

# Enhancing Innovation and Entrepreneurial Competences of Engineering Students through a Systematic Cross-Industry Innovation Learning Course

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## STRUCTURED ABSTRACT

### CONTEXT

The paper addresses the needs of medium and small businesses regarding qualification of R&D specialists in the interdisciplinary cross-industry innovation, which promises a considerable reduction of investments and R&D expenditures. The cross-industry innovation is commonly understood as identification of analogies and transfer of technologies, processes, technical solutions, working principles or business models between industrial sectors. However, engineering graduates and specialists frequently lack the advanced skills and knowledge required to run interdisciplinary innovation across the industry boundaries.

### PURPOSE

The study compares the efficiency of the cross-industry innovation methods in one semester project-oriented course. It identifies the individual challenges and preferred working techniques of the students with different prior knowledge, sets of experiences, and cultural contexts, which require attention by engineering educators.

### APPROACH

Two parallel one-semester courses were offered to the mechanical and process engineering students enrolled in bachelor's and master's degree programs at the faculty of mechanical and process engineering. The students from different years of study were working in 12 teams of 3...6 persons each on different innovation projects, spending two hours a week in the classroom and additionally on average two hours weekly on their project research. Students' feedback and self-assessments concerning gained skills, efficiency of learned tools and intermediate findings were documented, analysed, and discussed regularly along the course.

### RESULTS

Analysis of numerous student projects allows to compare and to select the tools most appropriate for finding cross-industry solutions, such as thinking in analogies, web monitoring, function-oriented search, databases of technological effects and processes, special creativity techniques and others. The utilization of learned skills in practical innovation work strengthens the motivation of students and enhances their entrepreneurial competences. Suggested learning course and given recommendations help facilitate sustainable education of ambitious specialists.

### CONCLUSIONS

The structured cross-industry innovation can be successfully run as a systematic process and learned in one semester course. The choice of the preferred working techniques made by the students is affected by their prior knowledge in science, practical experience, and cultural contexts. Major outcomes of the students' innovation projects such as feasibility, novelty and customer value of the concepts are primarily influenced by students' engineering design skills, prior knowledge of the technologies, and industrial or business experience.

### KEYWORDS

project-based learning, cross-industry innovation, new product development.

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## Introduction

The capability of R&D specialists and engineers to successfully run an innovation process faster, and more efficient is of high importance for the competitiveness of enterprises. The engineering educators have understood this industrial demand and gathered in the last two decades considerable experience in different education approaches in the systematic innovation. For example, Oget & Sonntag (2002) advocate the cognitive development combining problem based learning and systematic innovation with TRIZ methodology proposed by Altshuller (1984). Dym et al. (2005) consider the project-based learning as the most-promising educational model for design thinking. Badran (2007) investigates the relationship between creativity and engineering education and outlines the necessity of special courses and activities that would enhance innovative skills of graduate engineers. Harlim (2012) demonstrates that the enhancement of the problem solving skills of university students and of the experienced engineers requires different approaches. The previous research of the author (Livotov, 2015) underlines that the students have lower motivation in learning systematic innovation methods in comparison with the engineers. Buskes and Belski (2017) found that prior knowledge in science positively influence on engineering creativity and ideation abilities of students.

Numerous attempts and approaches to enhance the engineering creativity of the students systematically, applying tools of the theory of inventive problem solving TRIZ and knowledge-based innovation were undertaken through educational institutions. Belski (2007) and Cascini et al. (2008) report about the enhancement of thinking and problem solving skills of engineering students with TRIZ. Jirman and Busov (2010) propose to solve real case studies in the engineering classes. Ryyänen and Riitahuhta (2010) discuss the challenges of teaching TRIZ for university students. Witts, Vaneker and Souchkov (2010) evaluate the University summer course in systematic innovation and invention with a workload of 140 hours within two weeks. Domb, Miller and Czerepinski (2010) discuss the advantages of teaching TRIZ by getting out of the classroom. Nakagawa (2011) shares his experiences of teaching undergraduate students and engineers in creative problem solving and recommends the Unified Structured Inventive Thinking method which is easier to learn and to apply. The efficiency of the simple creative TRIZ inventive techniques, such as eight fields and interactions of the Substance-Field Analysis is experimentally confirmed by Valentine, Belski and Hamilton (2016).

Another approach for faster and easier cross-industry innovation is based on the interdisciplinary analogies. It promises advantages for SMEs in reduction of their R&D expenditures. The cross-industry innovation is commonly understood as identification of analogies and transfer of technologies, processes, technical solutions, working principles or business models between industrial sectors (Enkel & Gassmann, 2010). Echterhoff, Amshoff and Gausemeier (2013) underline a high potential of the cross-industry innovation to create radical ideas. Hahn (2015) proposes a comprehensive cross-industry innovation process in the field of telecommunication. VDI Standard (2016) includes modern TRIZ tools supporting cross-industry innovation such as function-oriented search and feature transfer. Vullings and Heleven (2017) define the 9-phases cross-industry innovation process. Kerl and Moehrl (2017) explore the case of multi-cross-industry innovation with at least three participants from different industrial sectors. However, engineering graduates and specialists frequently lack the advanced skills and knowledge required to run interdisciplinary innovation across the industry boundaries.

The presented study applies the project-based learning approach and proposes to integrate a novel easy-to-use cross-industry innovation tool into one-semester new product development courses for mechanical and process engineering students enrolled in bachelor's and master's degree programs. It evaluates the efficiency of the tool, compares the performance of students, and discusses the implications for engineering education and research.

## Educating Cross-Industry Innovation

Two parallel one-semester courses were offered to the mechanical and process engineering students enrolled in 4<sup>th</sup> semester of bachelor's and in 2<sup>nd</sup> semester of master's degree programs at the faculty of mechanical and process engineering of the Offenburg University. The students from different years of study were working in 12 teams of 3...6 persons each on their innovation projects, spending two hours a week in the classroom and additionally on average two hours weekly on their project research. Students' feedback and self-assessments concerning gained skills, efficiency of learned tools and intermediate findings were documented, analysed, and discussed regularly along the course.

The course combines a product development project (about 60% of the complete workload) with the auxiliary education in creativity techniques and problem-solving tools of the TRIZ methodology, as described in our previous research (Livotov, 2017). The engineering students started their project work with the formulation of the innovation strategy, 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 cross-industry innovation approach has been applied in the phases of innovation strategy formulation and of idea generation.

### Five analogies for rapid cross industry innovation

Gordon (1961) advocated that creative thinking in analogies belongs to efficient creativity techniques. To help increase the ideation capability of students, a new method using five analogies presented in Table 1, was proposed as simple cross-industry creativity tool. The recommended analogies were applied by all students individually for one educational problem and by the student groups in their semester projects as well.

**Table 1: Five cross-industry analogies**

N	Analogies	Corresponding creativity or TRIZ tools
1	How similar task/problem is solved in technical domains or fields of business similar to yours?	Morphological Analysis, Feature Transfer (TRIZ)
2	How similar useful function ( <i>primary or auxiliary</i> ) is realised in other technical domains?	Function-oriented search FOS (TRIZ)
3	How similar problem (e.g. <i>eliminate harmful effect</i> ) is solved in other technical domains?	Function-oriented search FOS (TRIZ)
4	How similar problem is solved in other technical systems on the micro or nano-level and on the macro level ( <i>scaling</i> )	TRIZ operator Size-Time-Costs; transfer to micro-level; transfer to super-system
5	How similar problem is solved in the nature (bio-organisms, plants, insects, fishes, animals, humans):	Bionic / biomimetics

The proposed educational problem of “*Monitoring the road surface condition by a car*” was pre-formulated and introduced to all course and experiment participants in same manner as follows: “A sensor, for example a camera, for detection of road condition (dry, wet, dirty, icy) is placed in a vehicle close to the road surface to detect its properties. This working principle requires a protection of the sensor from getting dirty or damages”. Moreover, the primary useful function “Control or analysis of surface properties” and the task for elimination of primary harmful effect “Protection of surfaces from getting dirty or damages” were pre-defined for the analogies 2 and 3 correspondingly. After three minutes of problem introduction that contained only the information presented above, all participants were asked to work individually and to record as many ideas as possible within 20 minutes.

### Experimental Methodology

Three groups of students from the Offenburg University and one interdisciplinary group of engineers participated in the experiment, as presented in the Table 2. The Control group did not use the analogies or any other creativity tools for idea generation. All other groups used five analogies for idea generation with a recommendation to spend about 4 minutes for each analogy. All the groups were supervised by the same tutor. The experiment participation was voluntary and anonymous. The form to record ideas was distributed to the participants just before the educational problem was presented.

The number of different ideas proposed by each individual participant, the distribution of these ideas over analogies, number of different ideas within each group were estimated by two independent assessors. Similar to the previous work of the author (Belski, Livotov and Meyer, 2016), the ideas were assigned to the nine fields of MATCEMIBD knowledge domains: Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological and Data processing.

**Table 2: Four groups of experiment participants**

Group	Description
1	40 Bachelor students: 15 persons in 4th semester of Mechanical Engineering Degree and 25 persons in 4th semester of Process Engineering Degree.
2	25 Master's students enrolled into the Master's Degree in Mechanical Engineering in 8 <sup>th</sup> or 9 <sup>th</sup> semesters
3	Industrial group of 13 engineers from 8 companies: mechanical, electrical, energy, construction engineers and physicists involved in R&D activities.
4	Control group: 40 Bachelor students in 4th semester of the Bachelor of Mechanical Engineering Degree

## Results

As formulated by Shah et al (2003), to the objective measures of ideation effectiveness belong quantity, variety, and quality of proposed ideas. The quantity and variety of ideas were evaluated in the experiment. The assessment of the ideas quality and novelty has not been performed in this study.

### Quantity of proposed ideas

The quantitative analysis of the results in different groups, presented in the Table 3, undoubtedly shows that the cross-industry analogies can effectively support the ideation process.

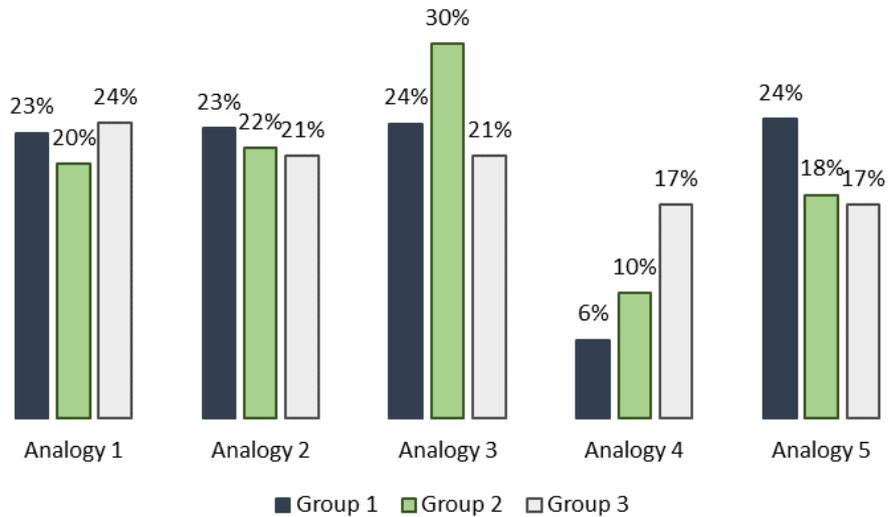
**Table 3: Quantity of ideas generated by participants from different groups**

Group	Number of participants	Total number of ideas	Number of different ideas	N. of ideas per person: Mean (SD)	Mean N. of different ideas per person
1 (Bachelor)	40	271	59	6.78 (SD=2.88)	1.48
2 (Master)	25	240	73	9.60 (SD=3.75)	2.92
3 (Industrial)	13	152	70	11.69 (SD=4.10)	5.38
4 (Control)	40	114	39	2.85 (SD=1.42)	0.98

The following are some outcomes of the Mann-Whitney Test that was used for the statistical comparison of responses in the experiments. A participant from each experimental group 1, 2 or 3 generated on average significantly more ideas than a student from the Control group 4: Control group 4 versus Bachelor group 1 with  $Z=-6.22$ ,  $p<0.001$ ; Bachelor group 1 vs. Master group 2 with  $Z=-2.97$ ,  $p<0.01$ ; Master group 2 vs. Industrial group 3 with  $Z=-1.40$ ,  $p<0.1$ .

The evaluation demonstrates also a higher degree of analogies-based creativity of the graduate students (group 2) versus the Bachelor students (group 1). Remarkably, there is no significant difference in the Bachelor group 1 in ideation productivity between 15 mechanical engineering students with 6.80 (SD=3.17) ideas per person and 25 process engineering students with 6.76 (SD=2.69) ideas per person. The Control group students did not propose any different ideas that were not generated by the students' groups 1 and 2 with the cross-industry analogies. At the same time, a direct comparison of different ideas from the groups 1 and 2 identifies 38 identical ideas only. Thus, the total number of different ideas proposed by the students from the groups 1 and 2 is 94. Comparing these 94 different ideas with 70 ideas of the Industrial group 3, one can identify 61 identical ideas. Therefore, the total number of different ideas generated in the experiment in the groups 1, 2 and 3 reaches 103.

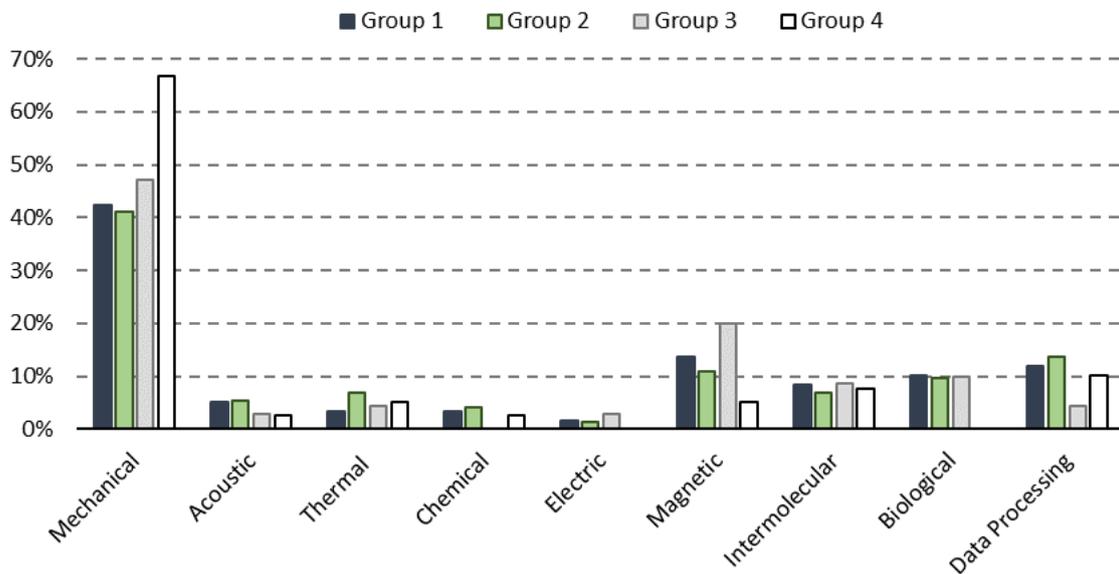
In general, the evaluation of the experiments confirms the advantages of applying all analogies. However, it is also interesting to compare the ideas productivity over cross-industry analogies. As presented in Figure 1, the Industrial group 3 has rather uniform distribution of ideas over all five analogies. On the contrary, the students in the groups 1 and 2 demonstrate their weakness in abstract thinking with the scaling-analogy N.4: Bachelor group 1 vs. Industrial group 3 with  $Z=-2.61$ ,  $p<0.01$ ; Master group 2 vs. Industrial group 3 with  $Z=-1.46$ ,  $p<0.1$ .



**Figure 1: Percentage of ideas created with different analogies (based on the total amount of ideas in each group of participants)**

### Variety of proposed ideas

In order to assess the variety of the ideas proposed in the experiment, the ideas generated in each group were assigned to the most appropriate knowledge domains or fields, using the MATCEMIBD classification. The distribution of different ideas over the nine MATCEMIBD categories in all groups is illustrated in Figure 2.



**Figure 2: Variety of different ideas and their distribution over the nine MATCEMIBD fields**

The students from the groups 1 and 2 proposed significantly broader ideas than the students from the Control group 4. Moreover, the students from the groups 1, 2 and the engineers show a similar distribution of their ideas over MATCEMIBD categories with exception of magnetic field and data

processing. Substantial differences are established in extraordinary high percentage of purely mechanical ideas (67%) and no biological ideas at all in the Control group 4.

### **Efficiency of ideation process using cross-industry analogies**

The number different ideas proposed in each group within one ideation session divided by the total number of the ideas in the session can characterize the efficiency of an ideation technique. This ideation efficiency value can be influenced by many factors and variables, such as qualification, experience, creativity, cultural and educational diversity of the participants but also by the number of group members. In the experiments the ideation efficiency doesn't exceed the value of 35% for the number of group members higher than 20.

Another parameter, which can be also used for ideation performance assessment, is the average time expenditures for one unique or different idea. This parameter was estimated for the Bachelor group 1 with 13.6 minutes, for the Master group 2 with 6.9 minutes, for the Industrial group 3 with 3.7 minutes, and for the Control group 4 with 20.5 minutes.

### **Discussion and Concluding Remarks**

The proposed course reveals the opportunities and challenges of the cross-industry innovation approach in the education and practice. The overall results of the study support the assumption that fast and easy-to-use ideation techniques based on five analogies can significantly improve idea generation outcomes both in the quantity and variety of proposed ideas. As estimated later in 6 industrial case studies, an interdisciplinary group of 15 engineers could generate with five analogies on average 78 different ideas per problem that corresponds to 5.17 unique ideas per person (SD=0.78) within 25 minutes. Smaller groups of the graduate students (3...4 persons per group) were able to generate in 7 educational projects on average 6.17 different ideas per person (SD=1.43) using 5 cross-industry analogies within 25 minutes, that corresponds to 21.7 different ideas per group.

The statistically significant empirical findings allow to recommend embedding the five analogies heuristic in engineering subjects dealing with product, process, service, or business model innovation. However, a profound education in advanced tools for cross-industry innovation, such as systematic web monitoring, function-oriented search, databases of technological effects, incl. application of the supporting software, is too time-consuming for one semester course and requires also a continuous supervising of individual students' work by the educators.

The study outlines that the ideation performance, based on the systematised analogical thinking, continuously grows with the engineering experience, and thus probably correlates with broader prior knowledge in the STEM subjects. The experiments show that the engineering creativity of students finishing the 4<sup>th</sup> semester of their Bachelor programs is lower than estimated values of the graduate students completing their Master's programs. At the same time, graduate students don't reach the benchmark performance of the interdisciplinary group of engineers. Even though the reasons for this finding are not sufficiently explored, the outcomes of the study should be taken into consideration by the educators in creativity and innovation.

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