TRIZ based tools for knowledge creation

Boris Zlotin
Alla Zusman

Introduction

Effective tools and processes for knowledge creation and innovation suitable for mass implementation within R&D divisions of large corporations are becoming a critical issue in the success of handling recent crisis of innovation[1]. The following scientific problems and situations require creative approach:

- Discovering new events, effects and phenomena
- Integration and hybridization of knowledge and ideas from different areas
- Create a model of a theory explaining a new event or a phenomenon
- Plan and develop experiments, an effective system for measurement, a method for processing information, etc.
- Finding new applications for new effects

Utilization of TRIZ approach to science has its own history[2]. In 1960 TRIZ founder Genrich Altshuller distributed his paper "How scientific discoveries are made", in which he formulated the basic approaches to development of methods for solving scientific problems[3]. In particular, he identified two classes of discoveries:

- Class 1 - Discovery of a new phenomenon or a fact
- Class 2 - Finding an explanation to a new phenomenon or a fact with unclear mechanism or nature

Based on analysis of limited number of both types of discoveries, he formulated about 10 useful recommendations helping make discoveries of the class 1 and 8 recommendations for class 2.

Later a proficient TRIZ specialist and educator Volyuslav Mitrofanov suggested the method of utilization of Patterns and Lines of Evolution for discovering new physical, chemical, etc. effects[4].

In this article, we would like to introduce certain tools, techniques and algorithms that have been in development and successfully utilized since the mid 1980s .

1 Zlotin, Boris and Alla Zusman. Directed Evolution of R&D organizations. (These proceedings).
[2] Zlotin, Boris, et al. "TRIZ Beyond Technology." *Proceedings from TRIZCon2000*. Worcester, Mass.: The Altshuller Institute for TRIZ Studies, 2000.
3 Genrich Altshuller. How scientific discoveries are made. Manuscript, 1960. Published later in the collection of works Solving Scientific Problems, Kishinev: STC Progress in association with Kartya Moldovenyaska, 1991. (In Russian).
[4] Volyuslav Mitrofanov, *From Manufacturing Defect to Scientific Discovery*, St. Petersburg: TRIZ Association of St. Petersburg, 1998.

Integration and hybridization of knowledge and ideas

It is well known that integration is one of the most effective methods of producing new theories from existing ideas (sometimes opposite ones). For example, complementary principle introduced by the famous physicist Niels Bohr. To ensure effective integration, a special hybridization methodology has been developed in TRIZ[5].

Hybridization is a specific process for combining different systems to build a new one. It is an important means by which both biological and scientific and technological systems evolve. Regarding evolution as a permanent process of hybridization helps us to understand that evolution relates to a family of systems (e.g., a population of fighter planes) rather than a specific one (the F-16 airplane, for example). Very often the evolution may be presented through a feature exchange (solutions, designs, specific technologies and processes, etc.) between family members. The hybridization technique provides the following advantages:

- The possibility of advancing a system through incremental, easy-to-accept steps.
- Exchanging proven and readily-available solutions and sub-systems between different systems accelerates evolution and increases the probability of successful implementation.

Besides the pure technological advantages, hybridization can be a strong psychological approach that provides:

- A new “big picture” of technology as a world of dynamic, flexible and prone-to-integration hybrids.
- The capability to easily, and without psychological pressure, mentally “disassemble” a complex system and reassemble it in a different way.
- A reduction in psychological inertia that enables you to critically analyze your own system and compare it to competing systems, and then trying to hybridize.

Create a model or a theory explaining a new event or phenomenon

Solving scientific problems and generation of new scientific concepts are based on the same approach named Problem inversion. The essence of Problem Inversion is simple: instead of asking *“How can a certain phenomenon be explained?”* one asks *“How can this phenomenon be produced under existing conditions?)* The problem therefore becomes a typical inventive problem and can be attacked using existing TRIZ tools. Based on this approach, the process has been developed for generating (building) new scientific concepts. The method includes the following steps:

- Formulate the original problem
- Problem amplification
- Problem inversion

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[5] Gerasimov, Vladimir, Gafur Zainiev, Ph.D. and Valery Prushinsky. *Hybridization of alternative systems.* TRIZ in Progress, Ideation International Inc, 1999, p.p. 221-224.

- Search for creative hints
- Utilization of resources
- Formulation and verification of obtained hypotheses

For more detail description, see Appendix 1.

Building new scientific concepts

In many situations, obtaining one or more explanatory mechanisms is enough for practical purposes. In other situations, a comprehensive new concept is needed. And algorithm including the following steps is recommended for concept development:

- Analysis of an existing system
- Synthesis of a new concept
- New hypothesis verification
- Further development of the new concept

The methodology was applied to build our own concepts in the following areas:

- Organization theory[6]
- Brain for evolution (a concept related to the theory of biological evolution)[7].

For more detail description, see Appendix 2.

Create experiments

Often verification experiments can be costly and time consuming. In these cases, TRIZ can offer knowledge base related to creative measurement and detection starting from certain Innovation Principles and Standard Solutions developed by Genrich Altshuller in the beginning of 1960s and the mid 1980s respectively. Today, a special module *Development and improvement of systems for measurement and control* including over 50 Operators (recommendations) is available to support this activity[8].

For selected recommendations, see Appendix 3.

Finding new applications for new events and effects and/or for preventing or eliminating harmful effects

Once the mechanism of a phenomenon is clear, one can consider the following:

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[6] See certain elements of the theory in Zlotin, Boris and Alla Zusman. *Directed Evolution: Philosophy, Theory and Practice*. Ideation International, 2001. Appendices 8and 9.
[7] To be published.
[8] The module is incorporated in the software Innovation Workbench (IWB) ® system.

- Find a useful application for the phenomenon
- Amplify the phenomenon
- Prevent undesired effects or eliminate its harmful consequences
- Create a method for the phenomenon early detection

For more detail, see Appendix 4.

Case studies

Production of micro-wire

This case study is based on the first scientific problem solved with the utilization of the technique *Create a model or a theory explaining a new event or phenomenon* (Appendix 1) by our student Mr. Anatoly Yoisher in 1984[9]. Mr. Yoisher applied the technique to a critical problem in the area of micro-wire production that had gone unresolved for more than 15 years.

Micro-wire contains metal core in glass insulation. Micro-wire production includes the following operations:

A portion of metal is placed in a thin glass pipe and is heated by microwaves. In the process of heating metal is melting and the glass to softening.

A glass rod touches the soften glass of the pipe that sticks to the rod. The rod is pulling the glass and attaches it to a rotating drum.

Rotating drum continues pulling and winding the glass capillary with the metal inside.

The method described above has been successfully utilized for producing micro-wire from over 50 various metals and allows. However, for the last 15 years, the company has failed to produce a micro-wire from a very important Indium-Antimony (In-Sb) alloy. For unknown reasons, the pulled micro-wire ruptured into small (0.5 mm) pieces. Under the microscope, these pieces looked pierced from inside out by thin metal needles.

It was known that In-Sb alloy differed from other metals that did not cause any troubles as it increased in volume during solidification by 18%. It was suspected that this property could contribute to the problem, however, it was unclear how. Extensive experimenting with the kind of glass, microwave power and cooling modes has resulted in increasing the pieces to 2.5-3 mm, while the minimum requirement was about 250 mm (10").

9 Genrich Altshuller, Boris Zlotin, Alla Zusman and Vitaliy Philatov, *Searching for New Ideas: From Insight to Methodology* (Kishinev: Kartya Moldovenyaska Publishing House, 1989, in Russian): 124.

After the problem inversion (How to destroy micro-wire?), Mr. Yoisher was forced to a conclusion that the best way to force the metal pierce the glass is to plug the capillary and increase internal pressure (for example, using the plug as a piston). It looked rather stupid, so he was close to give up. However, he has managed to make the next step.

The next step recommended looking for analogies and creative hints in other areas. In this case, it was rather easy, as Mr. Yoisher recalled how a bottle that he had left on his balcony during the winter got ruptured. The analogy helped overcome the psychological barrier.
The list of available resources was rather limited and included the alloy (liquid and solid) inside the glass capillary and its properties (unique feature of the In-Sb allow is to .

The easiest way to create a plug was to use the solidified alloy. The next inverted problem sounded as follows: How to force liquid metal solidification in at least two places with the liquid in between? As an experienced scientist, Mr. Yoisher has quickly realized that a well known effect of overcooled liquid behavior could be utilized.

When a very pure liquid (in this case, no crystallization centers are available) is being slowly cooled, the liquid can stay liquid under temperature much lower that the usual crystallization point. For example, when the usual distilled water is slowly cooled it can stay liquid until 20F (-10C). At the same time, the overcooled liquid can momentarily solidify under a very weak impact. For example, it is enough to click the glass with the overcooled water with a nail to turn it into ice in moment.

The following mechanism of the capillary rupture has been offered:

The liquid alloy in the capillary is overcooled to a temperature much lower than crystallization point. At a certain moment the solidification starts in a certain zone; increased volume of the alloy creates a compressions wave in liquid metal. The wave can create a new crystallization zone at a certain distance from the first one. Emerged crystallization fronts travel towards each other compressing the liquid. Under the pressure liquid metal can pierce the glass eventually breaking it when the two crystallization fronts come close.

Compression wave can create more than one crystallization zones. It is also important that additional zones always emerge at a certain distance, as additional latent heat is released in the crystallization zones, heating the alloy.

Emergence of multiple crystallization zones causes micro-wire rupturing into small pieces. It explained the reason why many years of experimenting resulted in limited increase of the pieces length, but could not resolve the situation completely.

Mr. Yoisher became very interested in revealed new mechanism as overcooling could be seen in other metals as well. It became rather clear how the hypothesis could be tested. Specialists in the area know that crystallization creates a weak luminescent light. The first attempt to view the crystallization process for different metals under the microscope showed several light spots. However, metals (alloys) that did not significantly expand under solidification did not cause capillary rupture.

How the newly revealed mechanism could contribute in the process of production of micro-wire from In-Sb alloy? Apparently, that oppositely to the existing practice, the cooling should be rather abrupt than gradual to prevent creation of an overcooled liquid effect. It was a very strange idea that contradicted all experiences and existing theories…

Mr. Yoisher spent about four hours for removal of complex device providing gradual cooling. Instead, he applied two cold water streams to the micro-wire – and obtained 15 meters of wire from the first attempt (used all available alloy material).

But the main benefit of the solution (besides completing Ph.D. dissertation and the possibility to quickly begin production of a new type of micro-wire) was that new mechanism of overcooled liquids in a capillary allowed to better understand why micro-wire from certain metals has unstable electrical and mechanical parameters and substantially improve the quality of all types of micro-wire produced.

Appendices

1. Create a model or a theory explaining a new event or phenomenon
2. Building new scientific concepts
3. Create experiments
4. Finding new applications for new events and effects and/or for preventing or eliminating harmful effects

References

1. Altshuller, Genrich, Boris Zlotin, Alla Zusman and Vitaliy Philatov, *Searching for New Ideas: From Insight to Methodology* (Kishinev: Kartya Moldovenyaska Publishing House, 1989, in Russian)
2. Altshuller, Genrich. How scientific discoveries are made. Manuscript, 1960. Published later in the collection of works Solving Scientific Problems, Kishinev: STC Progress in association with Kartya Moldovenyaska, 1991. (In Russian).
3. Zlotin, Boris and Alla Zusman. Solving Scientific Problems, Kishinev: STC Progress in association with Kartya Moldovenyaska, 1991. (In Russian).
4. Gerasimov, Vladimir, Gafur Zainiev, Ph.D. and Valery Prushinsky. Hybridization of alternative systems. TRIZ in Progress, Ideation International Inc, 1999, p.p. 221-224.
5. Mitrofanov, Volyuslav. From Manufacturing Defect to Scientific Discovery, St. Petersburg: TRIZ Association of St. Petersburg, 1998.
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8. Zlotin, Boris and Alla Zusman. Directed Evolution: Philosophy, Theory and Practice. Ideation International, 2001. Appendices 8 and 9.
9. Zlotin, Boris and Alla Zusman. Directed Evolution of R&D organizations. (These proceedings).

Appendix 1. Create a model or a theory explaining a new event or phenomenon

Step 1. Formulate the original problem

Formulate the original problem as follows:

There is a system called (*enter system name****). An inexplicable effect or phenomenon (useful, harmful or neutral) (****describe the effect/phenomenon****) occurs under the conditions (****describe the conditions****).***

Localize the existing phenomenon – define the area, other effects and the last events related to the phenomenon.

Step 2. Problem amplification

Try to amplify the effect, by replacing the phenomenon you want to create with an amplified one, in accordance with this template:

(*describe the amplified phenomenon****) under the given conditions (****describe****).***

For example, if a certain phenomenon we are trying to understand can be observed only occasionally or partially, the amplification would mean thinking how to produce it constantly, under any conditions and in full scale.

Another useful rule is to concentrate on reproducing the "last event", rather than preceding ones as they might not have any relations to the mechanism.

Step 3. Problem inversion

Replace the initial problem description as follows:

It is necessary to produce (*describe the effect****) under the given conditions (****describe****).***

The main purpose of the problem inversion is to change the way an individual thinks about the phenomena, which nature is unclear. Looking for explanation is rather a passive approach. TRIZ based Scientific Problem Solving (SPS) replaces the approach with pro-active ones. It recommends instead of explanations look for reproducing the phenomenon, if that was needed for a purpose, actually, inventing it. Because of problem transformation into inventive one, all TRIZ tools and approaches for generation new creative ideas can work.

Inventive approach also works in situations that seem clear, however, in fact available understanding is incomplete or plainly wrong. Typically, your understudying is incomplete, if:

- You cannot reproduce the phenomenon that seems understandable.
- You failed to explain the mechanism of the phenomenon to a teenager or an adult with different profession, without complex math or special terminology.

When dealing with undesired phenomenon, it is very helpful to start thinking about it as an effect that is needed for some useful purpose. Positive thinking is always constructive and can help to better understanding

Step 4. Search for creative hints

Consider the areas of science, engineering, or even everyday life where this same phenomenon is intentionally created. Where and in what way is this most easily realized? Consider if this way is available for solving the inverted problem.

If necessary, apply Inventive Problem Solving to find a way to produce the (*amplified phenomenon****).***

It is very hard to find an event or phenomenon that never had any analogs in the past. Moreover, often an effect we are trying to produce working with inverted problem can be rather widely utilized in some areas. If we succeed to find such area and how the effect can be produced in details, we automatically get all necessary explanations and check if it can work in our situation.

It is usually much easier to find analogous areas if we describe our effect in general terms rather than specific.

Step 5. Utilization of resources

Consider resources available in the system and its surroundings that are necessary for reproducing the given phenomenon (effect), in particular, ask the following questions:

Which resources are necessary to provide the (*amplified phenomenon****)?***

Which resources are necessary to provide the (*amplified phenomenon****) exist in:***

- System defined by the (**system name**)?
- Its sub-systems?
- Its environment?

How can the existing resources be transformed in order to provide the (*amplified phenomenon****)?***

An event or phenomenon takes place when all necessary components are in place, like energy, time, materials, and other necessary elements that in TRIZ are considered as resources. Once a hypothesis is build, its verification require to make sure all necessary components (resources) are available or could be easily obtained (even the most creative hypothesis will remain a hypothesis if the resources are not in place).

For further hypothesis verification, we need to consider the resources of the system and its surroundings in readily available form or could be useful after certain transformations.

Look for typical resources

Start from typical resources and their combinations, including:

- Available materials or substances
- Produced or supplied energy
- Free moments or periods of time
- Vacant space within an object
- Object structure
- System functioning
- Information about the system

Non-specific resources

Non-specific resources are the ones that are practically always there – like gravity, air, humidity, ambient temperature, Magnetic field of Earth, vibration from various transport, etc.

Accumulation of resources

Some resources are not capable to produce any effects unless being accumulated. These resources can accumulate slow and do not reveal themselves until reach a certain point. Once the critical amount is accumulated, a certain event can be triggered. In other situations, resources accumulate naturally, for example as a result of aging of materials, or chemical reactions.

Resources of changes

Another type of resources capable to produce new phenomena (including harmful ones) are various changes happened in the system. Because of that, if a new phenomenon occurred in the system, it is very important to track down all changes that happened in the system trying to link them to the event under question.

Effects

While trying to nail down unexplainable events, knowledge one can learn at school or at the university could be very helpful, especially physical, chemical geometrical and other effects. It happened many times when simple effects like thermal expansion or freezing water could produce quite remarkable things.

Step 6. verification of obtained hypotheses

Consider all obtained hypotheses and select the one that fits the real situation the most.

Verification is a typical scientific activity. It requires collection and analysis of information, sometimes to run special experiments to confirm the idea. The most important is to make sure that all resources necessary for the realization of the phenomenon under consideration are available in the system or its environment; or if something is missing, how it can make its way into the system to produce the phenomenon. It is like a secondary scientific problem that has to be solved for completing the work.

Очень важный вопрос если проблема не новая - почему раньше не предлагали такую гипотезу

In other situations, a creative approach is required to plan and run the verification experiments. For this purpose, TRIZ tools could be utilized, in particular, methods of synthesis and/or enhancement of systems for measurement and/or detection helping inventing verification experiments.

Appendix 2. Building new scientific concepts

Stage 1. Analysis of an existing system

Step 1.1. System analysis

Learn about:
- Sub-systems
- Super-systems
- Structure
- Functioning
- Basic postulates and original facts
- Basic patterns and known mechanisms
- History and dynamics of system evolution, basic trends and stage of evolution

Step 1.2. Other related systems

Learn about other systems related to the given one (analogies based on similar phenomena, approaches, etc.)

Step 1.3. Build and analyze the model of the system

Build and analyze the model representing the given system including:
- Building a simple model
- Identifying basic sub-systems of the model
- Identifying known limitations
- Trying typical and "universal" models

Step 1.4. Unveil and analyze the model's drawbacks

Analyze shortcomings of the model of the given system including:

- Revealing facts inconsistent with general patterns of evolution including
  - Poor founded postulates
  - Violating accepted boundaries
  - Internal contradictions
  - Hypothesis "ad hoc"[10]

[10] Ad hoc – a hypothesis introduced solely for the purpose to explain a new fact, which is not connected or correlated with other theories (Translator's note).

- Unsolved problems
- Revealing drawbacks associated with current stage of system evolution, for example, stagnation, etc.
- Formulating problems

Stage 2. Synthesis of a new concept

Step 2.1. Solve formulated problems

Solve formulated problems using scientific problem solving techniques: Problem Inversion approach, utilization of typical and universal explanatory mechanisms, etc.

Step 2.2. Integration

Combine all results in a new integrated model-concept that can complement or replace the original one. Structure the new concept and defining its boundaries and limitations.

Stage 3. New hypothesis verification

Step 3.1. Check for compliance with known facts

Check how the new concept fit the whole complex of existing facts and patterns in the area of concern.

Step 3.2. Check for compliance with other related theories

Check how the new concept relates to other theories (comply with the Principle of coordination[11])

Step 3.3. Predict new facts

Reveal new facts and patterns, predicted by the new concept; solve problems related to these facts verification (using TRIZ if necessary); conduct necessary verification experiments.

[11] "The Principle of coordination " introduced by physicist Niels Bohr states that any new more general concept has to include the old theory as a particular case (Translator's note).

Step 3.4. Test for the possibility of falsification

Test the new concept for the possibility of falsification[12] If at least one from the steps 3.1 - 3.3 produce negative results, return to the Stage 2 and formulate new problems related to the search of mechanisms that can explain deviations.

Step 3.5. New cycle

If at least one from the steps 3.1 - 3.4 produces negative results, return to the Stage 2 and formulate new problems related to the search of mechanisms that can explain deviations.

Stage 4. Further development of the new concept

Step 4.1. Utilize patterns of evolution

Apply patterns of evolution to the new concept including:
- Formulating the opposite concept. Trying to find conditions under which this anti-concept might become valid. Find a way to combine them in accordance with the pattern of integration of alternative systems and Complementary Principle[13].
- Consider applying other patterns of evolution

Step 4.2. Expansion

Describing new explanatory mechanisms obtained. Consider the possibility to expand them in other areas.

[12] Famous scientist Karl Popper has shown that a scientific theory or hypothesis could be valid only if an experiment could be created capable to invalidate (falsify) it. If such experiment cannot be even mentally imagines, we are dealing with faith rather than science. Unfortunately, Popper did not offer any tools for this process, for that reason this brilliant idea has not been utilized. TRIZ can offer such instrument – problem inversion. The process of "falsification" is similar to Failure Analysis application.

[13] The "Complementary principle" - another principle introduced by Niels Bohr, which states that two contradictory theories could be both valid and complement one another.

Appendix 3. Selected recommendations for building measurement and detection systems

When a creative approach is required to plan and run the verification experiments, one can utilize the following recommendations[14]:

- Check the availability of informational resources, in particular:
  - Fields of dissipation
  - Substance properties
  - Substance flows from a system
  - Transient substance or field current
  - Alterable properties of substances
- Consider performing measurements on a model or copy of the object being processed.
- Consider replacing measurements with a detection or dual detection process that indicates whether or not a parameter is within limits.
- If it is difficult to control a process, consider introducing an opposing process that can be easily controlled, and can be used to adjust or correct the results.
- Consider obtaining information about an object or system by subjecting it to some field (force, effect, or action), then measuring the resulting effect.
- If it is impossible to obtain information about the condition of an object or system, consider obtaining the information by introducing
- A field (force, effect, or action) that the object or system will transform into one of these easily measured or detected fields as tactile, olfactory, auditory, optical (visual) etc.
- Some additives that can become a source of easily-detected field:
  - A marker that will detect the needed events
  - A witness that will produce the needed information
  - A sensor or transducer that can present the desired information in the form of an easily-detected fields
- If it is impossible to implement additives into system, these additives should be implemented in the environment
- If it is impossible to implement additives into the system or environment these additives can be obtained in the environment itself, for example, by its destruction or by changing its phase state. Among other things, gas or vapor bubbles obtained by electrolysis, cavitation or other methods are often applied.
- If the desired information is presented in a weak form, or does not show up against a background of other objects, or other information, consider separating-out or highlighting the desired information.
- Consider giving the object or system or process special properties that will amplify the desired information, or will suppress undesired interference with recognition of the desired information.

[14] For more detail, see IWB® software.

- If it is impossible to directly detect or measure changes in the system and passing a field through the system is impossible as well, the problem can be solved by generating the oscillations of either whole system or its part; variations of their frequency gives information about changes in the system:
- If generating the oscillations of either whole system or its part is impossible, information about state of the system can be obtained from oscillations of external object or environment linked with the system.
- To improve effectiveness of measuring or detecting can be improved either by substituting one substance by ferromagnetic particles or by implementing the ferromagnetic particles in the system. Information about changes in the system can be obtained by detecting or measuring the magnetic field
- Effectiveness of the measuring system can be improved by applying many of physical phenomena, for example phases transformation, thermal expansion, thermocouple, piezoelectric, magnetostriction, luminescence, chemical indicators, etc.
- Effectiveness of Measuring System on any stage of evolution can be improved by creating bi- or poly-system.
- Effectiveness of Measuring System on any stage of evolution can be improved by transition from measuring the function to measuring first and/or second the derivatives of the function.

Appendix 4. Finding new applications for new events and effects and/or for preventing or eliminating harmful effects

Once the mechanism of a phenomenon is clear, one can consider the following:

- Find a useful application for the phenomenon
- Amplify the phenomenon
- Prevent undesired effects or eliminate its harmful consequences
- Create a method for the phenomenon early detection

Find a useful application for the phenomenon

We can try to find a useful application for new events (either useful or harmful). For this purpose, the following steps are recommended:

- Identify all possible resources associated with the effect
- Identify other systems in which these resources could be useful. Utilize lines of technical and market evolution, if necessary

Amplify the phenomenon

Understanding the mechanism of a useful phenomenon often allows amplifying or enhancing it making it stronger, more controllable, etc. For this purpose various TRIZ tools including patterns and lines of evolution could be utilized.

Prevent undesired effects or eliminate its harmful consequences

In certain situations harmful effects could be eliminated even their nature is unclear. However, the elimination and especially prevention of harmful effects is much more effective when we know the mechanisms responsible for their occurrence.

Create a method for the phenomenon early detection

Understanding of the phenomenon mechanisms often allows developing a method for its early detection and thus promptly and appropriate reaction. For detection, one can use recommendation from the section *Create experiments*.