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 The paper is addressing 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 the engineers, the students often demonstrate lower motivation in learning systematic inventive techniques, like 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. The paper briefly describes 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 the students, and underlines the main difficulties faced by the students in the course, especially in case of interdisciplinary problems.

APPROACH The mechanical engineering students are working in a course as R&D department, 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.

RESULTS The fast utilization of learned innovation skills in practice encourages the ability for self-directed learning and strengthens the motivation. As a full-scale new product development project integrated in the course 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 students' team. Examples demonstrate innovations strategies, solution ideas and concepts 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

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Introduction

The on-going qualification of R&D specialists and engineers in using efficient techniques for successfully running an innovation process becomes very important for the competitiveness of enterprises. In 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 in the USA (Domb et al., 2010) gathered considerable positive experience in different education approaches in the systematic innovation and in the theory of inventive problem solving TRIZ. For example, Valentine, Belski and Hamilton (2016) have found that even explaining engineering students how to apply even simple creative TRIZ inventive techniques such as MATCEMIB operator, results in significantly increase of students' long-term creativity. At the same time Harlim (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. Livotov (2015) underlines that the students have 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.

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 top 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 (Altschuller, 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-centred innovation process is 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 belong to the critical success factors in new product development. In the early stage of the process companies have to discover customers' latent needs or opportunities for customer's satisfaction of which the customers are unaware (Narver, 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). To such methods belong analysis of the customer working process (Bettencourt and Ulwick, 2008), analysis of market and technological trends known in TRIZ, evolutionary analysis of customer needs (Petrov, 2005).

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. 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 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 as well as implementation, validation and market launch of chosen innovation concepts.

The new development in the field of the 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, incl. 4 hours a week of lectures and practical work under guidance of a professor. The course is modelling the 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, 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.

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	Choice of 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 of the recent patent information, followed by description of all the essential components of actual technical systems with its useful functions and all undesired or negative properties (see Table 1, step 1 and 2). The thorough analysis of the customer working process and the analysis of market and technological trends by the web monitoring are additionally performed by the students for the complete identification of the customer needs. Based on identified market and customers' requirements and the detailed function analysis, a complete list of all thinkable innovation tasks is formulated in the step 3. These tasks are understood as customer benefits, which are independent from known technologies or solutions and correspond to further improvement of positive functions or to the elimination of negative properties in analyzed products or properties.

After the capturing of customer benefits is completed, in step 4 the importance of each benefit and its current performance has to be evaluated from a customer's point of view 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 the phase 2.

In one of the courses a group of 29 students (8th and 9th study semesters in the Master of Mechanical Engineering degree) at the Offenburg University was involved into development of a new high-quality motor-driven chainsaw for forest, park and garden applications. The estimation of market potential of innovation tasks on example of the petrol-driven chainsaw is illustrated in the Table 2. The top 10 of the 50 benefits of the petrol-driven chainsaw users with were selected by the students as innovation tasks for the new chainsaw development.

Table 2: Top 5 of the 50 benefits of the petrol-driven chainsaw users with 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%
…	…	…	…

The phase 2 of the innovation process "Innovation concept development" is based on comprehensive initial problem analysis performed in the phase 1. All innovation tasks selected in the step 5 of the phase 1 are understood in the next step 6 as partial problems $P_1 \ldots P_N$, as illustrated in the Figure 1. The strongest TRIZ inventive principles replace in the step 6 the random brainstorming, increasing the quality and quantity of ideas within a short period of time. For each partial problem several ideas must be generated as well as no relevant idea should be overseen. After the ideation process, the proposed ideas should be combined to 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 the step 8 and limited through concept optimization in the step 9. The synthesis of a concept in step 9 is completed if suitable complementary solutions were chosen for each problem. Several competitive concepts can be created and compared here with different objectives such as the maximum growth of total product performance, optimization of the costs, risks or R&D expenditures. The process ends with well-founded selection of preferred innovation concept in the 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 skills in the problem analysis and inventive problem solving with the TRIZ methodology. Such skills are gained in the course through 7 supporting training units presented in the Table 3. The integration of these auxiliary training units in the first part of the course encourages and students for the fast utilization of learned skills in the phase new concept development.

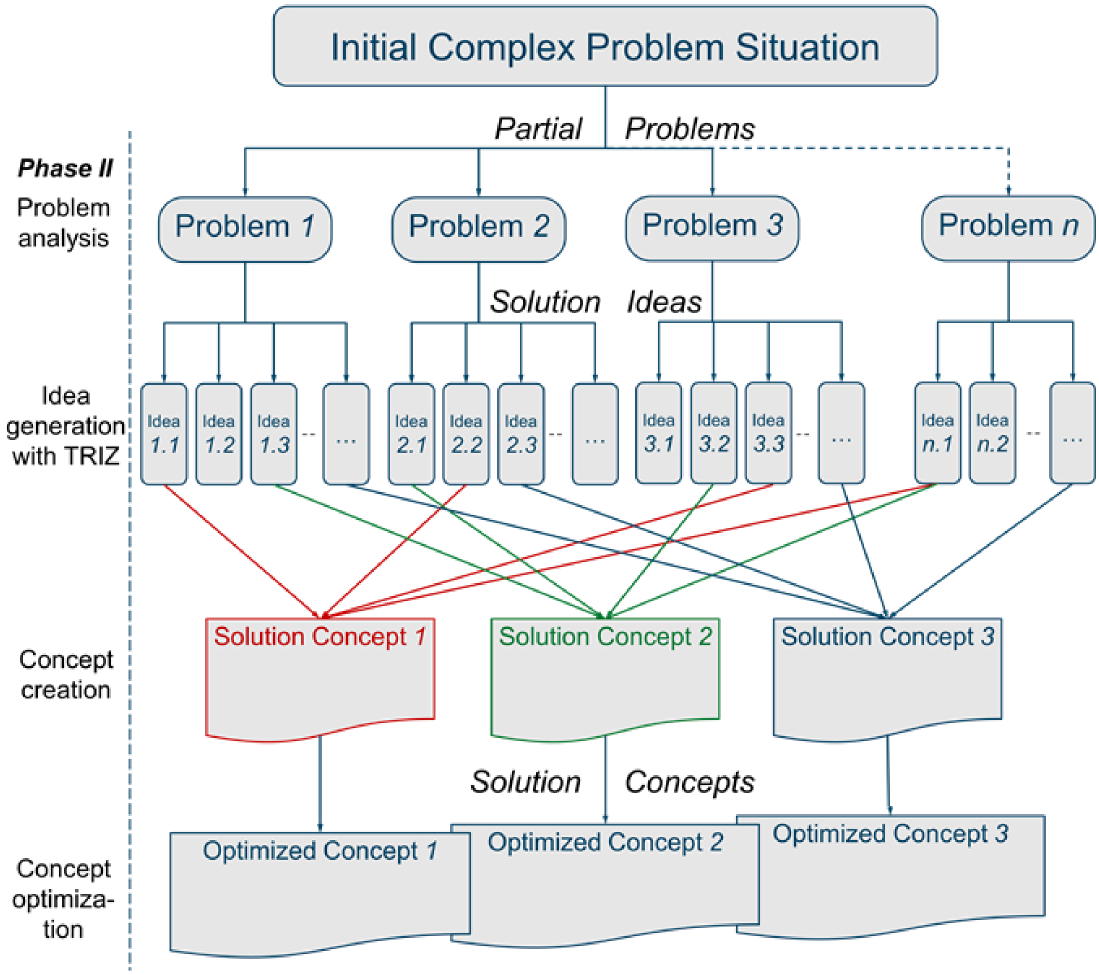

Figure 1: Phase 2 of the project run in the course - Innovation concept development

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 inventive principles.	2…3
4	Costs reduction and trimming in technical systems.	1…2
5	Short form of inventive algorithm ARIZ, identification of physical contradictions and their resolving 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 the 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) 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) was proposed by the author at the Offenburg University. 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 fields of the MATCEMIB heuristic (Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, and Biological fields), two additional fields - 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 also to take into consideration the aspects of information and data processing in the control system, and the issues related to the Human-Machine-Interface HMI in a mechatronic system.

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 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 same problem by different student's groups.

Concluding Remarks and Outcomes of the Course

The proposed course simulates the challenges of the early phase innovation project. The immediate utilization of learned innovation skills in practice motivates students to learn the creativity and inventive methods dynamically and proactively. As a full-scale new product development project integrated in the course 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 students' team.

The course offered since 2014 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 new product development projects, such as lawnmower, chain saw, core drilling machine, dishwasher, robot vacuum cleaner, automated car wash, electric power tools etc. They students demonstrated competent application of the learned skills and could select systematically top 5 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 project work.

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.

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