

Exploring application of AI technologies for engineering education in systematic invention and innovation

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CONTEXT

The application of advanced Artificial Intelligence technologies in engineering education is an emerging interdisciplinary research area that aims to transform the design, process and assessment of teaching and learning. The paper addresses the need for universities to train students as future R&D professionals in efficient techniques for successful innovation and inventive problem solving. This goal faces the challenge of integrating various AI tools into engineering curricula to gain a comprehensive understanding of AI applications in an educational context.

PURPOSE OR GOAL

The increasing diffusion of rapidly developing AI technologies led to the idea of the experiment to combine TRIZ-based automated idea generation with the natural language processing tool ChatGPT, using the chatbot to interpret the automatically generated elementary solution principles. The article explores the opportunities and benefits of a novel AI-enhanced approach to teaching systematic innovation, analyses the learning experience, identifies the factors that affect students' innovation and problem-solving performance, and highlights the main difficulties students face, especially in interdisciplinary problems.

APPROACH OR METHODOLOGY/METHODS

This paper presents the results of the experimental application of AI-aided automated ideation in educational settings and compares them with the published experimental studies on enhancing engineering creativity. In the experiments conducted, several design problems were offered to mechanical engineering students in different semesters of their studies. Among the typical objective metrics of ideation effectiveness, the quantity, variety (breadth) of ideas and ideation productivity were used to evaluate the ideation results.

ACTUAL OR ANTICIPATED OUTCOMES

The overall results of the experiments confirm that the proposed AI-supported method for the automated formulation of TRIZ-based elementary solution principles can significantly improve the quantity, variety and thus the quality of idea generation. In addition, AI-based technologies can significantly increase the productivity of automated ideation by processing a larger number of applied elementary solution principles. Finally, the automated ideation allows students to explore a significant part of the inventive knowledge base without extensive preparation or training.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The authors suggest that engineering educators should consider incorporating this approach into their professional activities. The results presented may help universities to improve or enhance their performance in teaching interdisciplinary new product development, systematic innovation and inventive problem solving.

KEYWORDS

AI aided Innovation, Automated Ideation, TRIZ Inventive Principles

Introduction

The ability of R&D specialists and engineers to successfully run an innovation process faster and more efficiently is of great importance for the competitiveness of companies. Engineering educators have understood this industrial need and over the last two decades have gained considerable experience in different educational approaches to systematic innovation. For example, Oget & Sonntag (2002) advocate the cognitive development that combines problem-based learning and systematic innovation with the theory of inventive problem solving TRIZ (VDI, 2016). Dym et al (2005) consider project-based learning to be the most promising educational model for design thinking. Badran (2007) examines the relationship between creativity and engineering education and outlines the need for specific courses and activities that would enhance the innovative skills of graduate engineers. Harlim (2012) shows that improving the problem-solving skills of university students and experienced engineers requires different approaches.

The author's previous research (Livotov, 2015) highlights that students have lower motivation to learn systematic innovation methods compared to engineers. As experimentally confirmed by Belski et al. (2019), the inventive principles and heuristics of the TRIZ methodology (VDI, 2016) help to systematically improve the ideation performance of students and professionals. However, these methods and approaches to systematic innovation often don't belong to the obligatory components of engineering studies today. In addition, the existing subjects in engineering curricula still offer too few opportunities for structured innovation and inventive thinking.

In order to make the application of TRIZ inventive principles faster and easier for students without prior knowledge of TRIZ, the authors proposed a semantic transformation, defined as a collection of rules that specify how inventive principles can be represented in a less abstract form as a finite number of automatically generated solution ideas. According to (Livotov, 2021), in order to initiate the automatic generation of ideas for a given problem, it is only necessary to define the following problem-specific categories Working tool, Target object (which is affected by the working tool), Useful action, Harmful effect. The semantic transformation then generates up to 200 solution ideas distributed over the problem definition categories as follows: modification of the working tool (88 ideas), modification of the target object (45 ideas), improvement or transformation of the useful action (56 ideas), elimination of the harmful effect (11 ideas). In practice, the top 15...30 automatically generated ideas with the highest statistical ranking deliver at least 3...6 workable solutions. Table 1 illustrates the procedure of the automated idea generation for the problem "Ship hull cleaning", i.e. how to intensify the cleaning of the hulls of large ships from marine organisms (algae and shell layers) by means of high-pressure water jets without damaging the paint layer. In this example the following four categories were used as input for the problem definition: A. Water jet (Working tool), B. Marine organisms (Target object), C. Surface cleaning (Useful action), D. Paint layer damage (Harmful effect).

Table 1: Example of automated idea generation for four problem definition categories

Automatically generated ideas or recommended solution principles	Problem category	Statistical Ranking	Abstraction level	Technical domain
10. Use water jet in form of solid particles or granules	A. Working tool	High	Medium	Mechanical
89. Change the aggregate state of marine organisms to solid, liquid, or gas	B. Target object	High	Medium	Thermal
134. Perform a part of surface cleaning process in advance as a pre-treatment	C. Useful action	High	Low	Universal
193. Use condition monitoring to predict paint layer damage and avoid it	D. Harmful effect	Medium	Medium	Digital

As shown in Table 1, each idea can be characterised by its statistical ranking or frequency of application of the underlying inventive principles (high, medium or low), its level of abstraction

(from low - for easily implementable solutions to medium and high for ideas requiring additional analysis or research), and its technical domain (design, mechanical, acoustic, thermal, chemical, electromagnetic, intermolecular, biological, information (digital) or universal). A diagram in Figure 1 illustrates the diversity of the 200 underlying solution principles for automated idea generation. The large number of underlying solution principles enables systematic ideation by selecting or discarding specific engineering domains. For example, a mechanical engineering ideation process often starts with the evaluation of design and mechanical ideas, and can then be progressively expanded to include acoustic, electromagnetic, thermal, digital, intermolecular and other solution principles. A typical process engineering ideation session may start with the universal solution principles, which are more general and independent of any specific engineering domain.

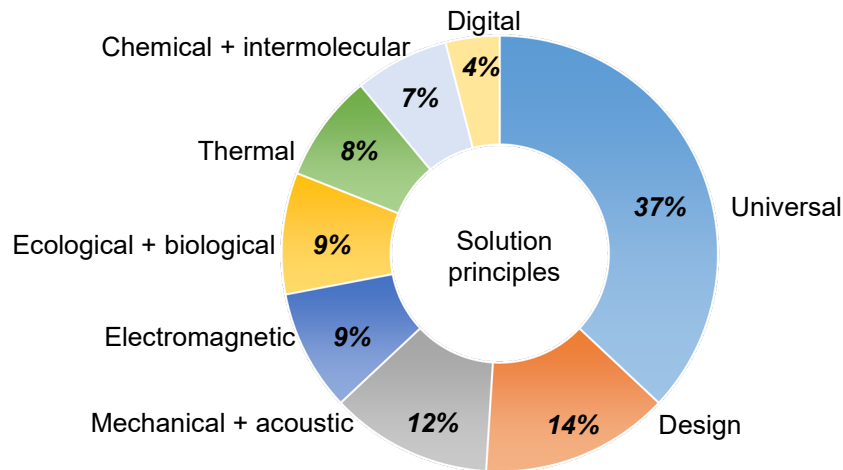


Figure 1: Variety of the underlying elementary solution principles for automated ideation

As outlined by Buskes and Belski (2017), prior knowledge in science and technology positively influences students' engineering creativity and idea generation skills. Our experimental experience in applying the automated idea generation method in educational settings or in student project work confirms this observation. Due to a lack of knowledge, students often overlook promising solution ideas or are unable to transform them into feasible solution concepts. In this context, the increasing diffusion of rapidly developing generative AI technologies led to the proposal to combine TRIZ-based automated idea generation with natural language processing tools such as OpenAI ChatGPT or Google Bard, using the chatbots to interpret the automatically generated elementary solution principles.

In the following two sections, the authors illustrate and discuss the proposed approach to Artificial Intelligence (AI) assisted automated idea generation, and then describe and evaluate its application in the students' project work in the one-semester course on Inventive Design and New Product Development. The concluding remarks give a critical overview of the experience gained and outline possible directions for future research.

AI-aided Automated Idea Generation

To illustrate the specific outcomes of the AI-aided ideation, this section presents the application of the Open AI chatbot ChatGPT3.5 (<https://chat.openai.com/chat>, last accessed on 06.07.2023) for the systematic search of solution ideas for the problem of cleaning ship hulls, mentioned in the introduction: "How to intensify the hull cleaning of ships from marine organisms (algae and shell layers) with high-pressure water jetting without paint layer damage?"

In the previous experiments conducted by the authors in 2019 (Livotov et al., 2019), the same problem was offered to 18 undergraduate students in the 4th or 5th semester of the bachelor's degree in mechanical or process engineering and 11 graduate students in the 8th and 9th semester of the master's degree in mechanical engineering. No special explanation of inventive

principles or any introduction how to apply them has been offered to the students. The problem was introduced to all groups for 3 minutes using a PowerPoint slide with the problem statement and a photo. All students were given 10 minutes to individually record as many ideas as possible by using concrete recommendations of the five elementary inventive principles, printed on the idea-generation forms:

- a) Change the aggregate state of the water jet or maritime organisms e.g. solid to liquid or liquid to gas - or vice versa.
- b) Change the concentration or consistency of the water jet or maritime organisms.
- c) Change physical properties of the water jet or maritime organisms: pressure, density, hardness, viscosity, conductivity, magnetism etc.
- d) Change the temperature of the water jet or maritime organisms.
- e) Change other chemical properties of the water jet or maritime organisms (formulation, pH, solubility etc.), change process chemistry.

The filled idea-generation forms were evaluated by the authors. On average each student proposed 6.3 ideas (each graduate student 7 different ideas and each undergraduate student almost 6 different ideas).

A similar experimental approach was used for idea generation with ChatGPT3.5. For a problem on how to intensify the cleaning of the ship hulls from marine organisms using high-pressure water jetting, the chatbot “outperformed” the students, suggesting 35 different ideas for 10 automatically generated solution principles, as illustrated in Table 2. The elementary solution principles were processed within seconds in separate chats, while each chatbot response was regenerated 3 times without changing the text of the requests.

Table 2: Automatically generated ideas and examples of corresponding interpretations by ChatGPT

Automatically generated solution principles	Interpretations by ChatGPT3.5
1. Use water jet in other aggregate state	cavitation cleaning, high-pressure steam, ice particles, dry ice
2. Change mechanical or surface properties of water jet	increase pressure, add abrasives
3. Change electromagnetic properties of water jet	electrolysis, electromagnetic fields
4. Change the temperature of water jet	combine water and steam cleaning
5. Change chemical properties of water jet	altering pH, enzymes, biocide
6. Pre-arrange water jet so it can come into action at the most convenient position and without losing time	optimal angle and pressure for different areas: propeller, rudder, etc.
7. Divide water jet into several independent parts	nozzle with multiple outlets
8. Design the water jet to be dismountable	better accessibility of ship parts
9. Replace the water jet by several smaller units	independent, synchronized jetting
10. Use water jet in form of solid particles or granules	re-use particles in water stream

Similar results of AI-supported ideation with TRIZ inventive principles were also observed in other case studies. However, the following aspects need to be discussed. First, AI-supported ideation without the use of appropriate TRIZ invention principles for the targeted search for solutions often leads to rather poor results. Table 3 summarises and compares the ChatGPT results for the ship hull cleaning problem without any TRIZ support (only 6 ideas proposed; see left column) with a TRIZ-based prompt (11 ideas; right column) after 3 regenerated answers. It is interesting to note that the application of only one inventive principle “*Change the aggregate state of water jet*” in ChatGPT leads to a total of 15 ideas, whereas in a similar case each student would propose on average 6...7 ideas using 5 inventive principles.

However, only the first 4 out of 10 ChatGPT “ideas” correspond to the given inventive principle “*Change the aggregate state*”, while the remaining 7 ideas refer to other solution approaches. This phenomenon of the chatbot providing ideas outside the defined search field should be taken into account when using it.

Table 3: Typical ChatGPT3.5 responses without (left column) and with TRIZ support (right column)

Request without prompt: How to intensify the ship hull cleaning from maritime organisms with high pressure water jetting	Request with a prompt: Change aggregate state of the water jet to intensify ship hull cleaning from maritime organisms
1. Use the correct nozzle	1. High-pressure jet with cavitation cleaning
2. Increase the water pressure	2. Use overheated water, high-pressure steam
3. Use the appropriate flow rate	3. Using ice particles
4. Adjust the spray angle	4. Using dry ice
5. Use hot water	5. Increasing water temperature
6. Consider using cleaning agents	6. Increasing water pressure
	7. Increasing the flow rate
	8. Using a biocide or special cleaning agent
	9. Using special nozzles or attachments
	10. Using brushes or scraping tools

It is noteworthy that ChatGPT3.5, in its first response to a TRIZ prompt, proposes the use of cavitation cleaning technology and gives a detailed explanation of how to implement it. In the authors' previous experience, cavitation cleaning was not mentioned in any of the responses from students or engineers. The chatbot also points out the potential negative side effects of cavitation cleaning, such as damage to sensitive surfaces or coatings, higher energy consumption, and more complicated and expensive equipment than water jetting.

Another example of an automatically generated solution idea N.82: Apply phase transitions in the water jet during its operation, from solid to liquid, from liquid to gas, etc., which is more abstract and usually leads to questions from students, shows that ChatGPT3.5 doesn't struggle with too abstract invention principles. The chatbot gives a clear explanation of the approach that “... involves using water that has been transformed from a solid to a liquid or from a liquid to a gas to clean the ship's hull. For example, the use of ice pellets or dry ice (solid CO₂) can be effective in removing marine organisms from ship hulls. When these materials are blasted at the hull at high speed, they can break up the organisms and loosen them from the surface. Another approach is to use steam jets to clean the hull. Steam can be very effective in removing stubborn marine fouling and can also help to disinfect the hull.”

One more example illustrate how routinely ChatGPT3.5 identifies ways to minimize environmental impact of water jetting when supported by the TRIZ solution idea N66: Use natural or easily recyclable materials or substances in the water jet:

1. Bristle brushes made from natural materials such as coconut fibers or biodegradable plastics.
2. Bio-based cleaning agents made from natural, plant-based ingredients such as citric acid, vinegar, or baking soda.
3. Enzyme-based cleaners used to break down and remove organisms from the hull without causing harm to the marine environment.
4. Non-toxic antifouling coatings from natural or easily recyclable materials such as copper or silicone.
5. Recyclable water jet materials that can be reused multiple times such as glass beads, walnut shells, or corncob.

6. Recycled water, electrolyzed water.
7. Water-soluble materials: like salt, sugar etc.

The quality of ChatGPT answers was *usually* better and more detailed than the typical students' ideas. In fact, the use of automated idea generation, or rather automated prompting, makes the idea generation process with TRIZ and ChatGPT more productive, repeatable, and complete. Furthermore, the ideation results show a high breadth of proposed ideas across all engineering domains due to the high diversity of underlying elementary solution principles for automated ideation (as illustrated in Figure 1).

In order to compare the results of prompted idea generation using different AI tools simultaneously, in an additional experiment, the prompt "Change the aggregate state of the water jet to intensify the cleaning of the ship hulls from marine organisms" was also offered to ChatGPT4.0 and Google Bard (accessed on 08/09/2023). Apart from ChatGPT3.5 with 16 different ideas (see Table 3), ChatGPT4 also provided 16 different ideas and Google Bard 12 different ideas each. However, out of a total of 44 ideas, only 23 were unique, i.e. different. It is interesting to note that each of the AI-based chatbots contributed with unique solution ideas that were "overlooked" by the others, as shown in Figure 2.

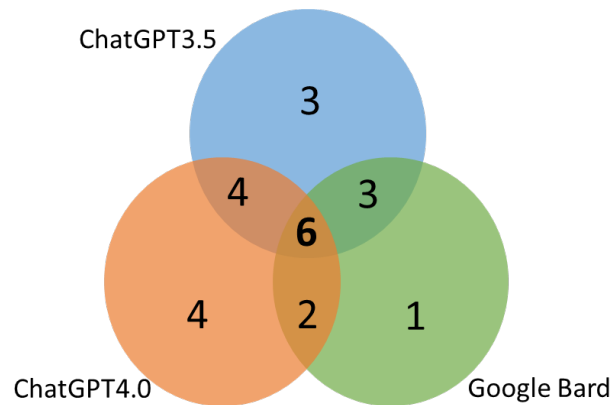


Figure 2: Number of common and unique ideas proposed by ChatGPT 3.5, 4.0 and Google Bard

For example, ChatGPT4.0 proposed a hull cleaning concept based on accelerated thermal cycles and the use of cryogenic fluids, and Google Bard suggested mixing water and air and using the force of the air to break the bond between marine organisms and the ship's hull. In general, the use of different chatbots to generate ideas prompted by inventive principles proved to be useful as the number of different ideas increased and the search for solutions became more complete. This observation was also confirmed by 2 other case studies, which are not described further in this article.

Verification of AI-aided Ideation through Student Projects

The following section describes and evaluates the application of AI-based automated idea generation for 10 inventive problems using student projects from the one-semester course Inventive Design and New Product Development at the Offenburg University. 4 groups of undergraduate and graduate students from different years of study participated in the experiment. Two undergraduate students belonged to the 5-6th semester of Mechanical and Process Engineering program, whilst 9 graduate students were in their 8th and 9th study semesters of the Master Degree in Mechanical Engineering. All eleven students were comprehensively advised in application of ideation tools by the same tutor. The students worked in 4 groups with one product development project task per group. Within each project task, they identified several invention problems and applied ChatGPT3.5 enhanced by automated idea prompt generation using the elementary TRIZ invention principles.

For each problem, the following procedure was used to search for new solution ideas. In the first step, after completing the problem definition as shown in Table 4, the problem was processed by

ChatGPT with 3 regenerations of the answers. All the different ideas were identified and documented by the students. In the second step, the students applied the method for automated idea generation for given problems and selected between 1 and 4 TRIZ-based elementary solution ideas for their application as prompts in new chats in ChatGPT. After 3 mandatory regenerations of ChatGPT responses in one chat, the number of unique ideas proposed by ChatGPT for each problem, in addition to the ideas in the first step, was also identified and documented by the students. All student protocols were checked by the tutors.

The chosen two-step ideation procedure represents a typical way to generate more ideas with less effort. Therefore, students had to decide for themselves which and how many of the automatically generated prompts should be used in ChatGPT. The prompting procedure could be stopped after the first prompt if, in the opinion of the students, at least one valuable and feasible solution idea had been found. Table 4 shows that in 7 out of 10 problems the students were satisfied with only one prompted response of ChatGPT. In three other cases, 3 or 4 prompts were needed to find a satisfactory solution. On average each prompt helped ChatGPT to generate 4.3 new unique ideas, with an average total number of ideas of 14.8, ranging from 12 to 26.

The reasons why students chose one or another of the automatically generated TRIZ-based solutions ideas were not analysed. However, the students were advised to select the most promising elementary solution principles, taking into account their statistical ranking, implementation effort (abstraction level) and the corresponding engineering domain (design, mechanical, acoustic, thermal, chemical, electromagnetic, intermolecular, etc., as shown in Fig. 1). It is interesting to note that 15 out of the 17 elementary TRIZ solutions principles selected by students were different.

It is clear that the application of the described AI-based ideation approach in an industrial environment would require the use of a significantly larger number of automatically generated solution prompts. Such a procedure will dramatically increase the number of inventive ideas, but it also requires an automated approach to creating a structured pool of hundreds of ideas.

Table 4: Results of ChatGPT application for AI-aided ideation in student projects: number of ChatGPT ideas without prompts, new ideas with prompts, total number of different ideas

Problem definition	N. of ideas w/o prompts	N. of ideas with prompts	N. of prompts	N of ideas, total
1. Uniform heating of the grill surface	11	15	4	26
2. Avoid contamination by grilled food	12	14	3	26
3. Minimise heat losses from the grill to the surrounding	5	12	3	17
4. Changing the temperature of a jacket or coat	4	4	1	8
5. Enabling waterproofness of a jacket or coat	6	4	1	10
6. Enabling breathability of a jacket or coat	6	3	1	9
7. Theft protection of the bicycle frame	7	5	1	12
8. Theft protection of bicycle components: saddle, light, ...	8	4	1	12
9. Increase overall theft protection of a bicycle	8	5	1	13
10. Reduce wear and tear of the floor	8	7	1	15
<i>Mean value per problem</i>	<i>7.5</i>	<i>7.3</i>	<i>1.7</i>	<i>14.8</i>

Concluding Remarks and Outlook

Among the typical objective metrics of ideation effectiveness, such as quantity, variety, novelty, quality, and feasibility of the proposed ideas (Shah et al., 2003), the quantity and variety (breadth) of ideas can be positively influenced by the presented application of the generative AI-tools. According to Diehl and Stroebe (1991), there is a positive correlation of $r = 0.82$ between the number of high-quality ideas and the total number of ideas. Thus, increasing the quantity of ideas with ChatGPT indirectly helps to generate more ideas of higher quality. In addition, according to the Bounded Ideation Theory (Briggs and Reinig, 2010), the upper bound of high-quality solution ideas is limited for the closed-ended problems. So, generating a larger number of different viable ideas contributes to a complete solution search and increases the probability that all useful solution ideas will be found.

The higher quantity of ideas can also be ensured by the high number of applied elementary TRIZ inventive principles used as prompts. However, also in the new context of the AI-aided invention and innovation, the novelty, quality (value) and feasibility of ideas, are still strongly influenced by the personal creativity, motivation, knowledge level and skills of the professionals.

Moreover, in certain problem situations, not all TRIZ solution principles can be reliably processed by ChatGPT3.5 and require adjustments in the regeneration of prompted queries. In our experiments, ChatGPT's initial response was often incomplete, sometimes too superficial, inaccurate or, more rarely, incorrect. In any case, it is recommended to regenerate a prompted request at least three times to obtain an almost complete response.

Ideas for classical design problems are still too general to be implemented quickly because the results of AI-based text-to-image transformation are still unpredictable and frequently require numerous iterations. However, some studies (Brad, 2023) show promising results in using advanced text-to-image AI systems such as MidJourney to visualise product ideas in the early stages of the design process.

Applying a large number of TRIZ invention principles (10 or more) often requires time-consuming summarising, condensing and structuring of generated ideas. However, delegating this task to ChatGPT has also shown promising results. The limitations of the presented idea generation approach include the unexamined influence of the detailed description of the initial problem situation and of the additional explanations of the applied TRIZ-based elementary solution principles. It is expected that the results of the AI-supported idea generation can be improved or at least influenced by these factors.

Finally, an additional intervention is required to combine the proposed individual ideas into a workable solution concept. AI-supported ideation, using elementary TRIZ or other solution principles as prompts for ChatGPT, can provide significant support in guided brainstorming sessions. At present, however, ChatGPT is not able to identify a strong, sometimes "unthinkable" combinations of ideas or to find synergies between different solution approaches. Strategies for extending and applying existing AI technologies and tools for generating and optimising innovation concepts are the subject of current research.

The proposed ideation approach equips students with advanced knowledge and skills in the field of systematic AI-assisted invention and innovation and requires very little time for training, about 2 academic hours. After the training, the students can reliably apply the method for automated idea generation and select the solution prompts for application in Open AI ChatGPT, Google Bard or similar AI-based applications. For the 11 students who were part of the project work, even a small amount of work had a positive effect on their self-confidence and inventive skills.

The continued rapid development of Large Language Models such as for example ChatGPT or Google Bard will definitely change the way we teach creativity and inventiveness in engineering. Currently, these generative AI tools often lack human-like creativity and abstract thinking, which are essential for solving inventive problems. However, it is very likely that future advances in the field of AI will enhance the creative potential of generative AI tools, enabling them not only to act as creative assistants to specialists, but also to autonomously generate inventive and high-quality

solution concepts. For this reason, the authors also suggest that engineering educators should consider incorporating the AI-assisted invention and innovation into their professional activities now, to gain and evaluate their experience and be prepared for future technological breakthroughs.

References

- Badran, I. (2007). Enhancing creativity and innovation in engineering education. *European Journal of Engineering Education*, Oct. 2007, 32(5), 573-585, DOI: 10.1080/03043790701433061.
- Brad, S. (2023). Enhancing Creativity in Deep Learning Models with SAVE-Inspired Activation Functions. In: Towards AI-Aided Invention and Innovation. TFC 2023. IFIP Advances in Information and Communication Technology, vol 682, pp. 147-171. Springer, Cham. https://doi.org/10.1007/978-3-031-42532-5_12
- Belski, I., Skiadopoulou, A., Aranda-Mena, G., Cascini, G., Russo, D. (2019). Engineering Creativity: the Influence of General Knowledge and Thinking Heuristics. In L. Chechurin & M. Collan (Eds.), *Advances in Systematic Creativity* (pp. 245-263). McMillan https://doi.org/10.1007/978-3-319-78075-7_15.
- Briggs, R.O. and Reinig, B.A. (2010), "Bounded Ideation Theory", *Journal of Management Information Systems*, Vol. 27, Vol. 1, pp. 123–144. <http://doi.org/10.2753/MIS0742-1222270106>
- Buskes G. and Belski, I. (2017), Prior Knowledge and Student Performance in Idea Generation. Proceedings of the 28th Annual Conference of the Australasian Association for Engineering Education (AAEE 2017), Sydney, NSW, Australia; 12/2017, 354-361.
- Diehl, M., Stroebe, W. (1991), "Productivity loss in idea-generating groups: Tracking down the blocking effect", *Journal of Personality and Social Psychology*, vol. 61, No. 3, pp. 392–403.
- Dym, C. I., Agogino, A. M., Eris, O., Frey D. D. & Leifer, L.J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, January 2005, 103-120.
- Harlim, J.M. (2012). Identifying the factors that impact on the problem solving performance of engineers. PhD thesis, 2012, School of Electrical and Computer Engineering Royal Melbourne Institute of Technology, RMIT University, Melbourne, Australia.
- Livotov, P. (2015). Measuring Motivation and Innovation Skills in Advanced Course in New Product Development and Inventive Problem Solving with TRIZ for Mechanical Engineering Students. *Procedia Engineering*, Volume 131, 2015, Pages 767-775
- Livotov, P., Chandra Sekaran, A.P., Mas'udah (2019). Lower Abstraction Level of TRIZ Inventive Principles Improves Ideation Productivity of Engineering Students. In: Benmoussa, R., De Guio, R., Dubois, S., Koziolęk, S. (eds) *New Opportunities for Innovation Breakthroughs for Developing Countries and Emerging Economies*. TFC 2019. IFIP Advances in Information and Communication Technology, vol 572, Pages 526-538. Springer, Cham.
- Livotov, P. (2021). Method for Formulation, Selection and Application of Elementary TRIZ Inventive Principles for Automated Idea Generation. In: Borgianni Y., Brad S., Cavallucci D., Livotov P. (eds) *Creative Solutions for a Sustainable Development*. TFC 2021. IFIP Advances in Information and Communication Technology, vol 635 (pp. 315-329). Springer, Cham.
- Oget, D. and Sonntag, M. (2002). *Cognitive Development with TRIZ and Problem Based Learning*. Proceedings of the 2nd ETRIA World Conference, Strasbourg, France, 6-8 Nov. 2002, ISBN 2-86820-227-6, p. 35-40.
- Shah, J.J., Vargas-Hernandez, N., Smith, S.M. (2003), "Metrics for measuring ideation effectiveness", *Design Studies*, 24(2), pp. 111-134.
- VDI Standard 4521. (2016). *Inventive problem Solving with TRIZ. Fundamentals, terms and definitions*. Beuth publishers, Duesseldorf, Germany.

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