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Measuring Motivation and Innovation Skills in Advanced Course in New Product Development and Inventive Problem Solving with TRIZ for Mechanical Engineering Students

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Abstract

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. It briefly describes the program of a novel one-semester-course of 150 hours in new product development and inventive problem solving with TRIZ methodology, offered for the master students at the Beuth University of Applied Sciences in Berlin. The paper outlines multi-source educational approach, which includes a new product development project (about 50% of the complete course), theory, practical work, self-learning with the software tools for computer-aided innovation, and demonstrates examples of the students work. The research part 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. It describes a method for measurement of education efficiency and compares the results with educational experience in the industry. The presented results can help universities to establish the education in new product development or to improve its performance.

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Keywords: TRIZ education at universities; new product development; inventive problem solving; measuring education efficiency; innovation process

1. 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 as well as academia [1, 3-9, 11-14], have gathered
considerable experience in traditional education approaches in the TRIZ methodology and innovation, such as face-to-face seminars, courses etc. Nevertheless the question, how to measure the enhancement of the student’s innovation and problems skills, still remains insufficiently explored. The recent research [15] 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.

This paper presents in short some results of the novel course in new product development and inventive problem solving with TRIZ methodology held in 2013 for the master students in mechanical and production engineering, which may be relevant for further improvement of student’s education.

The one-semester course has a total workload of about 150 hours, incl. 4 hours a week of lectures and practical work under guidance of a professor. The course combines a product development project (about 50% of the complete workload) with the traditional education forms and homework as described in the appendix A.

2. Measuring motivation and the growth of the student’s innovation skills

The estimation of initial motivation and of the total innovation skills of the students was performed in accordance with the universal mathematical model for numerical evaluation of innovation key figures, proposed by the author in [10, 16]. For this purpose a special questionnaire (see Table 1) with ten major innovation skills was offered to the students at the beginning and at the end of the course. At the beginning of the educational period, students have to evaluate their personal attitude about the importance $X_i$ of innovation skills and their current satisfaction with their own skills (initial skill performance $Z_i$), using a scale from 0% to 100% (100% - very high level of importance or performance, 80% - high, 60% - middle, 40% - low, 20% - very low import or performance).

Formula (1) allows one to calculate the initial motivation $p_i$ for each skill as a metric for the need of action in the learning process. The information about the skills with higher motivation $p_i$ values (column 3 in Table 1) is very useful for teachers to recognize the true needs of individual course participants and for learner-centered education. With the help of equation (2), another important metric, the initial total skills performance $V_I$ at the beginning of the course, can be calculated.

$$ p_i = \frac{(X_i + a X_i (X_i - Z_i)) (1 - Z_i)}{\sum_{i=1}^{n} (X_i + a X_i (X_i - Z_i))} $$

(1)

$$ V_I = \sum_{i=1,n} Z_i (X_i + a X_i (X_i - Z_i)) \sum_{i=1,n} (X_i + a X_i (X_i - Z_i)) $$

(2)

$p_i$ - initial motivation to improve a personal innovation skill, %;
$V_I$ - initial total skills performance at the beginning of the course, %;
$X_i$ - importance of the innovation skill, 0...100%;
$Z_i$ - initial skill performance at the beginning of the course, 0...100%;
$n$ - total number of skills learned in the course, $n = 10...20$;
$a$ - adjustment coefficient, $a = 1.0$.

At the end of the educational period, students are asked to evaluate the change in performance of each innovation skill and thus to estimate the final skill performance $Z_f$ with the following procedure: add 10% to the initial performance $Z_i$ for minor improvement of a skill ($\Delta Z_i = 10\%$); add 20% in cases of noticeable improvement of a skill ($\Delta Z_i = 20\%$); add 30% or more in cases of disruptive improvement of a
skill (see column 6 in Table 1). For estimation of final performance values $Z_f$, following absolute scale from 0% to 100% can be applied: 20% - very low performance, 40% - low, 60% - middle, 80% - high, 100% - very high level of performance. If for example the initial skill performance $Z_i$ was estimated with 80% ($Z_i = 80\%$) and the growth of performance as disruptive ($\Delta Z_i = 30\%$), the final skill performance $Z_f$ cannot exceed 100%. The final total skills performance $V_f$ can be estimated with formula (2) and then compared with the initial total performance $V_i$. The proposed approach reflects primarily the individual perception of students.

Table 1. Measuring motivation and effectiveness of a course by students (evaluation example for one course participant).

| No. | Innovation skills, to be trained in the course (list can be extended by learner) | Motivation $p_i$ [%] | Importance of skill $X_i$ [%] | Initial skill performance $Z_i$ [%] | Gain in skill performance $\Delta Z_i$ [%] | Final skill performance $Z_f$ = $Z_i$ + $\Delta Z_i$ [%] |
|-----|---------------------------------------------------------------------------------|----------------------|-------------------------------|---------------------------------|---------------------------------|-----------------------------------------------|
| 1   | Exact and well founded definition of tasks for new product development           | 4,3                  | 60                            | 40                              | 10                              | 50                                            |
| 2   | Solving of complicated “bottle-neck” technical problems                         | 5,6                  | 100                           | 60                              | 10                              | 70                                            |
| 3   | Cost reduction in all steps of innovation process and new product development    | 2,4                  | 60                            | 60                              | 20                              | 80                                            |
| 4   | Anticipatory detection of technical failures in new product concepts            | 5,6                  | 100                           | 60                              | 10                              | 70                                            |
| 5   | Fast and correct evaluation of ideas and innovation concepts                     | 3,9                  | 80                            | 60                              | 10                              | 70                                            |
| 6   | Enhancement of personal creativity in daily work                                 | 3,9                  | 80                            | 60                              | 10                              | 70                                            |
| 7   | Fast and systematic inventive problem solving                                   | 4,3                  | 60                            | 40                              | 30                              | 70                                            |
| 8   | Precise prediction of future technical product features                         | 2,4                  | 40                            | 40                              | 10                              | 50                                            |
| 9   | Systematic analysis of initial problem situation                                | 5,6                  | 100                           | 60                              | 20                              | 80                                            |
| 10  | Systematic solving of non-technical or organizational problems                  | 5,6                  | 100                           | 60                              | 10                              | 70                                            |

Initial total skills performance $V_i = 56\%$

Final total skills performance $V_f = 69\%$

Growth of total skills performance $\Delta V = V_f - V_i = 13\%$

Calculated with (1), (2) for $n=10$ and $a=1$

Importance / Performance scale: 20% - very low; 40% - low; 60% - middle; 80% - high; 100% - very high.

Added value scale for performance $\Delta Z$: 10% - minor, 20% - noticeable, 30% or more - disruptive improvement of a skill.

The comparison of the initial motivation of master students and the industrial course participants in accordance with the method described above is presented in the Table 2 and in Fig. 1.

Remarkably that at the beginning of the course the personal attitude about the total innovation skills of the students with $V_i = 56\%$ is higher than the personal average perception of same value for the engineers with $V_i = 51\%$. The further analysis (Table 2) reveals that the students show lower motivation in learning TRIZ methodology in comparison with the engineers, especially regarding the core TRIZ competences as a problem solving methodology, as illustrated in Fig. 1: fast and systematic inventive problem solving
(skill 3), systematic analysis of initial problem situation (skill 4) and solving of complicated “bottle-neck” technical problems (skill 5). These intuitively anticipated facts to a certain extent may be explained by the lack of the practical R&D experience of the most students.

Table 2. Comparison of the initial motivation of course participants - engineers vs. master students in the last year of education.

| No. | Innovation skill                                                                 | Importance Engineers $X_i$, [%] | Satisfaction Engineers $Z_i$, [%] | Importance Students $X_i$, [%] | Satisfaction Students $Z_i$, [%] | Motivation Engineers $p_i$, [%] | Motivation Students $p_i$, [%] |
|-----|-----------------------------------------------------------------------------------|----------------------------------|-----------------------------------|-------------------------------|-----------------------------------|---------------------------------|---------------------------------|
| 1   | Enhancement of personal creativity in daily work                                   | 76                               | 52                                | 81                            | 61                                | 4,2                             | 3,8                             |
| 2   | Exact and market-oriented formulation of tasks for new product development         | 83                               | 65                                | 81                            | 55                                | 3,2                             | 4,5                             |
| 3   | Fast and systematic inventive problem solving                                      | 88                               | 46                                | 83                            | 60                                | 6,3                             | 4,1                             |
| 4   | Systematic analysis of initial problem situation                                  | 81                               | 44                                | 90                            | 59                                | 5,7                             | 4,8                             |
| 5   | Solving of complicated “bottle-neck” technical problems                           | 82                               | 42                                | 75                            | 47                                | 6,1                             | 5,1                             |
| 6   | Precise prediction of future technical product features                            | 86                               | 53                                | 69                            | 40                                | 4,9                             | 5,3                             |
| 7   | Fast and correct evaluation of ideas and innovation concepts                       | 70                               | 41                                | 79                            | 55                                | 5,0                             | 4,4                             |
| 8   | Anticipatory detection of technical failures in new product concepts               | 88                               | 58                                | 88                            | 66                                | 4,4                             | 3,7                             |
| 9   | Systematic solving of non-technical or organizational problems                    | 82                               | 54                                | 80                            | 66                                | 4,4                             | 3,1                             |
| 10  | Cost reduction in all steps of innovation process and new product development      | 84                               | 52                                | 78                            | 49                                | 5,0                             | 5,1                             |

Fig. 1. Motivation of students and engineers to learn TRIZ skills (skills No. 1 - 10; s. description in the Table 2).
The different personal perception of the course efficiency by the students and the engineers is illustrated in the Fig. 2, which presents the final total skills performance $V_F$ as a function of growth of total skills performance $\Delta V$. By the end of the course the engineers reported the higher growth of their total innovation skills (average value of $\Delta V = 19\%$, estimated for 25 course participants), compared with the noticeably lower average $\Delta V$ value for the students ($\Delta V = 13\%$, estimated for 15 course participants).

Also the trend lines for both learner groups are opposite:

- the students learn more if their initial innovation skills were higher at the beginning of the course,
- the engineers with higher initial skills perceive less skill growth through the course.

For the engineers the education can be considered as successfully accomplished if at least one of the two following conditions is fulfilled:

1. $\Delta V \geq 15\%$ - the growth of total skills performance $\Delta V = V_F - V_I$ is higher than $15\%$.
2. $V_F \geq 70\%$ - final total skills performance $V_F$ is higher than $70\%$.

As the students seemingly cannot evaluate their initial innovation skills correctly, mostly due to the lack of practical experience in innovation and inventive problem solving, one can evaluate the result of the course as positive, if the total growth of skills $\Delta V$ is equal or higher than $15\%$.

Fig. 2. Final total skills performance $V_F$ and related growth of total skills performance $\Delta V$ for the reference groups of 15 mechanical engineering students (a) and of 25 industrial engineers (b)

3. Calculation of idea generation and problem solving skills

A method to calculate the idea generation and problem solving skills was proposed and introduced for evaluation of the self-learning work of students. In the self-learning trainings units (s. Appendix A) the students had to generate ideas for predefined tasks and problems with various recommended solution principles, such as inventive or separation principles, standards, operators of the AFI-method, evolution patterns and others. The students had to fulfil each problem solving exercise, obeying the following methodical rules:

- **Discipline**: transform technical systems and generate ideas only in the directions proposed by the inventive principles.
- **Creativity**: try to generate at least one idea with each recommended principle, even if the problem cannot be solved in one step.

Formula (3) allows one to calculate the Score $S$ for a problem solving exercise as a metric of corresponding innovation skill:

$$S = 0,5 \left( N_I + N_{PI} \right) / N_S$$
$N_I$ - total number of ideas, proposed for innovation task (metric of the discipline);
$N_{PI}$ - number of solution principles, to which at least one idea was generated (metric of the creativity);
$N_S$ - number of TRIZ solution principles recommended for innovation task.

The application of the formula (3) for one problem solving exercise is illustrated in the Table 3 and in Fig. 3. This calculation method may be especially very useful for the fast or computerized evaluation of student work in big classes with hundreds of proposed ideas.

Table 3. Estimation of the Score (3) for idea generation skills. (Example of an exercise: 395 ideas submitted by 37 students).

| Metric                                      | Min. Value | Max. Value |
|---------------------------------------------|------------|------------|
| Total number of proposed ideas $N_I$        | 8          | 16         |
| Number of solution principles, with at least one idea $N_{PI}$ | 8          | 11         |
| Number of recommended solution principles $N_S$ | 11         |            |
| Score for problem solving exercise $S = 0.5 (N_I + N_{PI}) / N_S$ | 0.73       | 1.14       |

Fig. 3. Distribution of the Score (3) for idea generation skills. (Example of a problem solving exercise fulfilled by 37 students).

4. A new product development project as a part of the course

In order to augment the student’s motivation to learn TRIZ, a new product development project with a workload of about 75 hours was offered during the course. The innovation project is modeling the early stage of a real industrial innovation process, starting with the 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 innovation project within a course was dedicated to the development of a concept for the innovative equipment of the lecture room or auditorium for about 100 students. The project includes two initial phases of innovation process - well founded definition of customer-driven innovation strategy, followed by the implementation of innovation strategy, as shown in the Table 4.
Table 4. 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 on the market | 6        | Systematic idea generation with TRIZ   |
| 2        | Functional analysis of the product      | 7        | Enhancement of ideas to solution ideas |
| 3        | Capturing desired customer benefits     | 8        | Evaluation of enhanced solution ideas  |
| 4        | Evaluation market potential of benefits | 9        | Innovation concepts development        |
| 5        | Formulation of the innovation strategy | 10       | Choice of the optimal innovation concept|

The method for customer-driven innovation strategy formulation and planning of R&D activities starts with the analysis of market and patents, followed by description of all the essential components of technical systems on the market with its useful functions and all undesired or negative properties (see Table 4, step 1 and 2). Based on known market or customers needs and the detailed functional analysis, a complete list of all thinkable innovation tasks has to be formulated (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. The top 6 customer benefits with highest market potential from a total number of 35 identified benefits are presented as example in the Table 5. They were used in the project as guidelines for definition of the innovation tasks and new concept development.

In spite of the fact that students themselves were the main target customer group of the project, the majority of students faced difficulties in the formulation of their own benefits or customer needs especially in the step 3. The proposed benefits were often closely associated with known technologies, or solutions, for example “enable on-line digital copies of lecturer’s notes on the white board” instead of “save of lecturer’s notes completely without efforts”. Sometimes the benefits were formulated too generally and not measurable for further development, for example “intuitive operation of the board and other devices”. Practically the same difficulties were faced also by the engineers taking the similar course. However the students, even working in the small teams of 4...6 persons, required significantly more teacher’s assistance. The resulting time losses did not allow accomplishing the second phase of the innovation project in the same semester.

Table 5. Example of the innovation strategy formulation (fragment; calculation method – see [10, 16])

| Benefits of customer group (students) | Market potential | Importance | Satisfaction | Critical segments |
|--------------------------------------|------------------|------------|--------------|------------------|
| Nr.                                   | Total product value: % | 56,6% | %          |
| 22 No reduction of image quality on the screen/board by the sun or the ambient light. | 2,8 | 91% | 38% | 92% |
| 19 All handwritten notes in class can be restored and shown again. | 2,7 | 89% | 37% | 92% |
| 6 Handwritten notes and formulas on the writing surface available as digital document. | 2,3 | 77% | 35% | 79% |
| 15 Excellent visibility and readability of the writing surface from any angle in the lecture room. | 2,3 | 96% | 50% | 74% |
| 12 Availability of power supply for each student. | 2,1 | 72% | 33% | 70% |
| 27 Minimize noise of the audience (eg. conversations) in the lecture room. | 2,1 | 89% | 47% | 78% |
5. Discussion of results

The experience in the realization of the educational course and the analysis of participants work and feedback allows one to summarize the following conclusions and recommendations for measuring motivation and innovation skills:

1. The students demonstrate 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.

2. The fast utilization of learned innovation skills in practice encourages the ability for self-directed learning and strengthens the motivation. A full-scale new product development project integrated in the course is too time-consuming for this purpose. One or two smaller real inventive tasks seem to be more promising for visible growth of student’s motivation.

3. The proposed methods to measure the enhancement of student’s innovation skills and to estimate the score for idea generation and problem solving work enable the accountable improvement and better control of the learning process.

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