Modelling Innovation Process in Multidisciplinary Course in New Product Development and Inventive Problem Solving

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SESSION S2: Educating the Edisons of the 21st Century

CONTEXT This paper addresses the needs of the universities regarding qualification of students as future R&D specialists in efficient techniques for successfully running innovation process. In comparison with engineers, students often demonstrate lower motivation in learning systematic inventive techniques, for example, TRIZ methodology, and prefer random brainstorming for idea generation. The quality of obtained solutions also depends on the level of completeness of the problem analysis, which is more complex and time-consuming in the case of interdisciplinary systems. This paper briefly describes a one-semester-course of 60 hours in new product development with the Advanced Innovation Design Approach and TRIZ methodology, in which a typical industrial innovation process for one selected interdisciplinary mechatronic product is modelled.

PURPOSE The article investigates the opportunities and advantages of a novel educational approach, analyses the learning experience, identifies the factors that impact the innovation and problem-solving performance of students, and underlines the main difficulties faced by the students in the course, especially in the case of interdisciplinary problems.

APPROACH The mechanical engineering students are working in a course as R&D department. They formulate a comprehensive innovation strategy and define the measurable goals for innovation tasks first. This is followed by idea generation and the creation, evaluation, and comparison of new product concepts for further implementation.

RESULTS Fast utilisation of learned innovation skills in practice encourages the ability of self-directed learning and strengthens the motivation. As a full-scale new product development project is too time-consuming for one semester, the idea generation and problem-solving phase should be limited to one or two inventive tasks for each team of students. Examples demonstrate innovation strategies proposed by the students during the course.

CONCLUSIONS The presented results, including recommendations for selected tools and educational methods, can help universities to establish the education in comprehensive new product development and systematic inventive problem solving or to improve its performance.

KEYWORDS new product development; inventive problem solving; innovation process; TRIZ methodology

Introduction

An ongoing qualification of R&D specialists and engineers in techniques that ensure a successful running of an innovation process has become very important for the competitiveness of enterprises. Over the last two decades, industrial companies, e.g. Samsung (Kim et al., 2005) or Siemens (Adunka, 2007), as well as numerous universities and educational institutions in Australia (Belski, 2007), Czech Republic (Jirman and Busov, 2010), Finland (Ryynänen and Riitahuhta, 2010), France (Oget and Sonntag, 2002), Italy (Cascini et al., 2008), Japan (Nakagawa, 2007), the Netherlands (Witts et al., 2010) and the USA (Domb et al., 2010) have gathered considerable positive experience in different education approaches in the systematic innovation and the theory of inventive problem solving TRIZ. For example, Valentine, Belski, and Hamilton (2016) have found that explaining how to apply even simple creative TRIZ inventive techniques such as MATCEMIB operator to engineering students results in a significant increase in the students' long-term creativity. At the same time, Harlim (2012) demonstrates that the enhancement of the problem-solving skills of university students and experienced engineers requires different approaches, which have to be investigated more thoroughly. Livotov (2015) underlines that students have lower motivation in learning TRIZ methodology than engineers, especially regarding such core TRIZ competences as fast and systematic inventive problem-solving.

TRIZ and Advanced Innovation Design Approach

The theory of inventive problem-solving (TRIZ), developed by Altshuller and his co-workers (Altshuller, 1984), is today considered as one of the most organized and comprehensive methodologies for invention knowledge and creative thinking (Cavalucci et al., 2015). This statement can be confirmed by the analysis of the most-cited scientific publications on innovative design performed by Chechurin and Borgianni (2016). In addition to its unique ideation techniques, TRIZ includes different problem definition methods, such as Substance-Field Analysis and the System Operator (Altshuller, 1984), Function Analysis (VDI Standard, 2016), Cause-Effect Chain Analysis (Dobrusskin, 2016), Root-Conflict Analysis RCA+ (Souchkov, 2005), and others. Harlim and Belski (2015) discuss the implications of these and other TRIZ tools for problem definition on the design of educational programs. Spreafico and Russo (2016) analyse TRIZ tools used in more than 200 industrial case studies and underline that the classical easy-to-use problem definition tools are at the bottom of the list with the frequency-of-mention of 16% for TRIZ Function Analysis and 13% for the System Operator.

The early stage of the customer-centered innovation process has been one of the focal points of the innovation research over the last decade (Kotsemir & Meissner, 2013). The challenges of the front-end innovation have defined the new development directions of the TRIZ methodology (Litvin, 2011; Abramov 2014). In accordance to Cooper and Kleinschmidt (2007), a high-quality innovation process, including its comprehensive and fault-free execution, belongs to the critical success factors in new product development. In the early stage of the process, companies have to discover the latent needs of customers or opportunities for customer satisfaction of which the customers are unaware (Narver et al., 2004). A number of researchers have reported on various new methods to uncover customer needs in addition to the classical voice-of-the-customer approaches (Christiano et al., 2000). Analysis of the customer working process (Bettencourt and Ulwick, 2008), analysis of market and technological trends known in TRIZ, and evolutionary analysis of customer needs (Petrov, 2005) are some of these new methods.

The consolidation of a comprehensive front-end innovation process with 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. This research work has resulted in the definition of the new Advanced Innovation Design Approach (AIDA). The AIDA innovation process with self-configuration, self-optimization, self-diagnostics, and intelligent information processing and communication comprises the following typical phases with feedback loops and simultaneous auxiliary or follow-up processes: uncovering of solution-neutral customer needs, technology, and market trends, identification of the needs and problems with high market potential and formulation of the innovation tasks and strategy, systematic idea generation and problem solving, evaluation and enhancement of solution ideas, creation of innovation concepts based on solution ideas, evaluation of the innovation concepts, and implementation, validation, and market launch of chosen innovation concepts.

The new development in the field of systematic innovation discussed above has been implemented in a novel course in new product development and inventive problem solving for mechanical engineering students. The one-semester course has a total workload of about 120 hours, including 4 hours a week of lectures and practical work under the guidance of a professor. The course is modelling a front-end innovation process and combining a product development project (about 50% of the complete workload) with the auxiliary education in creativity and problem-solving techniques of the TRIZ methodology. The engineering students are working in a course as R&D department. They formulate a comprehensive innovation strategy and define the measurable goals for innovation tasks first. This is followed by the idea generation and the creation, evaluation, and comparison of new product concepts for further implementation.

Educating Front End Innovation Process

The innovation process run in the course includes two initial phases: definition of customer-driven innovation strategy, followed by the innovation concept development, as shown in the Table 1. The engineering students are working in a course in the small teams of 4...6 persons.

Table 1: Structure of the innovation project in the course

Step No.	Phase 1 Innovation strategy formulation	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 process mapping	7	Combining ideas to the solution 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	Choosing the optimal innovation concept for the implementation

The method for customer-driven innovation strategy formulation and planning of R&D activities starts with the analysis of situation on the market and the recent patent information, followed by a description of all the essential components of the actual technical systems, their useful functions, and undesired or negative properties (see Table 1, Steps 1 and 2). A thorough analysis of the customer working process, the market, and current technological trends by the web monitoring are additionally performed by the students to obtain a complete picture of customer needs. A complete list of all thinkable innovation tasks is formulated in Step 3 on the basis of the identified market and customer requirements and a detailed function analysis. These tasks are understood as customer benefits, which are independent of known technologies or solutions and correspond to the further improvement of positive functions or the elimination of negative properties in the analysed products.

After the capturing of customer benefits is completed, the importance of each benefit and its current performance is evaluated from a customer's point of view in Step 4 using a scale from 0% to 100% (100% - very high level of importance or performance, 80% - high, 60% - middle, 40% - low, 20% - very low importance or performance). The task with the higher importance and lower performance can be selected later for the ideation and new concept development in Phase 2.

In one of the courses, a group of 29 students in their 8th and 9th study semesters of the Master of Mechanical Engineering degree program at the Offenburg University was involved in the development of a new high-quality motor-driven chainsaw for forest, park, and garden applications. The estimation of the market potential of innovation tasks using an example of a petrol-driven chainsaw is illustrated in Table 2. The top 5 of the 50 benefits of using a petrol-driven chainsaw with the highest market potential were selected by the students as the innovation tasks for the new chainsaw development.

Table 2: Top 5 of the 50 benefits of using a petrol-driven chainsaw with the highest innovation and market potential estimated by the students

No	User benefit (innovation task)	Importance	Performance
1	26. Indicate trees under tension	77%	30%
2	1. Low weight of chainsaw	93%	52%
3	44. Low noise emission	75%	40%
4	46. Easy and quick cleaning	85%	54%
5	28. Effortless delimbing	88%	57%

Phase 2 (Innovation concept development) of the innovation process is based on a comprehensive initial problem analysis performed during Phase 1. All innovation tasks selected in Step 5 of Phase 1 are understood in Step 6 as partial problems $P_1 \ldots P_n$, (see Figure 1). In this step, the strongest TRIZ inventive principles replace random brainstorming, increasing the quality and quantity of ideas within a short period of time. For each partial problem, several ideas must be generated, and no relevant idea should be overseen. After the ideation process, the proposed ideas should be combined with the solution concepts (Step 7). A robust solution concept delivers solutions for all partial problems. The solution concepts often have their secondary side-effects, like costs, risks, or R&D expenditures, which must be identified in Step 8 and limited through concept optimization in Step 9. The synthesis of a concept in Step 9 is completed if suitable complementary solutions have been chosen for each problem. Several competitive concepts can be created and compared at this stage with different objectives, such as the maximum growth of total product performance and optimisation of the costs, risks, or R&D expenditures. The process ends with a well-founded selection of preferred innovation concept in Step 10.

Educating Auxiliary Inventive Skills

The efficiency of the students' work in the second phase of the innovation process strongly depends on their engineering creativity and problem analysis and inventive problem-solving skills using the TRIZ methodology. Such skills are obtained during the course through seven supporting training units presented in Table 3. The integration of these auxiliary training units in the first part of the course encourages students to immediately apply their newly-acquired skills in the new concept development.

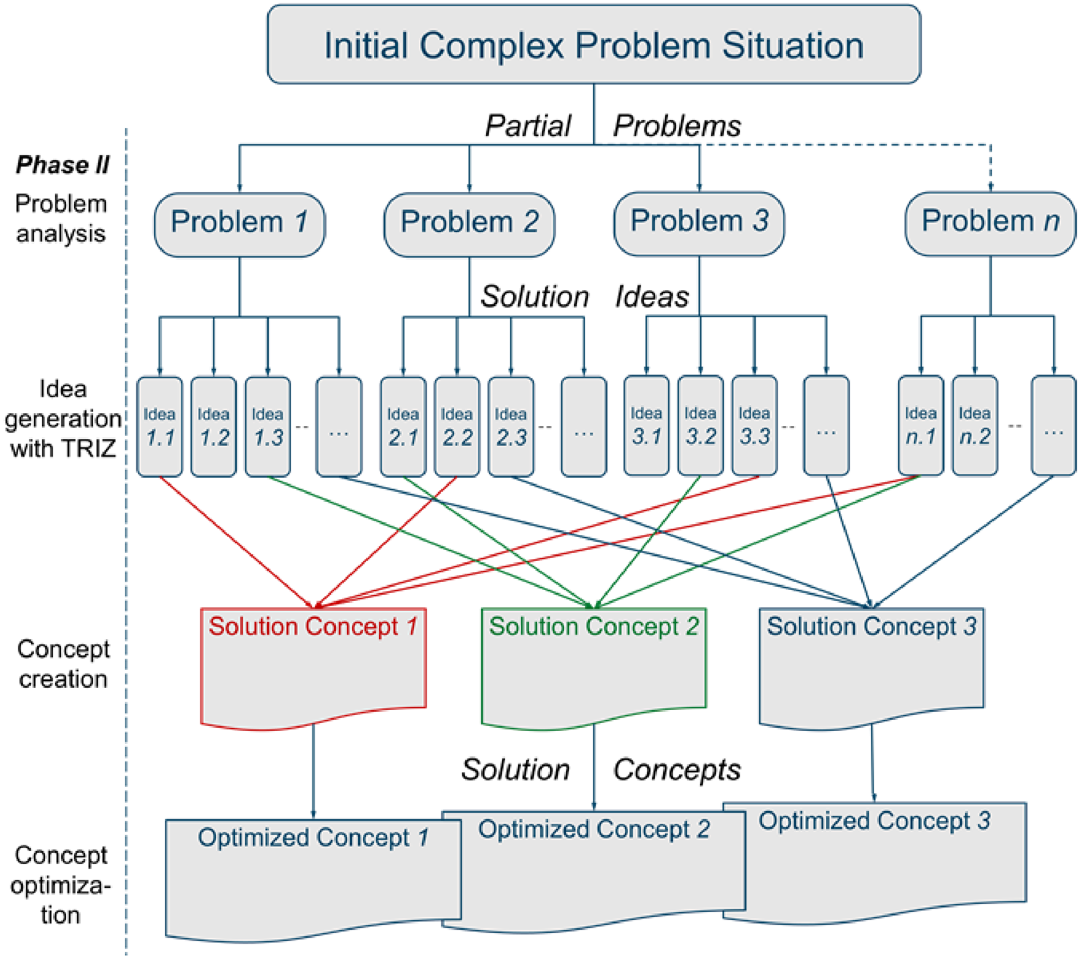

Figure 1: Phase 2 of the project run during the course - Innovation concept development

Table 3: Auxiliary training units in the inventive problem solving

No.	Title of training unit	Number of exercises
1	Enhancement of personal creativity, resources- and contradiction-oriented thinking, System Operator	4…5
2	Elimination of undesired properties and harmful effects with cause-effect analysis and 40 TRIZ inventive principles	2…3
3	Solving engineering contradictions with 40 TRIZ principles	2…3
4	Cost reduction and trimming in technical systems	1…2
5	Inventive algorithm ARIZ (short form), identification and resolving of physical contradictions with separation principles	2…3
6	Anticipatory failure identification: prediction of potential failure scenarios for new products or processes	2…3
7	Prediction of future technical product features with evolution patterns of technical systems	1…2

Challenges of Mechatronic Systems

When applying TRIZ for inventive problem solving, the quality of obtained solutions depends on the ability of students to understand problem situation completely and to identify the core engineering contradiction(s) of the technical system. The complexity of these tasks increases when dealing with interdisciplinary mechatronic problems. 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.

Table 4: Illustration of the Cause-Effect-Matrix (CEM) for interdisciplinary systems

Negative **Consequences**									
...									
Negative **Effect** (level 1)									
Causes of negative effect									
Fields of the Substance-Field Analysis:	1. Mechanical	2. Acoustic	3. Thermal	4. Chemical	5. Electrical	6. Magnetic	7. Intermolecular	8. Information, data processing	9. Biological, Human

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) proposed by the author at the Offenburg University can be suggested. The CEM combines a simple TRIZ ideation technique MATCEMIB known in the Substance-Field Analysis (Valentine, Belski and Hamilton, 2016) with the cause-effect-consequence observations in a problem situation. Table 4 explains the fast CEM method, which helps to identify interdisciplinary root-cause chains and can support students during the whole problem formulation process. Supplementary to the eight MATCEMIB fields (Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, and Biological fields), two additional fields, namely the information field and the influence of human operator, are included in the positions 8 and 9 of the matrix. These two additional fields help mechanical engineering students to take into consideration the aspects of information and data processing in the control system and the issues related to the Human-Machine-Interface.

For example, starting with mechanical cause of a negative effect at the bottom level (e.g. bearing friction, see Table 4), a student can easily see and document the negative thermal effect (overheating) that may further lead to a chemical problem (e.g. degradation of grease properties). Another example shown with the dotted line starts with the acoustic consequences of a harmful effect (e.g. noise) caused by the electrical field (e.g. electrical drive) due to the human operator error. Different cause-effect-consequence chains can be checked rapidly top-down or vice versa in this way. Nevertheless, the fast and at the same time complete and error-free problem situation analysis remains one of the challenging factors in the educational process as the results of student work demonstrate a large variation in the interpretation of the same problem.

Concluding Remarks and Outcomes of the Course

The proposed course simulates the challenges of the front-end innovation project. The immediate utilization of learned innovation skills in practice motivates students to learn creativity and inventive methods dynamically and proactively. As a full-scale new product development project is too time-consuming for one semester, the idea generation and problem-solving phase should be limited to one or two inventive tasks for each team of students.

The course offered since 2015 at the Offenburg University was highly appreciated by the majority of participants, who were able to propose or to decisively codetermine the areas of their innovation projects for several new products, such as lawnmower, chainsaw, core drilling machine, dishwasher, robot vacuum cleaner, automated car wash, electric power tools, etc. The students of the course demonstrated competent application of the learned skills and could systematically select top five innovation tasks from the identified 30 to 60 solution-neutral customer needs. The application of the TRIZ inventive principles enabled an efficient development of patentable ideas and solution concepts during the project.

The presented analysis and experience, including recommendations for selected tools and educational methods, can help universities to establish the education in comprehensive new product development and systematic inventive problem solving or to improve its performance.

References

Abramov, O.J. (2014). TRIZ-assisted Stage-Gate Process for Developing New Products. *Journal of Finance and Economics*, 2014, Vol. 2, No. 5, 178-184.

Adunka, R. (2007). *Lessons Learned in the Introduction of TRIZ at Siemens A&D*. Proceedings of the 7th ETRIA World Conference, Frankfurt, Germany, 6-8 Nov. 2007, Kassel University Press, ISBN 978-3-89958-340-3, p. 127-129.

Altshuller, G.S. (1984). Creativity as an exact science. The theory of the solution of inventive problems. Gordon & Breach Science Publishers, ISSN 0275-5807.

Belski, I. (2007). *TRIZ Course Enhance Thinking and Problem Solving Skills of Engineering Students*. Proceedings of the 7th ETRIA World Conference, Frankfurt, Germany, 6-8 Nov. 2007, Kassel University Press, ISBN 978-3-89958-340-3, p. 9-14.

Bettencourt, L. & Ulwick, A. (2008). The customer-centered innovation map. *Harvard Business Review 86 (5)*, 109-114.

Cascini, G., Regazzoni, D., Rizzi, C. & Russo, D. (2008). *Enhancing the innovation capabilities of engineering students.* Proceedings of the TMCE Conference, April 21–25, 2008, Izmir, Turkey, Edited by I. Horváth and Z. Rusák, ISBN 978-90-5155-045-0, p. 733-742.

Cascini, G., Rotini, F. & Russo, D. (2009). *Functional Modeling for TRIZ-Based Evolutionary Analyses*. Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 5, Design Methods and Tools (pt. 1), Palo Alto, CA, USA, 24.-27.08.2009. ISBN 978-1-904670-09-4.

Cavallucci, D., Cascini, G., Duflou, J., Livotov, P., Vaneker, T. (2015). TRIZ and Knowledge-Based Innovation in Science and Industry. *Procedia Eng. 131 (2015),* 1–2. doi:10.1016/j.proeng.2015.12.341.

Chechurin, L. & Borgianni, Y. (2016). Understanding TRIZ through the review of top cited publications. *Computers in Industry*, Volume 82, October 2016, Pages 119-134, https://doi.org/10.1016/j.compind.2016.06.002.

Christiano, J.J., Jeffrey, Liker, K. & White, C.C. (2000). Customer-Driven Product Development Through Quality Function Deployment in the U.S. and Japan. *Journal of Product Innovation Management*, 17, 286-308.

Cooper, R.G. & Kleinschmidt, E.J. (2007). Winning businesses in product development: The critical success factors. *Research-Technology Management*, vol. 50, no. 3, May-June 2007, pp 52-66.

Dobrusskin, C. (2016). On the Identification of Contradictions Using Cause Effect Chain Analysis. *Procedia CIRP*, 39 (2016) 221–224, doi:10.1016/j.procir.2016.01.192.

Domb, E., Miller, J., Czerepinski, R. (2010). *Improve TRIZ Teaching and Learning by Getting Out of the Classroom*. Proceedings of the 10th ETRIA World Conference, Bergamo, 3.-5. Nov. 2010, Bergamo University Press, 346 p., ISBN 978-88-96333-59-4.

Harlim, J.M. (2012). Identifying the factors that impact on the problem solving performance of engineers. PhD thesis, 2012, School of Electrical and Computer Engineering Royal Melbourne Institute of Technology, RMIT University, Melbourne, Australia.

Harlim, J. & Belski, I. (2015). On the Effectiveness of TRIZ Tools for Problem Finding. *Procedia Engineering*, Volume 131, Pages 892-898, doi:10.1016/j.proeng.2015.12.400.

Jirman, P. & Busov, B. (2010). *Solving cases studies in TRIZ education at Technical Universities in the Czech Republic*. Proceedings of the 10th ETRIA World Conference, Bergamo, 3.-5. Nov. 2010, Bergamo University Press, 346 p., ISBN 978-88-96333-59-4, pp. 285-291.

Kim, J.-H., Lee, J.-Y., Kang, S.-W. (2005). *The Acceleration of TRIZ Propagation in Samsung Electronics.* Proceedings of the 5th ETRIA World Conference, Graz, Austria, 16.-18. Nov. 2005, p. 151-164, ISBN 3-7011-0057-8.

Kotsemir, M. & Meissner, D. (2013). Conceptualizing the innovation process - trends and outlook. Series: science, technology and innovation. *Higher School of Economics Research Paper* No. WP BPR 10/STI/2013. SSRN: http://ssrn.com/abstract=2249782.

Litvin, S. (2011). *Main parameters of value: TRIZ based tool connecting business challenges to technical problems in product/process innovation*. Presentation at the 7th TRIZ Symposium, Yokohama, Japan. 09.11.2011.

Livotov, P. (2015). Measuring Motivation and Innovation Skills in Advanced Course in New Product Development and Inventive Problem Solving with TRIZ for Mechanical Engineering Students. *Procedia Engineering,* Volume 131, 2015, Pages 767-775.

Nakagawa, T. (2007). *Education and Training of Creative Problem Solving Thinking with TRIZ/USIT.* Proceedings of the 7th ETRIA World Conference, Frankfurt, Germany, 6-8 Nov. 2007, Kassel University Press, ISBN 978-3-89958-340-3, p. 95-102.

Narver, J.C., Slater, S.F., MacLachlan, D.L. (2004). Responsive and Proactive Market Orientation and New-Product Success. *The Journal of Product Innovation Management*, 21, 334–347.

Oget, D. & Sonntag, M. (2002). *Cognitive Development with TRIZ and Problem Based Learning.* Proceedings of the 2nd ETRIA World Conference, Strasbourg, France, 6-8 Nov. 2002, ISBN 2-86820-227-6, p. 35-40.

Petrov, V. (2005). *Laws of Development of Needs.* Proceedings of the 5th TRIZ Future Conference, Graz, 16.-18. Nov. 2005, Leykam Buchverlag, ISBN 3-7011-0057-8, pp. 195-204.

Ryynänen, L.E., Riitahuhta, A. (2010). *Challenge of Teaching TRIZ for University Students*. Proceedings of the 10th ETRIA World Conference, Bergamo, 3.-5. Nov. 2010, Bergamo University Press, 346 p., ISBN 978-88-96333-59-4.

Souchkov, V. (2005). *Root Conflict Analysis (RCA+): Structuring and Visualization of Contradictions.* Proceedings of the 5th ETRIA TRIZ Future Conference, Graz, Austria, November 16-18, 2005. Leykam Buchverlag, ISBN 3-7011-0057-8.

Spreafico, S. & Russo, D. (2016). TRIZ Industrial Case Studies: A Critical Survey. *Procedia CIRP.* Volume 39, 2016, Pages 51-56. doi:10.1016/j.procir.2016.01.165.

Valentine, A., Belski, I., Hamilton, M. (2016). *Engaging engineering students in creative problem solving tasks: How does it influence future performance?* Paper presented at 44th SEFI Conference, 12-15 September 2016, Tampere, Finland.

VDI Standard 4521. (2016). Inventive problem Solving with TRIZ. Fundamentals, terms and definitions. Berlin, Germany.

Wits, W.W., Vaneker T.H.J., Souchkov, V. (2010). *Full Immersion TRIZ in Education*. Proceedings of the 10th ETRIA World Conference, Bergamo, 3.-5. Nov. 2010, Bergamo University Press, 346 p., ISBN 978-88-96333-59-4.