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TRIZ FOR PROBLEMS OF CLASSICAL PHYSICS ON THE EXPERIENCE OF THE EUROPEAN PROJECT BASED ON NANOWIRES RESEARCH

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Abstract: *The article is devoted to the experience of using heuristic methods, including such tools as TRIZ in the framework of the Horizon2020 Marie Curie project INDEED, which focus lies on the research of materials and innovative de-vices based on nanowires. For more than three years of project duration, there have been an TRIZ course held with the focus on physics problems and a series of inventive workshops that have been delivered for the project participants. This article summarizes the experience of introducing heuristic methods, in particular TRIZ, for problems of classical physics, such as mod-eling processes, studying the properties of new innovative materials, and conducting laboratory experiments. The discussion given in this article is based on a survey for physicists conducted among the consortium partici-pants after the completion of the project.*
Key words: *TRIZ, TRIZ for Physics, Heuristics*

1. INTRODUCTION

1.1 The premises of the research

For more than half a century TRIZ has been successfully utilised as a toolkit for inventive problem solving. Being born as a theory at a patent office in 1956 by Genrich Altshuller and then evolving during subsequent decades, TRIZ was mostly being developed as a tool to solve engineering and technical problems [1]. Thus, being nowadays a recognizable tool in the industrial community TRIZ is increasingly mentioned in academic circles and due to the community, TRIZ is still being developed and acquired with new theoretical and practical tools. How-ever, despite the fact that many conceptually new technical solutions appeared with the help of TRIZ methodology, it is not so often mentioned as a tool for scientific discoveries in the academic environment or for mathematical and (theoretical) physical problems [2].

According to the Altshuller, physics knowledge is crucial to effectively apply TRIZ. Therefore, in the literature there are quite a few references to the im-portance of physics in the application of TRIZ. However, physics as a subject is perceived rather from the point of its basic concepts and physical effects and phenomena [3], and not from the point of the mathematical apparatus used or as physics modelling concepts heuristics. Thus, there are textbooks [4, 5] and different teaching materials on the use of physics in the practice of TRIZ and on the use of TRIZ for problems in physics [6]. Heuristic methods in physics have also been highlighted outside the TRIZ community [7-10].

At the same time, in the scientific literature there are not many references with cases of TRIZ application for practical problems in the field of advanced physics [2].

Thus, successful TRIZ cases are rarely found in classical physics or pure chemistry, or in narrow sciences as nanophysics or quantum computing, while the main successful case studies related to TRIZ are located on the periphery between different spheres closer to engineering, often additionally being integrated with other tools [2].

Being a part of the broad European consortium, which develops innovations in the field of nano-physics, the authors had the opportunity to test the hypothesis - how effective will be TRIZ as a toolkit for scientists in solving problems in the field of classical physics. Thus, after a series of workshops, seminars and an online course on TRIZ for PhD students of the consortium during three years of the project, a survey was organized about the effectiveness of heuristic methods for systematizing creativity in the framework of participants' individual research. The main objectives of the survey, as of the present paper, are the following re-search questions:

- How effective and how much applicable are heuristic methods and, in particular, TRIZ, in research for problems of classical physics?
- Which tasks could be a subject for heuristic for physicists to be applied? (De-signing an experiment, modeling, etc.)

1.2 INDEED Consortium

INDEED is a consortium of 14 European Universities and 2 Industrial partners companies [11]. The main scientific objectives of the consortium is to translate semiconductor nanowire technology to the market-ready products. These re-search goals are closely related to many scientific as well as industrial challenges for the consortium research teams, including research of nanomaterial properties and development of nanowire-based devices.
Thus, to support the heuristic stage of the research and development processes the consortium was strengthened with TRIZ toolkit materials and practical work-shops. TRIZ was practised in a form of three-days in-class mini course, several in-class workshops and one online lecture. Despite that, the materials of the developed online course on TRIZ (textual materials, video lectures and quizzes) have been available online for project participants [12].

2. SURVEY-BASED INSIGHTS

2.1 Participants background and research scope

In order to reflect more broadly the context of the survey participants research and the experience of using TRIZ, the respondents were asked various questions, including those not directly related to TRIZ. Despite the not so high number of people who took part in the survey (12 people according to the number of PhD students in the consortium), there are some recognizable patterns in answers that evidence some insights. However, not all the questions of the survey are referred in this chapter, since some of them didn’t appear to be informative enough to draw conclusions, nonetheless, a complete list of questions and answers is presented separately in the Appendix (Q1-Q27).
Audience background. Thus, most of the respondents are from the Academy. Although due to the fact that the consortium involved not only Universities, but also industrial enterprises, some respondents were the representatives of the Industry (Q1).
Despite a significant number of parallel research and development challenges, the main activities of the consortium are related to the research of the material properties, the creation of new composites and technologies for their creation, as well as the invention of new functional devices at the conceptual level, i.e. at the level of practical and theoretical physics. However, there were also industrial partners within the consortium with commercial market-ready products with more technologically-oriented research (Q2). But in general, the activities of the respondents are quite closely related to modeling and conducting experiments, with a certain part devoted to theoretical affairs (Q3, Q4).

2.2 Patents as a research references for survey participants

Every patent application is an invention that emerged as a result of the heuristic process of idea generation [13]. From this point of view, it was interesting to determine what is the attitude of the respondents for patents as a source of heuristic solutions. Therefore, participants were also asked a number of questions about their attitudes and experiences with patents.
Thus, all respondents, without exception, stated that they use only scientific literature, and not patent or other data, as textual references and insights source for their research (Q6, Q9). Thus, among the respondents' answers, there are no patent sources, such as Web of Science Derwent Index or Google Patents as a search for

references (Q7). Although all survey respondents did not point to the patent databases as relevant for research information sources, the audience is not avoiding the patenting routine, almost half of the respondents have authorship or co-authorship of the patent (Q8, Q10).

2.3 Participants and heuristic methods

The audience attitude towards heuristic methods is well illustrated with the fact that just waiting for a right idea is perceived as a better method for some respondents than resorting to heuristic methodologies to purposefully generate ideas towards a specific problem solution. Thus, being faced with an obstacle on their research, almost all respondents are looking for the necessary answers in the scientific literature. However, some respondents noticed that when facing a problem in research they've been trying to move at the level of model and finding the solution there, what is a positive point, because the process of the right model identification is, in fact, a very heuristic process, if the classical models for some scenario does not fit. Thus, instead of some heuristic formal methodologies for ideas generating, survey participants preferred talking with colleagues (brainstorming) or looking for insights on the internet (Q12).

It is also has to be noted, that the respondents do not deny the existence of heuristic methods as such; moreover, most of them noticed that they often use basic heuristics such as the “principle of symmetry” or “the principle of analogy”, i.e. techniques that are used rather subconsciously and are very general (Q13).

At the same time, the absence of an idea is perceived as a lack of some knowledge, rather than lack of vision of the right way to go, what is pointed by the fact that facing an obstacle in the research, respondents are first trying to look for answers in existing solutions, rather than trying to come up with something conceptually new from scratch, and not vice versa (Q14). Another motivation for starting to search the problem solution not with the process of generating ideas is that the last is explicitly perceived as a spontaneous rather than systemic process (Q16), and as a result, imagined as a poorly controlled process.

At the same time, the visible reluctance to generate ideas is not associated with the presence of a right idea at any given time, what is seen from that most of the respondents did not hesitate that in their research there were situations when they were confused and did not know what to do at the moment (Q17). Moreover, divergent thinking has no less value than convergent thinking, i.e. generation of ideas is perceived as an important component of research (Q18), which also speaks in favor of the hypothesis that the process of generating ideas is perceived in the academic sphere as a process that is important, but actually difficult to affect.

2.4 Participants and working heuristics

The success of individual research respondents first of all relates to the results of experiments, and as a related factor, technological capabilities (which is quite natural as it is a necessary condition for research in the field of nano-physics and research of nanomaterials). In second place due to the survey it was the internal laboratory team and networking within the project.

Although the reasons listed above are too fundamental, almost half of the respondents said that the success of their research was also due to a bright idea. (Q19). At the same time, almost all survey participants agreed that the epistemic values, i.e. pure knowledge is more important than non-epistemic, i.e. heuristics for their research. (Q20).

Thus, key *taking aways* that can be made from the specifics of the respondents' answers:

- Heuristics in classical physics problems is fundamental, but it's hard to ad-dress heuristics as a methodology.
- Moreover, the epistemic of knowledge is more important than the heuristic in the opinion of all respondents.

The comments that were given by the respondents with their thoughts and point-ed challenges related to heuristic methods in the open-ended questions are presented in the next chapter.

3. DISCUSSION

Almost every question in the survey had a separate field for free form comments. Also the last question of the questionnaire was asked in a free form, this question was: “Please, as specific as you could formulate, describe please, your Invention process. How do you act, when you need a new idea? What is your own silver bullet?”. The thoughts and reasoning of researchers from the field of physics who had an experience of acquaintance with TRIZ and had the opportunity to apply it for their own research with the authors' comments are given in this chapter. Thus, on the one hand, a small number of respondents (which are PhD students and not TRIZ experts, what influences the survey results) is definitely a limitation of the present article, on the other hand, more comments and opinions can be more personally addressed.

One of the main ideas given by survey participants during the whole survey creates a whole distinguished cluster about the importance of epistemic values. Starting from the fact that when building a model of a problem, the most difficult task is finding other models in the literature, and not coming up with a new one, and ending with the fact that in working with electronic nano materials, patents as a source of information are not particularly useful, justifying the low demand of the audience on patents generated insights among all respondents. Many respondents also wrote that when faced with difficulties in the research, they first of all begin to look for solutions in the scientific literature, i.e. fill the knowledge gaps, but not concurrently addressing the heuristic support.

Obviously, despite the high degree of formality in disciplines such as physics and mathematics, heuristics in solving non-classical problems from these disciplines is important [14]. The participants themselves also proved that they see heuristics as an important component. At the same time, as the survey shows, physicists are reluctant to resort to methods that automate or formalize heuristics. However, among the comments, the respondents also clearly stated that TRIZ proved itself effective for the related applied or technical problems.

4. CONCLUSION

The present research paper goal was to identify the effectiveness of formal heuristic methods as TRIZ for physicists, and to identify the attitude of the academic community to heuristic methods for mathematical and physical problems. The survey that was prepared for the research included 27 questions to identify the background, the participants main research and development routines and the experience and thought on heuristic methods exploitation during the project in-volved in innovative nanowires devices design. The analysis is based on the Survey results filled in by the 12 PhD students conducting physical research related to nanowires electrical properties, applications and design.

From the survey result analysis we conclude that TRIZ as a toolkit has its challenges for full utilisation for classical physics problems. Thus, as we could see the main survey participants' objection is related to the low level of applicability of heuristic methods when modelling a problem or conducting an experiment, which is the main routine of the physicist researching the nanomaterials. Thus, in these activities, as stated, the epistemic values are much more appreciated than the non-epistemic and at the same time, the obstacles met during the research as a rule perceived as a lack of knowledge rather than a lack of the ideas. At the same time the participants also pointed out the high importance of ideas when conducting a research and mentioned using different inventive principles and patterns when met a conceptual obstacle. It is indicating the hypothesis that, in the mathematical and physical problems world, heuristic methods are possibly hidden in a more complex physical apparatus and live in another form as just a book or table of different heuristic models that has to be used in different situations. Thus, the heuristic toolkit for physicists would consist not only of physical world patterns but also should include mathematical apparatus and models to better suit scientists' routine.

5. APPENDIX

The survey questions and participants answers:

Q1: As a part of the INDEED Consortium, are you the representative of Academia or Industry?

Answers: Academia (83,3%), Industry (16,7%)

Q2: Have you been involved in the technical processes of new commercial products/technology development?

Answers: Yes (41,7%), No (33,3%), Hard to say (25%)

Q3: What are the main activities within your Research? What would describe your Research the best?

Answers: Mathematical Modelling (8,3%), Physical Modelling (25%), Scientific literature reading (33,3%), Patents reading (0%), Research supervising (41,7%), Experiments Design (75%), Experiments Conduct (66,7%)

Q4: What is the most frequent question word in your research?

Answers: Why? (16,7%), How? (33,3%), Both (41,7%), Hard to say (8,7%)

Q5: When you model physical phenomena, what takes most of your efforts?

Answers: To define the structure of the model (33,3%), To define parameters of the model (16,7%), Both (16,7%), Hard to say (16,7%), We don't do too much modelling (8,3%), To look in the literature if another clever model exits (8,3%)

Q6: What were your main textual references during the Research?

Answers: Scientific literature (100%), Non-scientific literature (0%), Pa-tent documents (0%), Talking to people at conferences and in the community (8,3%)

Q7: Which of those databases have you used while research conduct?

Answers: Lens.org (0%), Google Scholar (66,7%), Web Of Science (Core Collection) (75%), Derwent Index (WOS) (0%), Scopus (33,3%), Scopus (patents) (0%)

Q8: Have you ever read a patent? How many of them have you read?

Answers: Never (25%), 1-5 (16,7%), 5-10 (33,3%), 10-50 (25%), 50+ (0%)

Q9: Have you used patent information as an insights provider/reference for your research?

Answers: Yes, I was working with patents a lot (8,3%), Yes, couple of times (16,7%), Not sure (8,3%), No, I had not used patents (58,3%), Mostly they are not helpful in electronic materials (8,3%)

Q10: Do you have authorship or co-authorship of any patent or patent application?

Answers: Yes (41,7%), No (58,3%), Hard to say (0%)

Q11: Impactful research is built on great ideas, so in your research:

Answers: You are mostly developing step-by-step specific idea (50%), You are constantly generating new ideas, try to reach general problem solution (33,3%), Hard to say (8,3%), Both new ideas and step by step approaches are needed, sometimes for the same problem (8,3%)

Q12: What is your typical strategy in a situation when your research encounters limitations or conceptual problem?

Answers: I am waiting for a right idea (41,7%), I am reading scientific literature (83,3%), I am reading patent data (0%), I am trying to use some heuristic conceptual design tools (8,3%), I am trying to find an answer or an insight in the internet (33,3%), I am trying to come up with a model of a problem (41,7%), I am trying to answer with the help of my colleagues (66,7%), Hard to say (0%)

Q13: There are many very simple heuristic tricks/principles that we use in our work and daily life. Which of the heuristic principles from the list have you used that lead to a successful problem solution or just was useful in your Research? Please add also your own ones that come to your mind.

Answers: Symmetry principle (63,6%), Analogy principle (90,9%), Inversion principle (18,2%), Homogeneity principle (18,2%), Asymmetry principle (0%), We don't give them names or systematize the approach (9,1%)

Q14: When you are looking for a new idea in your research, what is your strategy: to ground your search in existing solutions or methods or "to forget" intentionally the history of conventional ways of solving:

Answers: First, I try to project the known solutions onto a new problem (66,7%), First, I try to generate completely new ideas as if there were no history (16,7%), Hard to say (8,3%), Both of the above are useful at different times and we do both (8,3%)

Q15: In your opinion, is the solution to non-trivial problems more about individual (beautiful mind) or collective (brainstorming) work?

Answers: Individual (16,7%), Collective (33,3%), Both are equally important (50%), Hard to say (0%)

Q16: According to your opinion, the Idea generation process (those bright moments when you get an answer to the not trivial problem) is:

Answers: 1 (0%), 2 (16,7%), 3 (16,7%), 4 (58,3%), 5 (8,3%)

Q17: Was it hard to take the most resulting decisions in your Research?

Answers: Quite easy, I always knew what to do (0%), Actually I found myself in confusion couple of times (66,7%), Actually it was a big problem, I didn't find an effective approach (8,3%), Hard to say (8,3%), Which was the most resulting decision of mine?
This question applies to very few, I think. (8,3%), All of the top three have happened. Sometimes an idea works out, sometimes I get funded but the bright idea just doesn't work. (8,3%)

Q18: In your opinion, what is more important for successful research, divergent (generation of new ideas), or convergent thinking (development of the idea)?

Answers: Divergent thinking (16,7%), Convergent thinking (8,3%), Both are equally important (75%), Hard to say (0%)

Q19: The success of research depends on many quite different objective and subjective things. The success of your research is based on:

Answers: Strong literature review (25%), Bright idea (41,7%), Excellent team (58,3%), Project interaction possibilities (50%), Lab/technological opportunities (75%), Modelling results (25%), Experiments results (75%)

Q20: In your opinion, epistemic or non-epistemic values are more important when overcoming a problem or limitation in Research?

Answers: Epistemic (Measurable, Knowledge) (75%), Non-epistemic (Non measurable, Heuristics) (8,3%), Both (16,7%), Hard to say (0%)

Q21: Which of those Conceptual Design / Idea Generation methods you have heard of?

Answers: Axiomatic Design (0%), TRIZ (41,7%), Brainstorming (41,7%), Synectics (lateral thinking) (0%), None from the above (0%), TRIZ and brainstorming (16,7%)

Q22: The new results you deliver with your Research are more related to:

Answers: New material property identification (75%), New applications (25%), New theoretical models (16,7%), New business ideas (0%), New products (25%)

Q23: Have you tried TRIZ in your Research?

Answers: Yes (25%), No (75%)

Q24: In your opinion, may TRIZ be successfully applied in narrow parts of physics, e.g. nanophysics / nuclear physics / quantum mechanics, etc.?

Answers: No, TRIZ is too general for such areas, since they require too specific knowledge (16,7%), Yes, TRIZ is abstract enough to be successfully applied for any physics area (58,3%), Hard to say (16,7%), TRIZ seems to be more oriented towards applied or technical research (8,3%)

Q25: Do you have (and use often) your own successful "thinking patterns", analytical tricks, "best thinking practice" in your research?

Answers: Yes, actually quite often (16,7%), Rather "Yes", from time to time (33,3%), Rather "No" (41,7%), No (8,3%), Hard to say (0%)

Q26: Have you ever had a situation where a simple heuristic trick made it possible for you to make significant progress towards your research/engineering results?

Answers: Yes, actually quite often (9,1%), Yes, couple of times the solution of complex problem has been found with the help of quite simple idea (45,5%), Not really (23,7%), Hard to say (18,2%)

Q27: Characterize what is best describing your Research Result?

Answers: 1 (25%), 2 (41,7%), 3 (58,3%), 4 (50%), 5 (75%)

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7. REFERENCES

[1] Salamatov, Y. and Souchkov, V., 1999. *TRIZ: the right solution at the right time: a guide to innovative problem solving* (p. 256). Hattem: Insytec.

[2] Chechurin, L. (2016). *TRIZ in science. Reviewing indexed publications.* Procedia CIRP, 39, 156-165.

[3] Litvin, S., Petrov, V., Rubin, M., & Fey, V. (2007). *TRIZ body of knowledge. TRIZ developers summit*, Russia. Accessed December, 18, 2012.

[4] Seryi, A. (2015). *Unifying physics of accelerators, lasers and plasma*. CRC Press.

[5] Urasaev, V. (2006). *TRIZ in electronics.* Moscow Technosphere, 2006. – 320p

[6] Altshuller, G. S. (1984). *Creativity as an exact science: the theory of the solution of in-ventive problems*. Gordon and Breach.

[7] Feynman, R. P., Leighton, R. B., & Sands, M. (1965). *The Feynman lectures on physics;* vol. i. American Journal of Physics, 33(9), 750-752.

[8] Feynman, R. P., & Sackett, P. D. (1985). *''Surely You're Joking Mr. Feynman!'' Adventures of a Curious Character*. American Journal of Physics, 53(12), 1214-1216.

[9] Perelman, Y. I. (1962). *Physics for entertainment.*

[10] Perelman, Y. (2013). *Fun with maths and physics: Brain teasers tricks illusions*. Prodinova.

[11] https://www.indeednetwork.com, last accessed through the web: [04/2021]

[12] www.cephei.eu/en/online-courses/1226317/systematic-creativity-and-triz-basics/, last accessed through the web: [04/2021]

[13] Lee, C., & Lee, G. (2019). *Technology opportunity analysis based on recombinant search: patent landscape*

analysis for idea generation. Scientometrics, 121(2), 603-632.

[14] Polya, G. (1962). *Mathematical Discovery*, 1962. John Wiley & Sons.

TRIZ PENTRU PROBLEME DE FIZICĂ CLASICĂ PRIN EXPERIENȚA PROIECTULUI EUROPEAN BAZAT PE CERCETAREA NANOFIRELOR

Rezumat: Articolul este dedicat experienței utilizării metodelor euristice, incluzând instrumente precum TRIZ în cadrul proiectului Orizont 2020 Marie Curie INDEED, care se concentrează pe cercetarea materialelor și a dispozitivelor inovatoare bazate pe nanofire. Pentru mai mult de trei ani de durată a proiectului, a avut loc un curs TRIZ cu accent pe probleme de fizică și o serie de ateliere inventive care au fost oferite participanților la proiect. Acest articol rezumă experiența introducerii metodelor euristice, în special TRIZ, pentru problemele fizicii clasice, cum ar fi procesele de modificare, studierea proprietăților noilor materiale inovatoare și efectuarea experimentelor de laborator. Discuția prezentată în acest articol se bazează pe un sondaj pentru fizicieni efectuat în rândul participanților consorțiului după finalizarea proiectului.

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