysis and others are already used.

Explaining and using further TRIZ tools like the size-time-cost operator, 40 inventive principles and principles of separating contradictory demands help to generate ideas for technical solutions. At the same time the TRIZ methodology is taught to the students in a learning-by-doing fashion.

In a further step the resulting ideas are discussed in the group and further developed. An assessment what ideas are best in viability and effectivity shows which of the ideas would be realized first in a real-life situation.

After working on several technical problems every student has created at least one satisfying technical solution. Finally, the students have the task to formulate an invention report including drawings, explanations, advantages, state of the art research, etc… This invention report is then taken to assess the individual performances.

6.3 Evaluation of Experience and Recommendations

From our point of view not many courses about Innovation, Invention, Patents, TRIZ are given in Engineering programs in German Universities. At least in my University it is the only course of this kind. At the same time it is important knowledge and experience. Especially it is very important and useful in Master programs. From student's side the course is evaluated with good results. Also the demand to participate in this course is excellent.

The course is also planned for the future. The number of participants should be limited to 25 students otherwise the involvement of all students in the seminar part is not given. Instead of working on self-given technical problems real life problems from companies or technical problems from innovation contests could help to foster the power of finding best solutions.

7 TRIZ Education at the Niederrhein University of Applied Sciences

7.1 Challenges Faced by Students Leaning TRIZ

Studying in the department of mechanical and process engineering at Niederrhein University of Applied Sciences has a very direct and close practical relevance for students. In the courses of the bachelor's degree program, for example, problem solving projects are carried out in group work directly after the TRIZ teaching modules in the 5th semester, during which tasks from industry are dealt with. During the 6th semester, after 12 weeks of practical work in an industrial company (the so-called practice phase), the bachelor's thesis is carried out directly in these industrial companies based on a similar industrial tasks. During the consecutive four-semester Master's program, in each semester we conduct a master project, each one with a new, industrial or research-oriented, task in groups. After all, the master's thesis itself consists of working on a problem solving project of an industrial or research-oriented task. Including the master's thesis, a student in our department has to carry out at least 6 comprehensive problem-solving projects alone or in group work.

The classical TRIZ tools are currently taught in the 4th and 5th Bachelor semesters and they are expanded and supplemented in the 2nd Master semester. The problem here is that although the students complete exercises and internships on the individual tools in the framework of the TRIZ lectures, they still have too little application experience to use the tools consistently and efficiently in the following problem-solving projects. In addition, both the professors' colleagues and the industrial supervisors in the industrial companies usually also have no application experience in the use of the TRIZ tools, but have been working for decades according to the classical "Methodical Design" of VDI 2221 [37] or the like. The tools specified in there (e.g. use of design catalogs and morphological matrix) partly contradict the problem-oriented and ideal-oriented concepts of TRIZ.

For this reason, the problem-solving steps and results that the students develop in their projects are often unconvincing and do not proof the effectiveness of TRIZ. If the students' projects are not accompanied by an experienced TRIZ user, the following mistakes are often made:

- Students see no need to use TRIZ tools as they (and their corporate supervisors) are satisfied with conventional solutions and compromises.
- The students want to start as soon as possible with the design work and ignore or even skip the problem analysis step.
- The resource analysis is done in a very superficial way; the students are satisfied with the first available solution ("I just want to pass").
- Contradictions are indeed formulated, but "solved" only with the Altshuller matrix using only innovation principles and because of that, they are not really disbanded in the sense of separation principles.
- A functional model is used to document the technical system, but further work is rarely done based upon this (contradiction analysis, trimming, etc.).
- RCA + is often used for problem analysis, but it rarely takes up the contradictions inherent in innovative problem solving.
- "Smart little dwarfs" are only reluctantly used because students feel ashamed doing so.

At first students just "stubbornly" do exactly what is given to them by the professor without recognizing relationships between the tools. In particular, they do not independently tackle new problems and innovative solutions. Students do not use different ways of solving or alternative tools than the ones explicitly learned and practiced, because an overview is missing. It takes some time and a lot of application experience for the students to recognize the interrelationships between the tools they can use in a goal-oriented way.

7.2 Didactical Concepts

From the perspective of the author there are didactically three main concepts needed to introduce and convince the students of using TRIZ tools successfully:

1. Initially the restriction to directly usable TRIZ tools, which are taught and practiced in a deliberately chosen order. Later the addition of TRIZ tools that require "more consistent TRIZ thinking".
2. The combination and conjunction of TRIZ tools with the tools established from decades of classical design methodology [49] and quality management.
3. The supervision and accompaniment, partly also management of student projects by a sophisticated TRIZ user, usually the teaching professor.

The presented findings and suggestions are based on nearly 15 years of teaching experience of the author in the TRIZ apprenticeship at the Niederrhein University of Applied Sciences in the field of mechanical engineering. Before the author was appointed to the Niederrhein University of Applied Sciences, he worked for 20 years in the industry, including 15 years in the product development and R&D management of textile-technological processes and textile production machines. In this respect, the author has both industrial application experience, including knowledge of application barriers, as well as many years of teaching experience with students and industrial seminars.

7.3 Didactical Concept 1: Limitation of Directly Usable TRIZ Tools

The students differ in several important characteristics from the problem solvers in the industry who have already been working on real life problem solving for several years. For example, at first students are quite open and uncritical, they believe everything one tells them to do, and they apply it without any previous thought. During the application of tools, questions and doubts arise, especially if direct benefit is not directly apparent. This makes it more difficult to convey the need for elaborate analyzes or the consistent use of methods. Industrial users quickly see the benefits of a more elaborate tool, as they quickly realize which existing barrier is being overcome. This "barrier experience" students do not have. It is therefore important to gradually introduce students from simple, quick-to-use tools to larger, more time-consuming tools. For example, the teaching experience and exam results show the following sequence of well-accepted methods to those with increasing application problems among the undergraduate students of the 4th semester:

- Functional Model
- Resource Analysis
- Feature Transfer
- Ideality
- Root Conflict Analysis (RCA +)
- Contradiction Analysis, Technical and Physical Contradiction
- Solving a Physical Contradiction with Separation Principles
- Smart Little Dwarfs

Accordingly, these tools are taught to the students almost in this order. When looking at the application in student projects and theses, particular attention is paid to the following points, some of which are also essential criteria for grading:

- We attach great importance to the description of the goal in the sense of ideality.
- We attach great importance to an extensive resource analysis.
- When a goal conflict arises in the requirements for the technical system we attach great importance to the formulation of the Physical (!) Contradiction and expect its entire solution using a Separation Principle.
- The Root Conflict Analysis (RCA +) is often used for problem analysis by the students, but the innovative potential of any conflict solution shown in the

RCA+ is often overlooked or ignored and should be taken up for an innovative solution.
- The Function Model is eagerly used, but the use of the contradiction analysis based on that model must be forced on the students by the supervisor.

7.4 Didactical Concept 2: Combination of TRIZ Tools with the Tools of Classical Design Methodology

Our experience and monitoring of application problems have shown that for the TRIZ-acceptance of professors-colleagues and industrial tutors, and thus automatically for the acceptance of the students, it is necessary to combine the TRIZ tools with the tools and methods of conventional construction methodology to integrate these.

Therefore, in the department of mechanical and process engineering at the Niederrhein University of Applied Sciences, the following conventional tools are taught in the bachelor modules "Methodical Design" in two semesters beside important TRIZ tools which were included and linked with suitable TRIZ tools:

- Requirement list according to VDI 2221 [37] linked to the innovation checklist and the ideality as well as the reference to goal conflicts,
- Phase model of product development according to VDI 2221 linked to the 4 problem-solving steps of TRIZ as for example defined in the Standard VDI 4521 [38],
- Operating principles and design catalogs linked to the resource checklist and the effect database of TRIZ,
- Function structure according to VDI 2221 linked to the TRIZ function model and its process-oriented extension [47],
- Evaluation procedure according to VDI 2225 [48] combined with ideality and ideal end result,
- Analogies and bionics linked to innovation principles,
- QFD linked to the contradiction analysis,
- FMEA linked to the Anticipatory Failure Identification.

The linking of conventional and TRIZ methods shows the TRIZ inexperienced industrial or academic supervisor of student works that TRIZ tools are simple additions but also more effective alternatives to conventional ways and tools, especially as the TRIZ tools directly provide relevant findings. Thus, the liking of the methods automatically increases the acceptance of TRIZ methods by the students.

7.5 Didactical Concept 3: Consistent Supervision of Student Projects

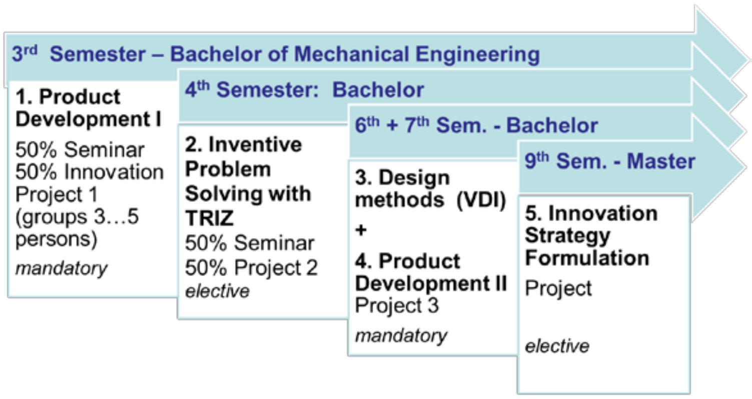
The supervision, accompaniment, and partly also management of student projects by an experienced TRIZ user, usually the teaching professor is an important precondition of successful learning. The exam results of the written exams show that some tools, such as the Function Model, are adopted very quickly and well mastered. Other steps, such as the complete resolution of Physical Contradictions, require practice and in particular direct control or feedback by the teacher as a supervisor.

It has been shown that close supervision of the students by an experienced TRIZ supervisor is necessary in order to motivate them to use individual TRIZ tools as well as to make sure that they are used consistently. The experience of recent years has shown that there is an increasing possibility to develop innovative solutions as far as the professor is available to the students as a consultant and method coach. Here, the work in the university does not differ from the experiences in the industry.

8 Teaching New Product Development and Inventive Problem Solving at Offenburg University

8.1 TRIZ Deployment at the Faculty of Mechanical and Process Engineering

Since 2013 TRIZ Methodology is a part of mandatory and elective courses for different bachelor's and master's degree programs in mechanical, material and process engineering and in mechatronics, as exemplarily shown in the Figure 1. The students



get acquainted with the TRIZ basic principles (Ideality, 9-Windows and contradiction-oriented thinking) and simple ideation techniques (such as MATCEMIB or Size-Time-Costs operators) in the 3rd semester within the mandatory Product Development I course with 4 weekly hours per semester (WHPS), followed by the elective course TRIZ and Inventive Problem Solving with 2 WHPS, two mandatory courses Product Development II and Design Methods with in total 8 WFPS, where TRIZ skills can be intensified or applied.

Fig. 1. TRIZ and Inventive Design embedded in the product development curriculum in mechanical engineering at the Offenburg University.

One of the objectives of such multi-stage educational approach is to motivate students to work inventively in the practice semester and in their degree theses, and to empower students to develop a product concept or to make an invention they can apply to patent or utility model.

Apart from education activities, the Lab for Product and Process Innovation of the Offenburg University is conducting interdisciplinary and application-based innovation research and development in the field of TRIZ methodology and Knowledge-based Innovation on the national [50] and European level [51]. These activities target consolidation of the innovation teaching and research activities in co-operation with the partners from industry and academia.

8.2 Integration of TRIZ Methodology into Innovation Design Process

Surveys across industries show that the integration of TRIZ basic principles and tools into all phases of new product development and design process is still relatively low and fragmental. In the cross-industry study [52], performed by the Offenburg University among 162 R&D managers and engineers of German industrial companies in 2016-17, the TRIZ tools rank with 14% in fifth place of the top five methods supporting innovation process, after brainstorming (76%), engineering design methods [49] (31%), diverse creativity techniques (29%), and Quality Function Deployment (21%).

The competitiveness of companies is defined by their long-term sustainable ability to maintain the competitive advantages, through both incremental and radical product, process, service or business model innovations with repeatable market success. In accordance to our research results, following skills of the graduates are expected by the industry: market and customer orientation, technology orientation, creativity, leadership, communication and knowledge management, risk and cost management, innovative climate, and innovation process and methods competences. The inventive problem solving, as a core competence of TRIZ, doesn’t belong to the top 10 innovation performance parameters from in total 80 [53].This experience, among other consequences, leads to a thorough reconsideration of educational approaches in TRIZ, existing since decades, and results in the necessity to better integrate TRIZ and other techniques into all phases of the innovation process and design practice. A series of research studies performed in 2012 demonstrates that the enhancement of the problem solving skills of university students and of experienced engineers requires different approaches which still have to be investigated more precisely [54]. As reported later in [55], the students show a lower motivation in learning TRIZ methodology in comparison with the engineers, especially regarding the core TRIZ competences such as fast and systematic inventive problem solving.

The consolidation of the comprehensive front-end innovation process with the advanced innovation methods and modern TRIZ tools has been proposed and explored in the research project "Innovation Process 4.0" run at the Offenburg University in co-operation with the industrial companies in 2015-2017 [50]. This research work resulted in the definition of the new Advanced Innovation Design Approach (AIDA) [56], which has been refined and further developed for the application in the field of process engineering in the context of the EU research project "Intensified by Design - Platform for the intensification of processes involving solids handling” within international consortium of 22 universities, research institutes and industrial companies under H2020 SPIRE programme [57].

8.3 Teaching Front End Innovation Process

The new findings discussed above, have been implemented in a novel course in new product development and inventive problem solving for mechanical engineering students [58]. The one-semester course has a total workload of about 120 hours, incl. 4 hours a week of lectures and practical work under guidance of a professor or supervisor. The course is modelling the front-end innovation process with the main steps presented in Table 2.

It combines a product development project (about 50% of the workload) with the auxiliary education in creativity and problem-solving techniques of the TRIZ methodology. The efficiency of the students' work in the innovation process strongly depends on their engineering creativity and skills in the problem analysis and inventive problem solving with the TRIZ methodology. Such skills are gained in the course through 8 auxiliary training units:

1. Enhancement of personal creativity, resources- and contradiction-oriented thinking, System operator.
2. Component and function analysis, contradiction identification.
3. Elimination of undesired properties and harmful effects with cause-effect analysis and 40 TRIZ inventive principles.
4. Solving engineering contradictions with 40 TRIZ inventive principles.
5. Costs reduction and trimming in technical system.
6. Short form of inventive algorithm ARIZ, identification of physical contradictions and their resolving with separation principles.
7. Anticipatory failure identification: prediction of potential failure scenarios for new products or processes.
8. Prediction of future technical product features with evolution patterns of technical systems.

The immediate utilization of learned innovation skills in practice motivates students to learn the creativity and inventive methods dynamically and proactively. The engineering students are working in a course as R&D team, starting their work with the comprehensive innovation strategy formulation, definition of the measurable goals for innovation tasks, followed by the idea generation and by the creation, evaluation, and comparison of new product concepts for further implementation. The course is optionally finalized by the systematic selection of the appropriate business model using the Business Model Navigator [59].

Table 2. Main phases and steps of the innovation project in the course.

Step No.	Phase 1. Innovation strategy definition	Step. No.	Phase 2. Innovation concept development
1	Initial situation analysis	6	Systematic idea generation with TRIZ
2	Function analysis of the product and customer's process mapping	7	Creation of innovation concepts through combining ideas concepts
3	Capturing solution-neutral customer needs (benefits)	8	Evaluation of innovative solution concepts
4	Evaluation of market potential of benefits as innovation tasks	9	Optimisation of the solution concepts
5	Selection of innovation tasks for the innovation strategy	10	Choice of the optimal innovation concept for the implementation

The observations made in the course show that mechanical engineering students primarily focus on the monodisciplinary mechanical problems and can oversee multidisciplinary interactions. In order to overcome such difficulties, the pre-defined set of system components for the function analysis can be recommended to the students. It reflects the typical structure of a mechatronic product: the basic mechanical structure, actuators, energy supply, sensors, control unit, software, information and data processor, mechanical, electrical, and human interfaces, etc.

If the identification of contradictions or cause-effect chains in mechatronic systems appears to be difficult, an easy-to-use method called Cause-Effect-Matrix (CEM) was proposed by the author at the Offenburg University [58]. The CEM combines a simple TRIZ ideation technique MATCEMIB known in the Substance-Field Analysis [16], extended by two additional fields - information field and the influence of human. These two fields help students also to take into consideration the aspects of information and data processing, and the issues related to the Human-Machine-Interface HMI.

9 Current Status of Creativity and Problem Solving Techniques in New Zealand Diploma in Engineering

9.1 Stakeholders' Perspective on Soft Skills of Engineering Graduates

It is critical for any provider of engineering education to maintain constant relationship with the local and national industry representatives. Such companies and government organizations are the main stakeholders for the institution and are the first places of employment of its graduates.

In our institution we conduct regular meetings of our academics with industry representatives. Also Engineering New Zealand (the institute of professional engineers) organizes regular forums and conferences where academics, students and industry liaise and discuss current state of the engineering education in New Zealand, its future directions, and requirements for successful employment of graduates.

At each of these events we hear a strong voice from the employers looking for more soft skills in our graduates. The list of such skills is growing from meeting to meeting and some of the most important ones are innovative thinking, problem solving and creativity techniques. Here I cannot speak for all engineering providers in New Zealand but in most cases engineering students are taught to use analytical means to prove the concept without application of any strict problem solving techniques. Clearly development of soft skills in graduates requires extra resources, perhaps additional courses specifically dedicated to the growth of such skills and even revised curriculum which would enable to include the soft skills content into engineering sub-jects.

Traditional set of courses per degree and cost of education makes it challenging to introduce additional papers to educational engineering programs. Replacing the existing courses or changing their content meets some surprising reaction from the industry because it is not prepared to sacrifice any technical substance in favor of the soft skills. And with the constantly growing volume of engineering knowledge that would be difficult to imagine a substitution of any of current course content with creativity related materials.

Framing the Challenge:

- Industry wants graduates with solid engineering knowledge and variety of soft skills such as problem identification, evaluation and solving, smart, critical and strategic thinking and many more.
- For students it is difficult to afford more time and money for education even realizing the benefits of it.
- Providers of engineering education have to be creative themselves to incorporate the soft skills listed by industry into the current engineering programs.

9.2 Proposed and In-Progress Solutions

Better Study of the Industry Needs. Closely working with the Engineering New Zealand and a survey template from the creators of TRIZ repository www.edisons21.com we are preparing a survey for professional engineers in New Zealand. In this survey along with the specific questions about creativity technique experiences we would like to ask professionals about the importance of introduction of the soft skills in their study. Based on their professional experience, what would they change in the curriculum, would they prefer more creativity and problem solving content over the technical one, etc.? Result analysis of this survey and other industry engagements will help us to influence future national engineering education and exchange the findings with wider community of engineering educators.

First Introduction of Students to TRIZ. During the second (last) semester of 2017 students studying Diploma in Engineering at the Toi-Ohomai Institute of Technology were introduced to various heuristics of TRIZ through the repository and then the students were asked to use the heuristics in their final year project. Overall the response was overwhelmingly positive and demonstrated significant degree of engagement [21]. This experience has also revealed various areas for future improvements including integration of the heuristics into other courses not just the final project.

Assessing TRIZ application. Starting from the first semester 2018 we have introduced TRIZ heuristics into the assignment of the final engineering project for electrical and mechanical cohorts. At the beginning of the project the students have to frame the problem using the Notion of Ideal Ultimate Result and Size–Time–Cost Operator heuristics and list all avail-able for the project resources using Notion of Resources. This is the first part of the study and after reflection on its application, adjustments will be made to the assignment and it will be issued to another class of project students.

9.3 Reflection on Previous Experiences and Thought for the Future

- Constructive feedback from all stakeholders including potential employers of the graduates is essential not just for curriculum modification but for the students to know what is expected from them on work placements.
- TRIZ heuristics have to be introduced from the beginning of engineering studies thus by the time of the final project students become familiar with the heuristics and can make own decision about their applications.
- We have found summative assessments and self-assessments of the heuristic applications more engaging providing for better outcomes.
- Perhaps we could share our resources and experiences with assignments and tasks dedicated to inventive problem solving in different disciplines and engineering courses.

10 TRIZ for Todays and Tomorrows Protagonists - Addressing Different Target Groups at the University of Applied Sciences Kaiserslautern

10.1 Challenge: Creating a Broad Awareness of TRIZ in Education and Science

The Kaiserslautern University of Applied Sciences (UAS) focuses on technology, economy, design and health as well as computer science as an integrating cross-sectional competence. It educates about 6,200 students in more than 50 courses of study and further education with about 550 employees and about 150 professors at three study locations in Kaiserslautern, Pirmasens and Zweibruecken.

About 5 years ago, TRIZ was only to be found as a special topic in the curriculum of the Master's degree in mechanical engineering and design at this university. In addition, TRIZ appeared at most as a marginal note in the design theory of different courses of study, e.g. industrial engineering, technical logistics, technical business administration.

The competence centre OPINNOMETH, founded in 2010, has set itself the task of increasing awareness for TRIZ. The approach chosen is initially aimed at making the methodology widely known. In order to achieve this, different target groups have been addressed with different forms of teaching and learning for several years. In the future, also research activities will increasingly be carried out in depth on the basis of this dissemination and awareness. This will then result in interdisciplinary research projects using or further developing TRIZ. Such a research project is currently in preparation.

However, the following paragraphs now represent the steps taken for the broad perception and recognition of TRIZ at the university.

10.2 Addressing Todays Protagonists: Bachelor Programs as Starting Point

The competence centre is located in the Faculty of Business Administration. The bachelor's program "Technical Business Administration" includes two classes on the subject of technology and innovation management. In a large part of this course, now students learn and rehearse TRIZ methods as a tool in successful innovation management. The teaching form is seminar-like - it consists of lectures, many exercises and teamwork tasks. Sometimes the students also take part in innovation con-tests. The TRIZ contents essentially consist of basic principles and methods, as they are also taught in MATRIZ Level 1 training courses [60].

The course enjoys great popularity. The application examples are usually not of high technological complexity, so that they can also be worked on by interdisciplinary students and students of business management with some technical interest. Non-technical TRIZ application examples also find their place.

In order to increase the motivation of the students, the competence center offers interested students an additional offer: They can voluntarily complete an additional training which prepares them for the MATRIZ-Level-1 examination. The examination voluntarily may then be taken at the competence centre outside the normal course of study.

Since two years, the concept is transferred to the faculty of logistics. It is implemented in a class called “creativity and problem solving” for Bachelor students of different logistics courses of studies.

10.3 Addressing Todays Protagonists: Master Programs Deepen the Relation between TRIZ and Innovation Management

In addition to the above-mentioned TRIZ courses in mechanical engineering, TRIZ teaching has also been integrated into interdisciplinary Master's courses now. In the Master's program "Industrial Engineering and Management", students spend one semester working on innovation tasks that have either been developed them-selves or are supported by industrial companies.

The focus here is on self-organized learning. The teams receive methodical support in the weekly meetings - here it concerns on the one hand TRIZ-basics, but also in particular TRIZ-forecasting. The concept of Directed Evolution® [61] according to Zlotin and Zusman is used as the guiding method. To enable profound learning, the students regularly reflect not only on the results of their work, but also on the working process itself. In addition, they are encouraged to reflect on the influence of the application of methods on their own personal development. In order to make this possible, a special learning setting has been created, that works with didactic elements such as learning diaries and portfolio examinations [62]. This setting was built up on some fundamentals of the concept of learning organizations [63].

Three years ago, the Competence Center launched the distance learning course "MBA Innovation Management". In this MBA program, one in-depth semester is completely dedicated to innovation management. TRIZ, in turn, plays an important role as an innovation methodology in this curriculum.

10.4 Addressing Tomorrows Protagonists: TRIZ Training of Academic Staff

The embedding of TRIZ in some courses already contributes to the fact that TRIZ is perceived more strongly at the university and by the current students. However, in order to achieve even stronger growth in significance in the future, also the academic staff has to be involved in TRIZ much more.

Therefore, the competence center has already conducted two TRIZ trainings for employees of the university. The training courses are aimed at scientific staff, re-search assistants, professors and administrative staff. Basic TRIZ topics are taught. Finally, participants can take the MATRIZ Level 1 exam [64].

This in-house training increases the proportion of academic staff with TRIZ knowledge. This in turn means that previous non-protagonists also include TRIZ in their courses. Furthermore, the number of people who will accept TRIZ as a method or object of research in future research projects is increasing.

10.5 Addressing Tomorrows Protagonists: Students of the Future Play TRIZ

Tomorrow's protagonists are not only the academic staff, but also the students of tomorrow. The TRIZ-episode “you are ingenious – especially with TRIZ-hints” in the series of events "Children University" provides children at the age of 8 to 12 with impressions about systematic inventing. In a game-oriented setting some inventive principles can be explored by the children at these events [65].

For 14- to 16-year-old girls and boys there are taster workshops in which you can get to know exemplary topics from different courses of study. Here, too, a workshop format has been integrated, in which the topics of "invention and innovation" are explored playfully with the help of a few TRIZ basics.

10.6 Experiences and Outlook

The Bachelor courses are very popular with students. This can be concluded from the regular lecture evaluations. More important, however, seems to be the qualitative observation that more students in this faculty now are taking part in innovation and idea contests. The offer of voluntary additional training is well received and more than half of the students decide to take the additional performance and take the Level 1 exam. As an outlook it can be stated here that the next revision of the bachelor courses of study in the business administration faculty will open the TRIZ class for further courses of study.

In the course of the lecture described above, students of the Master's program in "Industrial Engineering and Management" have also been able to participate increasingly in innovation contests and achieved some successes. The interest of industrial companies in setting tasks for this class also motivates students. Cooperation with industrial companies is increasingly targeted for the future.

The TRIZ training of academic staff has taken place twice. About 80% of the participants were scientific and research assistants and about 20% professors. The event was held on the initiative of the competence centre for the first time. Already the second implementation took place within the framework of the official internal university further education program. Here the next conduction is planned for the next years in the rhythm of 2-3 years.

The TRIZ event as part of the Children University has now become an integral part of the program. The workshops for 14 to 16 year olds are in high demand.

As mentioned above, all these awareness raising activities are not only important to teach many people today. They also support the future willingness to apply and further develop TRIZ within the framework of interdisciplinary research projects.

11 Concluding Thoughts and Recommendations

Engineering departments of universities face the challenge of graduating engineers with a balanced knowledge in engineering science, design and systematic innovation. However, only a minority of university educators possess sufficient expertise in TRIZ and advanced innovation design methods to teach or to integrate them in their courses.

Ideally engineering schools need to introduce stand-alone subjects that are specifically focused on TRIZ, KBI and other effective creativity techniques. Research evidence has demonstrated that the “enrichment” approach influences students’ problem-solving self-efficacy and creativity skills much more than all other engineering subjects taught at university.

When introduction of a stand-along subjects in impractical, engineering educators can embed simple ideation heuristics into existing discipline-based subjects. Although such “infusion” approach is not as effective as the “enrichment” approach, freely available educational materials [e.g. 18] could allow an educator with a limited knowledge in TRIZ to effectively teaching TRIZ heuristics to students.

Ideally, enhancement of creativity skills needs to continue over all three to five years of engineering study. Practically, it would be the most advantageous to the students if they learnt effective creativity methods as early in the engineering study as possible. This would allow many of them to apply these methods in their project work at university and to graduate with sound problem-solving and creativity skills.

Following concluding thoughts and recommendation can be helpful for universities to establish the education in new product development and systematic inventive problem solving or to improve its performance:

1. Teaching structured and comprehensive problem analysis approaches and thinking methods is worthwhile, as the number of problems and their complexity is rising.
2. Multiple perspectives (cultural, historical, theoretical, technological, economical etc.) enrich education in problem understanding and problem solving.

3. Fostering inventiveness is a necessity for both personal and corporate development and well-being in a complex world.
4. Universities as systems comprise different people in different roles, therefore TRIZ-education should not only focus students but also other system elements.
5. Teaching TRIZ can be very demanding as students often face difficulties in problem formulation and abstract thinking. Neither the educators nor the students should expect to have fun all the time.
6. Maintaining continuous engagement with the engineering professionals and the graduates, inquiring them about applications of problem solving techniques in their practices and recommendations for future engineering education.
7. Blending TRIZ heuristics into the technical content from the beginning of studies. Assessing applications of the heuristics by learners.
8. Recommendations for selected tools and educational methods, and sharing educational resources among academics through the TRIZ repository.
9. Students demonstrate often lower motivation in learning TRIZ in comparison with the engineers. The fast utilization of learned inventive skills in practice encourages the ability for self-directed learning and strengthens the motivation.
10. Students require skills to apply TRIZ individually, in smaller groups. They also should have an experience in moderating creativity or problem-solving workshops.
11. Because individuals develop skills and knowledge in systematic innovation over time, TRIZ education could accompany individuals over time - maybe in different settings and contexts.
12. One should also think how to support children with systematic creativity methods in the stage when they lose their light-hearted creativity on their way to get “serious” adults.
13. Students need to experience that everyone can be inventive in order to be self-confident to state their ideas as an engineer. One or two smaller real inventive tasks solved in a course can contribute for growth of student’s motivation.
14. Concerning inventive thinking the students not only need to learn methods to create ideas but also need to learn about the regulations of inventions made in a company as well as the formulation of an invention report as a base for patent applications.
15. Understanding of the TRIZ role in the new product development, innovation process, and innovation management in industrial companies is of importance.
16. TRIZ can actually be well integrated in engineering design classes. Basic concepts such as engineering and physical contradictions and their respective solutions use to be readily understood by students in bachelor programs, even from non-technical disciplines.
17. In bachelor programs, a small percentage of students from any discipline, including programs of health, social work, or management and economics, are attracted by the systematic problem-solving approach TRIZ constitutes, and successfully apply TRIZ to their respective subjects.

18. Participants in master classes use to be more critical on the recognizable gain from subjects taught. This poses the challenge to the TRIZ instructor to plausibly demonstrate the advantages that TRIZ methodology offers.
19. Some students become TRIZ enthusiastic users and later employ TRIZ tools in their graduation theses and at work. The inventive start-up activities should be supported at the universities also outside of the conventional classrooms.
20. Thinkable is an international certification scheme of TRIZ proficiency which attests students' special skills for job application.

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