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Web-Based Asynchronous Distance Education in New Product Development and Inventive Problem Solving for Industrial Companies

Pavel Livotov

Hochschule Offenburg - University of Applied Sciences, Department of Mechanical and Process Engineering,
Badstr. 24,77652 Offenburg, Germany

Abstract

Web-based learning is a rapidly growing area in education, which can offer a vibrant learning environment created using different teaching strategies, activities, and technologies. The paper addresses the needs of the industrial sector regarding the qualification of R&D specialists in using efficient techniques for successfully running an innovation process. It briefly describes the programme of a web-based course for asynchronous distance training in new product development and inventive problem solving with TRIZ methodology, which focuses on the main outcomes of learners - R&D leaders, engineers and product designers. The paper outlines a multi-source training approach and demonstrates different tools and educational methods, such as an interactive web-based learning platform, software tools for computer-aided innovation, and the design of instructions and manuals. Furthermore, it provides examples of training tasks and demonstrates the ideas proposed by the learners towards a solution. Finally, the paper presents a new approach for an innovation strategy formulation at the very early stages of new product development, which was also a part of the distance learning course. The research part of the article investigates the opportunities of asynchronous education, analyses the learning experience and underlines the main difficulties for engineers taking an asynchronous distance learning course. A special section describes a new method for the measurement of education efficiency. The presented results can help industrial companies to organize their internal education in innovation techniques or to improve its performance. The knowledge gained may also be interesting for trainers in systematic innovation and inventive problem solving.

Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC

Keywords: new product development; inventive problem solving; TRIZ methodology; anticipatory failure identification; innovation strategy formulation; web-based distance education; measuring education efficiency

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1. Introduction

The on-going qualification of R&D specialists and managers in using efficient techniques for successfully running an innovation process becomes very important for the competitiveness of enterprises, which resides in the ability of companies to continuously and profitably produce new products that anticipate the true requirements of customers and that meet the needs of the market. In the last decade, industrial companies [1, 13, 26], as well as academia [3, 4, 5, 6, 9, 11, 14, 21, 22, 25, 29], have gathered considerable experience in traditional education approaches in new product development and inventive problem solving, such as face-to-face seminars, courses etc. The potential, as well as the limits of web- based learning and training as a rapidly growing area in education, still remain insufficiently explored. For industrial companies especially, the asynchronous distance education could help in saving valuable time for specialists, giving them an opportunity to participate in a course at the time of their availability and convenience [26].

The recently developed distance learning course, with a total duration of 10 months, was offered for German speaking companies in 2009-2011 with about 50 participants a year. It consists of 10 obligatory training units with an estimated workload of about 8 to 12 hours per month and a complementary opportunity for learners to resolve their actual innovation problems under trainer supervision.

The numerous training tasks and examples of problems are focused on enhancing the following working skills by participants: contradiction-oriented way of thinking, optimal use of system resources, systematic and creative idea generation in cases of product development, process optimization and cost reduction, solving of bottle-neck problems, anticipatory failure identification, forecasting of possible future product features with evolution patterns, solving of non-technical business problems as well as formulation and implementation of customer-driven innovation strategy with an estimation of its market potential.

Obtained learning experience does not only allow us to emphasize the likely value of web-based distance training, but also allows us to identify the essential difficulties faced by instructors in developing and teaching the course. It also provides us with the opportunity to better understand the problems reported by learners. For example, despite prior expectations, the spatiotemporal isolation was a minor problem factor for participants in an asynchronous distance course. Acceptance of a continuous learning process and the availability of time resources within almost a year are the key aspects to be taken into consideration by the participants before taking a distance course. On the other hand, the trainers are committed to adapting and modifying instructional strategies to match the needs of individual course participants.

2. Research and practical tasks of the project

The preparation phase of the web-based training course for industrial learners (e.g. engineers, new product designers, innovation managers or researchers) was concentrated on following scientific and practical tasks:

- Well-founded selection of the competencies and skills to be learned or improved upon in the course,
- A range of examples and relevant problems for the broad circle of training participants who have different professional backgrounds,
- Estimation of reasonable workload and course duration considering the personal goals of learners,
- Development and adjustment of the web-based learning platform with integrated tools for product innovation and systematic problem solving.

The undertaking of the training course and the analysis of the work of the participants and their feedback had to provide detailed answers to the following questions:

- Is the asynchronous form of distance education suitable for training engineers in new product development and inventive problem solving?
- Which innovation tools and techniques are appropriate for asynchronous education and for successful application in practice with minor trainer's supervision?
- How to measure the enhancement of personal innovation and inventive skills by course participants and how to objectively evaluate the outcomes of distance education?

3. Definition of educational program

The selection of the competencies and skills to be learned during the course was undertaken using the results of the innovation study [20] carried out in more than 30 industrial companies. The following top 10 underserved needs of companies in new product development were gathered by conducting interviews with R&D leaders, innovation managers and engineers:

1. Fast idea generation and problem solving.
2. Solving of complicated “bottle-neck” technical problems.
3. Exact and well founded definition of innovation strategies and tasks for new product development.
4. Precise prediction of future technical product features.
5. Anticipatory detection of technical failures in new product concepts.
6. Cost reduction in all steps of the innovation process and new product development.
7. Minimization of organizational, personnel and financial risks in innovation projects.
8. Tracking of new technology trends and transferring technologies from other industries.
9. Fast and correct evaluation of ideas and innovation concepts.
10. Clearly arranged and readily available storage of all relevant data in an innovation process.

In accordance with the quantitative evaluation of the study [20], these innovation skills are of high importance for companies but the satisfaction level with their performance is low. Aiming for a higher performance level for the innovation skills listed above (see pos. 1-6), the 10-month educational program was proposed and undertaken in the distance learning course. The curriculum contains 10 trainings units and is presented in Table 1. It was mostly based on the methods of the Theory of Inventive Problem Solving (TRIZ), which is regarded today as the most comprehensive and systematically organized invention knowledge and creative thinking methodology [2, 17, 30]. The TRIZ tools can significantly assist in enhancing the performance of the majority of innovation skills selected for the distance learning course. Regarding the underserved need for a well founded definition of market-driven strategies for new product development, a new systematic approach for innovation strategy formulation was created in the course.

More than 30 problems and exercises in the course come from the industrial environment and were proposed predominantly by participants of earlier face-to-face educational seminars in systematic innovation. All training units provided learners a complementary opportunity to additionally resolve their actual problems with the gained skills while being under trainer supervision.

The average workload between 8 to 12 hours per month was estimated with the help of an initial questionnaire filled in by all participants at the beginning of the course. The questionnaire also helped to identify the competence level of participants, their personal goals and their expected outcomes.

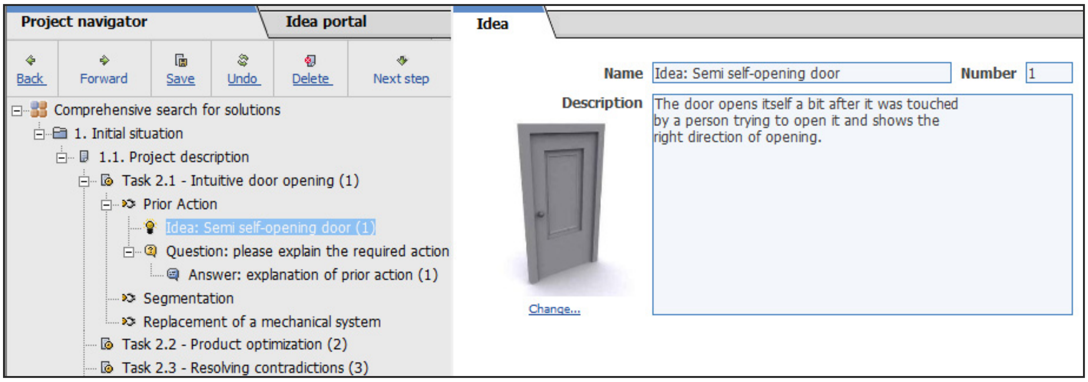
The educational materials contained methodical instructions and worksheets for each training unit in PDF and MS Word formats, a handbook in systematic innovation and inventive problem solving with TRIZ methodology [17] and the software TriSolver Idea Generator & Manager for off-line work. The complete course was available online on the web-based learning platform on the Internet, making it possible to access learning materials via the Internet at any time, both for learners and instructors.

4. Web-based learning platform

One of the goals of this project was to develop the educational web-based tools for asynchronous distance learning based on the available state-of-the-art internet technologies. This included the possibility to enable a personalized working space for course participants, therefore providing them with individual supervision by the trainer. The learning platform was built as a standard MS SQL database, combined with a web-based user interface with multi-user access.

Fig. 1 provides a practical example that illustrates the structure and realization of a training unit in the learning platform. The navigator on the left hand side of the screenshot displays the structure of the training unit with the all tasks, recommended solution principles, ideas and questions from the learners and the corresponding comments and answers from the trainer. All steps and results of the training process are continuously and fully documented and can be displayed as a table or exported into MS Excel or Word files.

In each training unit the learner have to read methodical explanations of the project description in the platform and the provided training materials (handbook, power point presentations etc.). They then have to start to analyze and generate ideas task by task via the Internet. During this work, they can formulate a question to the instructor or vice versa, the supervisor can give some ongoing recommendations directly in the work space of the learning platform. The web-based training environment makes it possible to access learning materials at any time, both for learners and instructors. For systematic idea generation and inventive problem solving, the learning platform contains a package of innovation tools of TRIZ methodology, such as: functional and contradiction analysis, inventive algorithm, 40 inventive principles, separation principles, anticipatory failure identification and trends of technical evolution. An easy-to-use interface and an on-line guide, help to introduce inventive techniques in the learning process and for learners to utilize them. The training approach and applied innovation methods are briefly explained in the next section.



- Comprehensive search for solutions
  - 1. Initial situation
    - 1.1. Project description
      - Task 2.1 - Intuitive door opening (1)
        - Prior Action
          - Idea: Semi self-opening door (1)
          - Question: please explain the required action
            - Answer: explanation of prior action (1)
        - Segmentation
        - Replacement of a mechanical system
      - Task 2.2 - Product optimization (2)
      - Task 2.3 - Resolving contradictions (3)

Name: Idea: Semi self-opening door
Number: 1
Description: The door opens itself a bit after it was touched by a person trying to open it and shows the right direction of opening.

Fig. 1. Realization example of the training unit 2 in the web-based learning platform.

A typical feedback loop demonstrating the instructor-trainee's question-answer-relation is shown in Fig. 1 under the Task 2.1 “How to open a door intuitively in the right direction - pull or push?”. While generating ideas with the help of recommended TRIZ innovation principles, a learner fails to find an idea with the principle of prior action, asks the instructor a question on the learning platform, receives an explanation a day later and finally proposes an idea of a door, which opens itself a little after the door handle has been touched. This initial short door movement makes the right direction of opening obvious. Another example of instructor-trainee communication is presented in the appendix.

5. Training units

As shown in Table 1, three levels of difficulty – low, medium and high - were anticipated by the trainer team for the 10 training units of the course. These levels correspond to the expected trainer support expenditures: level 1 – all tasks are almost self explanatory, level 2 – supervisor must support and give examples, usually at the very beginning of the training unit; level 3 – instructor has to guide learner in each step of the learning process.

The course starts with a lower difficulty level and ends with higher level training units. The same “principle of rising difficulty level” was also implemented within each training unit: easy tasks in level 1 at the start were followed by more comprehensive problems in level 2 or 3. For the training tasks of level 3, the learning materials with detailed step-by-step explanations and case studies were available online and off-line. The last task of each training unit provides the learner an opportunity to apply gained knowledge for solving any real technical problem, preferably in the field of their own professional competence under supervision of the instructor.

Table 1. Training units of the asynchronous distance learning course.

No.	Title of training unit	Number of tasks	Difficulty level, D_a*
1	Enhancement of personal creativity. Systematic contradiction-oriented way of thinking.	9	1 (low)
2	New product development and problem solving with help of contradiction analysis and TRIZ inventive principles. Part 1: Elimination of undesired properties and of harmful effects in new product development and product optimization.	4	2 (medium)
3	New product development and problem solving with help of technical contradiction analysis and TRIZ inventive principles. Part 2: Costs reduction and process optimization.	3	2 (medium)
4	Solving of difficult problems. Part 1: Short form of inventive algorithm ARIZ, identification of physical contradictions and their resolving with separation principles.	5	2 (medium)
5	Solving of difficult problems. Part 2: Comprehensive form of inventive algorithm ARIZ, including functional and resources analysis, identification and resolving of technical and physical contradictions.	2	3 (high)
6	Anticipatory failure identification: analysis of failures which happen for no apparent reason; prediction of potential failure scenarios for new products or processes.	5	2 (medium)
7	Prediction of future technical product features with evolution patterns of technical systems.	3	2 (medium)
8	Systematic search for solutions for non-technical tasks in business, management and service.	3	1 (low)
9	Formulation of customer- and market-driven innovation strategies with high success potential in the early stage of innovation process.	3	2 (medium)
10	Development of new product concepts with measurable innovation success. Systematic implementation of innovation strategies into solution concepts.	2	3 (high)

*) difficulty levels anticipated by the trainers: 1 (low) – tasks are almost self explanatory, 2 (medium) – supervisor supports at the very beginning of the training unit, 3 (high) – instructor has to guide the learner in each step of the learning process.

5.1. Training unit 1 – Basic skills

The first unit is dedicated to the enhancement of personal creativity and a development of a systematic contradiction-oriented way of thinking by the learners. The following techniques are to be applied and practiced within simple technical systems, such as portable umbrella, PC keyboard etc.:

- Task 1.1. Creativity operator size-time-costs-X (any other system parameter can be varied for X).
- Task 1.2. Formulation of technical contradictions and the corresponding ideal final results.
- Task 1.3. Principle and directions for increasing ideality in technical systems.
- Task 1.4. Principle of self-service and self-management.
- Task 1.5. Identification and mobilization of resources.
- Task 1.6. Principle of extraction and trimming of objects and functions.
- Task 1.7. Principle of universality.
- Task 1.8. Principle of converting harm into benefit.
- Task 1.9. Application of the trained techniques in tasks 1.1 – 1.8 for a system proposed by a learner.

5.2. Training units 2 and 3 – Work with inventive principles

The 40 inventive principles [2] are the most well-known and the most frequently applied TRIZ operators, which may be very successful in fast and systematic idea generation for solving simple to moderately difficult problems. In the course, the classical principles were extended with approx. 30 additional sub-principles [17], which were introduced as new positions in the numbered list, as the following example of the principle "*Inversion*" with additional sub-principle *d)* demonstrates:

a) Instead of performing an action dictated by the specifications, carry out the reverse action.
b) Make a moving part of the object or the outside environment fixed and the fixed part movable.
c) Turn the object upside down.
d) *Perform the process or its phases in the reversed order.*

The training tasks focused on the following types of problem solving skills:

- Guided brainstorming with innovation principles as a creativity workout.
- Elimination of undesired properties and of harmful effects.
- New product development and product optimization.
- Solving of contradictions in design and construction work.
- Process optimization.
- Costs reduction.

For each of the mentioned tasks, a specific group of 10 to 20 inventive principles was recommended for the learners. For example, a group of recommended principles for design problems includes principles of segmentation, extraction, local quality, asymmetry, combining, universality, integration, anti-weight, inversion, spheroidality, dynamism, shift to another dimension, mediator, flexible shells or thin films and composite materials. Such groups of task-oriented principles can be easily created in the database of the learning platform and remain at the disposal of the users.

The learner began each problem solving exercise with the identification of technical contradiction, corresponding ideal final result and of the system resources, obeying the following three methodical rules:

- *Discipline*: transform technical systems and generate ideas only in the directions proposed by the inventive principles.
- *Systemic approach*: consider three system levels for system transformation: sub-systems – system – super-system.
- *Creativity*: try to generate at least one idea with each recommended principle, even if the problem cannot be solved in one step.

The evaluation of hundreds of ideas proposed by learners in this part of the distance learning course confirms that the best results can be achieved if these rules are followed exactly by the learners. The fulfillment of this requirement belongs to one of the main challenges for instructors. For example, for the educational problem 2.1 "How to open a door intuitively in the right direction – to pull or to push?" the principle "Copying" delivers a clear idea *to put an optical copy (static or movable) of a half-opened door on a door leaf, which shows the right way to open it.* Precisely this solution was proposed by the majority of course participants, who consequently applied the inventive principles correctly.

In another task, learners can also judge the competitiveness of the contradiction matrix against the 10 statistically strongest inventive principles. With noticeable effort, they have to formulate several contradictions with the matrix for one problem situation, in order to form a set of recommended principles. The correct application of the matrix in this case provides a small number of principles, which were recommended 3 to 8 times (e.g. principle N.35 - 8 times; principle N.5 - 5 times, principle N.19 - 3 times etc.) and a longer list of principles which were recommended only once. Comparing this recommended set of principles with the list of 10 strongest principles, demonstrates that the matrix does not deliver any significant outcomes.

5.3. Training units 4 and 5 – Work with inventive algorithm

The inventive algorithm ARIZ, as one of the comprehensive tools, was gradually introduced in the course during two training units, at first in a simplified short form and then in the complete form including detailed functional and contradiction analysis of technical systems [17].

The inventive algorithm in the short form was presented in the course in the following five steps with the help of several educational problems with a continuously increasing difficulty level:

1. Identification of the main conflicting pair in technical system.
2. Formulation and amplification of technical contradiction.
3. Definition of the corresponding ideal final result.
4. Identification and formulation of physical contradictions.
5. Resolving of physical contradictions with separation principles.

This fast problem solving approach found a high acceptance rate among learners. The evaluation of the training experience outlines some desirable preconditions of its successful and correct application in the distance course:

- available catalogue of typical physical contradictions,
- clear definition of operative zone and operative time of contradiction,
- thorough application of separation principles with sub-principles, which help to look at a physical contradiction from different points of view and to subsequently generate ideas for a solution (examples for separation in space and in time are presented in the Table 2).

Table 2. Separation principles for resolving physical contradictions [17].

No.	Separation principle	Sub-principles for separation of contradictory properties
1	Separation in space	1.1. Separation of contradictory properties into *several levels, layers, tiers*. 1.2. Separation in *different directions*, e.g. axial, radial, tangential, horizontal, vertical. 1.3. Separation through utilisation of *two or three-dimensional structures*. 1.4. Separation through utilisation or creation of *voids* in system or super-system. 1.5. Separation through utilisation of the *external surface* area of objects in the system. 1.6. Separation through utilisation of the *reverse* side or *interior* surfaces of objects. 1.7. Separation through *integration* of objects, e.g. vertically, horizontally or in a circle. 1.8. Dynamic spatial separation *in motion*, e.g. by applying centrifugal forces.
2	Separation in time	2.1. Separation in time of contradictory properties into two or more *phases* or time periods. 2.2. Periodic *alteration* of contradictory properties with synchronization of frequencies. 2.3. Utilising the time *before* the process, e.g. one property is carried out *in advance*. 2.4. Utilising or creating *pauses*, e.g. one property is carried out in the pause. 2.5. Utilising the time *after* the process, e.g. one property is attained after finished process. 2.6. Consider chronological or periodic changes of properties within the super-system.

The tasks proposed for training of the short form of inventive algorithm were reduced to one conflicting pair, so the identification of the technical contradiction was quite obvious. Here are some examples of the educational problems:

- How to eliminate heating of PC-beamer?
- How to avoid sparking in a brushed DC-motor?
- How to reduce the water consumption of a washing machine?
- How to increase load capacity of roller bearing?

For the task “roller bearing”, some typical examples of resolving physical contradiction “cage between rollers *separates* them to reduce the friction - cage *doesn’t separate* rollers to increase load total capacity of bearing” are presented in Fig. 2.

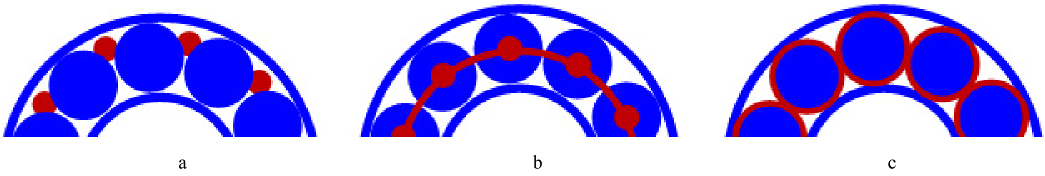


Fig. 2. Examples of resolving physical contradiction in space: (a) utilization of voids between rollers and outer ring; (b) separation in axial and tangential directions of bearing; (c) utilisation of the external surface of rollers.

Additional separation principles in the system’s structure, including separation by changing conditions and separation by phase transition (each with 4 sub-principles), were introduced in the training unit 5 in the complete form of inventive algorithm. The complete inventive algorithm was presented to the learners in two parts: 1. Problem analysis (10 steps) and 2. Search for solutions (16 steps). In spite of the availability of case studies and on-line instructions for training unit 5 the majority of learners had to be instructed by a supervisor in almost every step of the complete inventive algorithm. For example, the course participants were assisted in the correct definition of system components, their primary positive functions and negative properties, identification of a central technical contradiction in a system, abstract formulation of Ideal Final Result and physical contradictions.

5.4. Training unit 6 – Anticipatory failure identification

New production methods and systems often achieve an acceptable standard of reliability only after a large number of breakdowns. Therefore, methods of anticipatory failure identification (AFI), also known as “subversive analysis” [12, 15, 28], are growing in importance. Different to the existing quality control methods such as FMEA, HAZOP and others they help to determine the risk of potential breakdowns even when the experience is lacking. In the distance learning course the application of the AFI-method for analysis of previous failures, which happened for no apparent reason, was proposed to the learners. Another typical AFI-application, such as the prediction of potential breakdown scenarios for new products was offered as a facultative task.

Training unit 6 includes initially some introductory problems to be solved with the short form of AFI method, for example:

- explain the increased fuel consumption of an intact car after refuelling at a service station,
- explain seldom malfunction of the car rain sensor,
- explain the abrupt decrease in capacity of a notebook accumulator.

The short form of the AFI-method and typical difficulties of learners in its application are explained in Table 3. The analysis of typical learner difficulties shows that for a successful AFI application in the industrial practice a detailed step-by-step approach is practically unavoidable. Therefore, in the last task of the training unit the course participants had the opportunity to apply the complete AFI-approach available in the web-based learning platform. The majority of learners had to be instructed by a supervisor in practically each step of the method. The structure of the complete AFI-method with more than 70 steps provided in the learning platform is presented in Fig. 3.

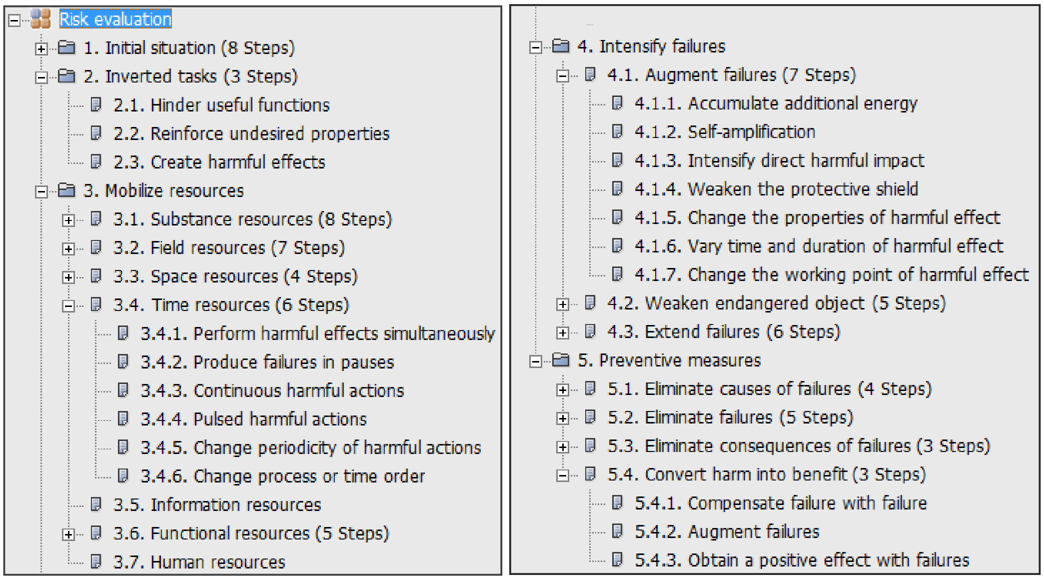
Table 3. Main steps of anticipatory failure identification (AFI) in the short form.

No.	Step of the AFI-method	Typical difficulties in the application of AFI-method
1	Formulate the inverted task: “What actions will definitely cause a system to fail?”	Unable to formulate the inverted task correctly, especially while analysing own practical problems.
2	Identify all resources of the system and the surrounding and use them for producing failures.	Important failure resources are often overseen.
3	Creative and systematic idea generation to produce failures. Use inventive principles and checklists of typical faults to find new “subversive” ideas.	Search for ideas is not systematic. Learners often forget the inverted task and tend to find ideas how to avoid failures.
4	Re-invert the problem formulation: failures, which possibly may occur at any time, have to be prevented.	Learners often skip the elimination of failure causes and concentrate their activities on the failure itself and elimination of its consequences.

5.5. Training unit 7 – Prediction of technical evolution

Training in the prediction of technical evolution was also separated into an introductory part and a comprehensive part. The introductory part was performed as a creative workout, enabling the generation of new possible product features with the recommended set of 12 augmented TRIZ inventive principles, which correspond to the main patterns of technical evolution: segmentation, combining, universality, dynamism, shift to another dimension, periodic action, feedback, self-service, replacement of mechanical system, pneumatic or hydraulic constructions, flexible shells or thin films, and porous materials. The learners, already experienced in the application of 40 inventive principles, succeeded in all proposed exercises.

On the contrary, the systematic and well structured application of evolution trends and checklists [17, 23] often provided with difficulties. Learners who were less experienced in TRIZ explained their problems as the lack of available information about the state-of-the-art of technical systems, unexpected high time expenditures and sometimes with too high a level of abstraction of the evolution laws.



- Risk evaluation
  - 1. Initial situation (8 Steps)
  - 2. Inverted tasks (3 Steps)
    - 2.1. Hinder useful functions
    - 2.2. Reinforce undesired properties
    - 2.3. Create harmful effects
  - 3. Mobilize resources
    - 3.1. Substance resources (8 Steps)
    - 3.2. Field resources (7 Steps)
    - 3.3. Space resources (4 Steps)
    - 3.4. Time resources (6 Steps)
      - 3.4.1. Perform harmful effects simultaneously
      - 3.4.2. Produce failures in pauses
      - 3.4.3. Continuous harmful actions
      - 3.4.4. Pulsed harmful actions
      - 3.4.5. Change periodicity of harmful actions
      - 3.4.6. Change process or time order
    - 3.5. Information resources
    - 3.6. Functional resources (5 Steps)
    - 3.7. Human resources
  - 4. Intensify failures
    - 4.1. Augment failures (7 Steps)
      - 4.1.1. Accumulate additional energy
      - 4.1.2. Self-amplification
      - 4.1.3. Intensify direct harmful impact
      - 4.1.4. Weaken the protective shield
      - 4.1.5. Change the properties of harmful effect
      - 4.1.6. Vary time and duration of harmful effect
      - 4.1.7. Change the working point of harmful effect
    - 4.2. Weaken endangered object (5 Steps)
    - 4.3. Extend failures (6 Steps)
  - 5. Preventive measures
    - 5.1. Eliminate causes of failures (4 Steps)
    - 5.2. Eliminate failures (5 Steps)
    - 5.3. Eliminate consequences of failures (3 Steps)
    - 5.4. Convert harm into benefit (3 Steps)
      - 5.4.1. Compensate failure with failure
      - 5.4.2. Augment failures
      - 5.4.3. Obtain a positive effect with failures

Fig. 3. Realization of the complete anticipatory failure identification (AFI) method in the learning platform.

5.6. Training unit 8 – Solving non-technical problems

The training in the solving of non-technical problems was focused on typical situations which can occur in R&D work, product management or marketing, such as:

- how to organize a meeting or conference without high time and personal expenditures,
- how to optimize an international joint-venture research and development project,
- how to improve acquisition activities for technical services.

Table 4. Double principles for resolving of non-technical problems (full description in [16]).

No.	Name of principle	No.	Name of principle
1	Combining – Separating	7	Standardisation – Specialisation
2	Symmetry - Asymmetry	8	Action - Reaction
3	Homogeneity – Diversity	9	Continuous – Interrupted action
4	Expansion – Reduction	10	Partial action – Excessive action
5	Mobility - Immovability	11	Direct action – Indirect action
6	Consumption – Regeneration	12	Prior action – Prior counteraction.

The 12 double principles for non-technical problems [16, 17] were recommended here as a tool for systematic idea generation and the resolving of organizational contradictions and conflicts (see Table 4). The principles also broaden the individual experiences and intuition of the managers and help them to quickly formulate several different solutions to difficult situations. Each principle represents two contradictory lines of action, which have to be taken into consideration when searching for solutions. There is no recommendation as to which action is the more suitable. The user is thus stimulated to think in a dialectic and creative way. The double principles can also be enhanced with the corresponding 40 inventive principles [16]. If physical contradictions were identified additionally during problem analysis, they could be resolved by separation in space or in time.

5.7. Training units 9 and 10 – Innovation strategy formulation and development of new product concepts

An exact and well founded definition of an innovation strategy as one of the crucial tasks in the new product development was offered in training unit 9, followed by the implementation of innovation strategy in training unit 10. Although the step-by-step method was undertaken in the learning platform, including on-line help and accompanying materials with explanations and examples, less than 20% of learners successfully completed these training units. These were planned as the final piece of work for the distance learning course. The individual steps of the method and the corresponding level of supervisor assistance expenditures are presented in Table 5.

The method for customer-driven innovation strategy formulation and planning of R&D activities, which was taught in the course via learning platform, is based on the thoughts and approaches published in [7, 8, 10, 18, 19, 24, 27]. It starts with description of all the essential components of a technical system on the market with its useful functions and all undesired or negative properties (see Table 5, 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 [10], which are independent from known technologies or solutions and correspond to further improvement of positive functions or to the elimination of negative properties. Especially in step 3, the majority of learners faced difficulties in the formulation of benefits. The proposed benefits were often closely associated with known technologies, for example “utilize flash drive in notebook” instead of “shorten laptop's boot time”. Sometimes the benefits were formulated too generally, for example “increase mechanical reliability of notebook” instead of “increase shock resistance in case of laptop falling”.

Table 5. Structure and estimated difficulty level of the training units 9 and 10.

Step No.	Training unit 9 – Innovation strategy formulation	Difficulty level, d *	Step No.	Training unit 10 – Innovation concept development	Difficulty level, d
1	Initial situation analysis on the market	1	6	Systematic idea generation with TRIZ	2
2	Functional analysis of the product	3	7	Enhancement of ideas to solution ideas	3
3	Capturing desired customer benefits	3	8	Evaluation of enhanced solution ideas	3
4	Evaluation market potential of benefits	3	9	Innovation concepts development	3
5	Formulation of the innovation strategy	2	10	Choice of the optimal innovation concept	2

*) estimated difficulty levels: 1 – tasks are self explanatory, 2 – supervisor must support at the very beginning of work on a training task, 3 – instructor has to guide the learner in each step of the learning process.

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). In practice, market surveys and customer interviews can be used additionally for the final estimation of importance and performance values of benefits. Obtained importance and performance values allow one to calculate the market potential for each benefit p_i (1), defined as its maximum contribution in the total growth of current product performance V (2). Identifying benefits with high market potential helps to formulate successful innovation strategies for new product development. A strategy with chances of high success in market should assure the anticipated growth of total product performance V of 15% or more.

$$p_i = \frac{(X_i + a\,X_i\,(X_i - Z_i))\,(1 - Z_i)}{\sum\limits_{i=1,n}(X_i + a\,X_i\,(X_i - Z_i))} \qquad (1)$$

$$V = \sum_{i=1,n} \frac{Z_i\,(X_i + a\,X_i\,(X_i - Z_i))}{\sum\limits_{i=1,n}(X_i + a\,X_i\,(X_i - Z_i))} \qquad (2)$$

p_i - market potential of benefit, %;
V - total product performance, %;
X_i - importance of benefit, 0…100%;
Z_i - current performance of benefit, 0…100%;
n - total number of benefits, n = 20…60;
a - adjustment coefficient, a = 0,5…2,0.

The recommended value of the adjustment coefficient $a = 1$, corresponds to the following conditions of the innovation opportunity metric $f(X_i;Z_i)=X_i+(X_i-Z_i)$ as a function of any fixed importance X_i const and performance Z_i, which may be considered as typical for the majority of practical cases [18, 27]:

$$f\,[X_{i\,const};\, Z_i=X_{i\,const}] = 0{,}5\, f\,[X_{i\,const};\, Z_i=0] \qquad (3)$$

Selected customer benefits with high market potential p_i form the innovation strategy (step 5) and create a pool of innovation tasks for systematic idea generation with the help of inventive principles in step 6. After ideation process, proposed ideas have to be condensed to the stronger solutions (step 7). For each task, at least two solution ideas have to be generated in the distance learning course.

Customer benefits also provide objective basis for idea evaluation directly in relation to the added value each solution delivers to the customers (step 8). The value of an idea is 100% if a customer benefit is satisfied to 100%. Additional evaluation criteria such as implementation and development expenditures, costs of the future product, risk of possible failures or malfunctions can also be taken into consideration.

To develop a new product concept, the most valuable idea must be selected for each customer benefit. The synthesis of a concept in step 9 is completed if suitable complementary solutions were chosen for each benefit. 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 and optimization of preferred innovation concept in step 10.

6. Measuring the efficiency of learner-centered education

In their feedback, course participants reported on the considerable enhancement of personal innovation and inventive skills. Nevertheless, objective evaluation of distance education outcomes and efficiency remains a significant task for the systematic improvement of the learning process.

Table 6. Measuring effectiveness of distance course by learners (evaluation example for one course participant)

No.	Innovation skills , to be trained in distance course (list can be extended by learner)	Enhancement potential p_i [%]	Importance of skill X_i, [%]	Initial skill performance Z_{Ii}, [%]	Gain in skill performance ΔZ_i, [%]	Final skill performance $Z_{Fi}=Z_{Ii}+\Delta Z_i$, [%]
1	*2*	*3*	*4*	*5*	*6*	*7*
1	Exact and well founded definition of tasks for new product development	8,2	80	40	20	60
2	Solving of complicated “bottle-neck” technical problems	5,2	60	40	20	60
3	Cost reduction in all steps of innovation process and new product development	5,2	60	40	10	50
4	Anticipatory detection of technical failures in new product concepts	5,2	60	40	30	70
5	Fast and correct evaluation of ideas and innovation concepts	4,7	80	60	10	70
6	Enhancement of personal creativity in daily work	4,7	80	60	30	90
7	Fast and systematic inventive problem solving	4,7	80	60	30	90
8	Precise prediction of future technical product features	4,7	80	60	10	70
9	Systematic analysis of initial problem situation	1,9	80	80	20	100
10	Systematic solving of non-technical or organizational problems	1,6	40	60	10	70

Initial total skills performance V_I = 54% *Final* total skills performance V_F = 73%

Growth of total skills performance $\Delta V = V_F - V_I = 19\%$ *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 ΔZ: 10% - minor, 20% - noticeable, 30% or more - disruptive improvement of a skill.

Based on the numerical approach presented in chapter 5.7, a special questionnaire (see Table 6) was offered to the learners at the beginning and at the end of the course. This checklist includes 10 main innovation and inventive skills to be taught during the course, and it can be also extended by the learners. 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_{Ii}).

Formula (1) allows one to calculate the improvement potential p_i for each skill as a metric for the need of action in the learning process. The skills with higher p_i values are presented in the top part of column 3 in Table 6. They reveal the motivation and main opportunities for enhancing the innovation expertise of learners. This information is very useful for instructors 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.

At the end of the educational period, learners are asked to evaluate the change in performance of each innovation skill and thus to estimate the *final* skill performance Z_{Fi} with the following procedure: add 10% to the initial performance Z_i for minor improvement of a skill (ΔZ_i =10%); add 20% in cases of noticeable improvement of a skill (ΔZ_i =20%); add 30% or more in cases of disruptive improvement of a skill (see column 6 in Table 6). For estimation of final performance values Z_{Fi} 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_{Ii} was estimated with 80% (Z_{Ii}=80%) and the growth of performance as disruptive (ΔZ_i =30%), the final skill performance Z_{Fi} cannot exceed 100%.

Now 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. The course can be considered as successfully accomplished if at least one of the two following conditions is fulfilled, as is illustrated for the reference group of 25 learners in Fig. 4:

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%.

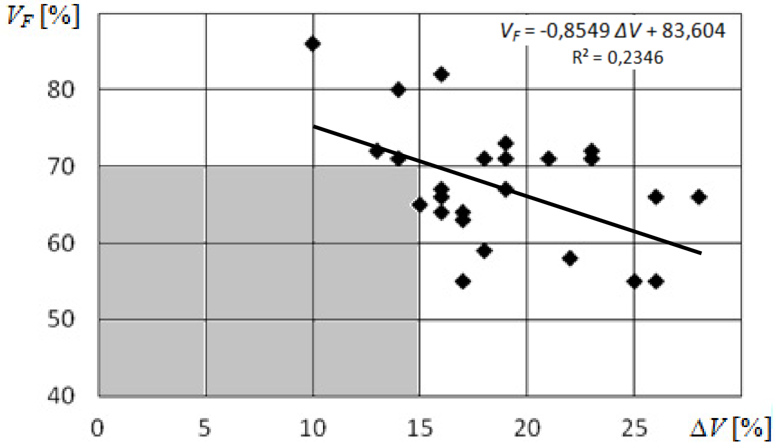


Fig. 4. Final total skills performance V_F and related growth of total skills performance ΔV for reference group of 25 learners.

7. Discussion of results

To evaluate which innovation tools and techniques are suitable for asynchronous education, the factual difficulty level of the training tasks can be compared with learner retention rate (see Fig. 5). The retention rate is an important gauge of any educational course success. It indicates the percentage of learners who remain at an educational course after they begin studying there. A high retention rate suggests a course is supportive and enjoyable and that the workload is manageable.

The average difficulty level D of the training course with number of training units n and number of tasks k_i in a training unit can be interpreted as the supervisor's assistance expenditures and calculated as follows:

$$D = \sum_{i=1,n} \frac{D_i}{n} = \sum_{i=1,n} \frac{\sum_{j=1,k_i} d_{ij}}{n \cdot k_i} \tag{4}$$

D - difficulty level of the training course;
D_i - difficulty level of the training unit;
n - number of training units;
d_{ij} - average difficulty level of a task;
k_i - number of tasks or steps within a training unit.

Estimation of factual difficulty levels D_i of training units with proposed procedure (4) demonstrates the highest rates of course abandonment in training units with difficulty $D_i > 2,5$ (see Fig. 5). The factual difficulty level of the complete training course $D=2,3$ was calculated for the reference group of 25 learners, who successfully completed the course. It is higher than the earlier anticipated difficulty level $D_a=2,0$ based on the involvement of the instructors, as shown in the Table 1. Therefore, the learner's perception of the course difficulty deviates from the estimation of instructors. Many learners expected an "easy" online course, which they can add to an already full schedule, incorrectly assuming that the complexity of course is lower than face-to-face education.

Together with the often reported lack of time resources of learners and lack of self-discipline for continuous learning within 10 months, the high difficulty of some tasks seems to be responsible for the low retention rates of the distance learning course. Also of importance is the fact that practically all students who successfully finished the course had prior practical experience in TRIZ methods, which were gained through conventional presence learning forms such as one-day seminars or introductory presence courses.

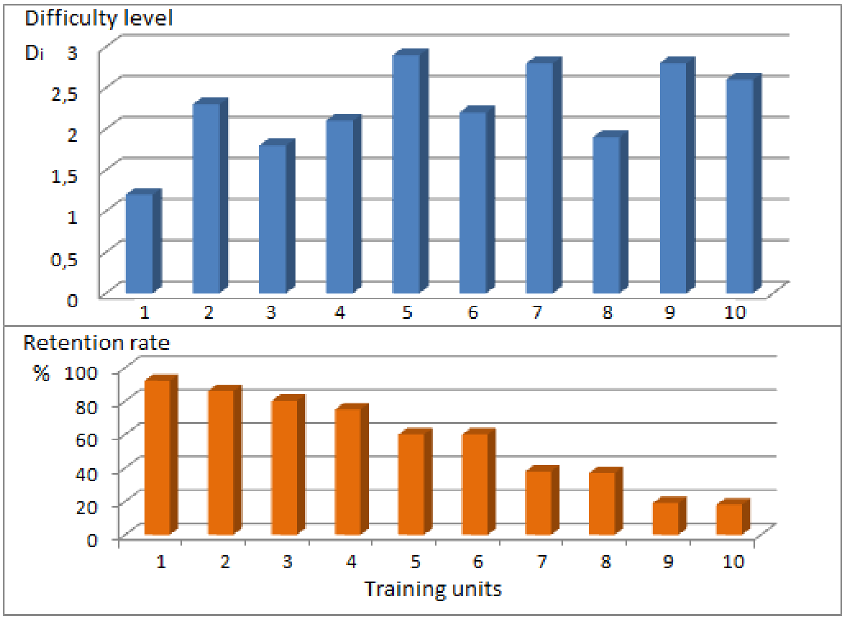


Fig.5. Comparison of estimated difficulty level *Di* of training units and corresponding retention rate in the distance course.

The first three research questions that guided this project were:

- Is asynchronous distance education appropriate for training in new product development?
- What is the optimal workload and course duration?
- What innovation tools and techniques are suitable for asynchronous education?

The experience in the realization of the training course and the analysis of participants work and feedback allows one to summarize the following conclusions and recommendations:

1. The asynchronous form of distance education is, in general, suitable for training in new product development and inventive problem solving within industrial companies. However, introductory one-day presence seminar for learners is recommended in order to reduce psychological barriers at the beginning of the distance learning course.
2. The integration of the asynchronous distance learning courses with conventional face-to-face teaching programs appears particularly promising, since it encourages and strengthens the ability for self-directed learning and the fast utilization of skills learned in practice.
3. The duration of the distance course for industrial learners with over-booked schedules should not exceed 5 to 6 months with a maximum workload of 2 hours a week.
4. The total number of tasks within a training unit should not exceed 4 to 5 tasks, in order keep a training unit clear and its workload manageable for learners and supervisors.
5. Instructors should motivate learners actively for a continuous learning process. If learners fall behind or abandon their work during the course, the trainer should help “to get them back on track”. In addition to the typical educational loop “learner asks → trainer answers”, the course administration has to ensure that all trainers’ requirements and recommendations are completely fulfilled by the learners.
6. By the selection of innovation methods a practical rule “Train in an asynchronous distance learning course only such methods, which can be *easily* explained in face-to-face training” can be helpful.
7. Tasks or methods with a high difficulty level, which require continuous instructor’s assistance to the learner in each step of the learning process, lead to high retention rates and should be avoided in the asynchronous distance course. To such innovation methods belong invention algorithm in its complete form, prediction of technical evolution with evolution patterns and the innovation strategy formulation (see training units 5, 7, 9 and 10). Face-to-face seminars or workshops are more efficient here.
8. Training units 1, 2, 3, 4, 6, 8 can be combined to the 6 months distance course with anticipated retention rate of about 70% to 80%, which is typical for e-learning or online education. Hence, such important innovation techniques and methods including inventive principles, separation principles and anticipatory failure identification can be successfully integrated into asynchronous distance education.
9. Spatiotemporal isolation is a minor problem factor for participants of asynchronous education if the trainer can comment on the results or answer questions on the web-platform within 1-3 days. On the other hand, the trainer is committed to adapting and modifying instructional strategies to match the needs and availability of time resources of individual course participants. For example, some essential aspects or questions can be also discussed by phone or, if possible, in short face-to-face sessions along the course. On the other hand, a manual with examples of solutions for typical training tasks reduces the time expenditure of instructors. Learners can compare their analytic or ideation work with solution samples and, if necessary, correct or complete their answers themselves.
10. A proposed approach to measure the enhancement of learner’s innovation skills and to evaluate the effectiveness of distance course enables systematic and accountable improvement of the learning process.

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Appendix A. An example of instructor-trainee asynchronous communication by means of web- based learning platform

In addition to the typical educational loop “learner asks "" trainer answers” mentioned in section 4, this example demonstrates another learner-trainer-relation in which the instructor has to check and comment on the trainee’s work in the learning platform on the one hand, and the learner is committed to react to all instructions on the other hand. It sometimes takes a lot of patience and effort, both for the instructor and the learner, in order to progress within a distance learning course.

The example below relates to Task 4.3 of Training Unit 4 “Problem solving with the short form of inventive algorithm ARIZ” and illustrates characteristic difficulties for learners in the first step of ARIZ “1. Identification of main conflicting pair in technical system” (s. also section 5.3). Two interventions from the instructor were necessary before the methodically correct formulation of the conflicting pair was finally proposed by the learner in the 3rd variant of the answer.

Task 4.3: How to reduce water and energy consumption of a conventional washing machine in cases of low filling level of the washing drum with laundry items, for example while washing only one small item?

Variant of the answer	Answer or formulation proposed by the learner	Intervention of the trainer (instructions or recommendations)
1	Conflicting pair: water and energy consumption versus size of the washing drum.	Consumption of water or drum size is not a component of a washing machine. Thus they cannot build a conflicting pair. Please look for a proper formulation.
2	Conflicting pair: low filling level of laundry items - washing drum.	Please list all essential components of the technical system “washing machine” and analyse what two components are mainly responsible for the problem.
3	Components: housing, washing drum, drive, controller, heater, water pump, water, detergent, laundry item ... Conflicting pair: washing drum – laundry item. Question: Is this correct?	Correct! In the next step please formulate and enhance the technical contradiction for this conflicting pair.

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