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Fostering Systematic Inventive Thinking (SIT) and Self-Regulated Learning (SRL) in Problem-Solving and Troubleshooting Processes among Engineering Experts in Industry

Moshe Barak
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Abstract

The present research addressed two unique aspects of fostering problem solving and inventive thinking among engineering experts: first, teaching the Systematic Inventive Thinking (SIT) method for problem solving and new product development; second, fostering Self-Regulated Learning (SRL) comprised of cognition, meta-cognition and self-efficacy beliefs among engineering experts. The pilot study involved observations at industry sites to learn about experts' thinking while solving problems. In the main study, we developed a 30-hour workshop on teaching SIT and SRL that was delivered to five groups of 20-25 engineering experts each (total n=110) at the workplace. The workshop included lectures, discussions, games and solving authentic engineering problems. Data was collected by means of questionnaires, interviews, problem-solving tests, observations and documenting class activities. The findings indicated that the participants significantly improved their competencies related to identifying problems in a given system, and suggesting more innovative solutions and less irrelevant solutions to these problems.

Keywords: problem solving, systematic inventive thinking, self-regulated learning

Introduction

It is widely agreed that one of the most important challenges for education today, and technology education in particular, is fostering individuals' creative thinking in areas such as problem solving, design, and invention of new products and services. This requirement is crucial not only for K-12 education but also for higher education and professional development of management and engineering staff in the workplace. Despite the huge amount of literature on creativity and problem solving available, the question of how to improve students' or engineers' problem solving and inventive thinking abilities continues to be of concern to researchers. One obstacle to achieving this goal is the common perception that creativity is an innate or God-given capability people either have or have not, but can only be improved a little by direct teaching. A second barrier in this regard is that the wish to teach people methods to reach 'unusual' or 'surprising' ideas sounds like an oxymoron. As a result, many studies on fostering creativity in technological design and problem solving focus merely on creating an environment or conditions for creativity, or encouraging students to "think outside the box." For example, among the most popular methods for seeking new ideas are brainstorming (Osborn, 1963), and divergent thinking or lateral thinking (de Bono, 1992), which actually intend to reach ideas randomly from nowhere.

For example, one creativity method often mentioned in the literature of brainstorming is to select a word randomly and think of as many uses as possible with this word in connection with the problem to be solved. It is often recommended to break the random word into its characteristics, and think about its functions, associations, metaphors, synonyms or antonyms. All these techniques are based on the hope that a random search in many directions may lead to finding a useful new idea.

Another difficulty that often accompanies efforts to foster creativity among young students or engineering experts is that programs for teaching creative thinking frequently address only a little of the broad literature on cognition and learning, such as fostering meta-cognition and reflection in the process of inventive thinking and creative problem solving. For example, according to Runco (2015), the term meta-creativity means using what is learned about creativity from the creativity research to be more creative, or 'being creative about creativity.' However, both creativity and the way to become creative remain somewhat mysterious. Van de Kamp, Admiraal, van Drie, and Rijlaarsdam (2015) found that explicit instruction of meta-cognitive knowledge in the context of divergent thinking in visual arts had a positive effect on fluency and flexibility but not on originality. Yet, studies that might help in fostering meta-cognition in creative thinking in technology and engineering are relatively rare. Accordingly, the research question that guided the present work relates to the effectiveness of teaching methods of systematic inventive thinking and problem solving in conjunction with fostering self-regulated learning in technology and engineering.

In the present study, we address these issues from two unique aspects: first, teaching methods for "Systematic Inventive Thinking" (SIT) to engineering experts; second, teaching aspects of self-regulated learning (SRL) in problem solving and inventive thinking in the engineering context. The following sections include a brief review of the literature on SIT and SRL, findings from a pilot study on inventive thinking and problem solving among engineering experts, and the contents and methodology of a course on SIT and SRL that was delivered to five groups of engineers at the workplace. Findings from the study in terms how the course affect participants' achievements and attitudes towards learning inventive problem solving, and the implications of this study for technology education are also discussed.

Literature Review

Systematic Inventive Thinking (SIT)

The term *inventive thinking* in engineering and technology relates to finding original and effective solutions to problems, or inventing new, useful products and services. *Systematic Inventive Thinking* (SIT) is a method of finding solutions to problems by making systematic alterations or manipulations with a system's components and attributes, rather than searching randomly for ideas using methods such as brainstorming. The SIT method (Horowitz, 2001; Turner, 2009; Boyd & Goldenberg, 2014), was derived from the TRIZ theory of inventive problem solving (Altshuler,1988).

Among the principles, or tools, learned in the course are:

- *Unification:* solving a problem by assigning a new use or role to an existing object;
- *Multiplication:* solving a problem by introducing a slightly modified copy of an existing object into the current system;
- *Division*: solving a problem by dividing or cutting an object or subsystem and reorganizing its parts;
- *Change relationships between variables or attributes:* solving a problem by adding, removing or altering relationships between variables;
- *Removal:* solving a problem by removing an object (with its main function) from the system; and
- *Inversion:* solving a problem by inverting the structure or functions of components in a system.

The following example demonstrates how a product or service could be improved using the principle of 'changing relationships between variables in a system.' Customers who order pizza by home delivery often complain that the pizza arrives later than promised or is not hot enough. The question is how to improve customer satisfaction. A conventional solution is to shorten delivery time, which is often expensive. According to the SIT method, we try to solve a problem using different components and processes already existing in the system, while adding a minimum of new resources. To apply the 'change relationships between variables' concept, we first make a list of all of the variables associated with the world of the problem, for example, pizza type, size, shape, delivery time and temperature. We also list the variables related to the customer, for example, residential area, distance from the pizza store, customer age or order time. The second step is to try to add, remove, or change relationships between two variables. For example, we can link the variable *price* with the variable *delivery time*, as illustrated in Figure 1.

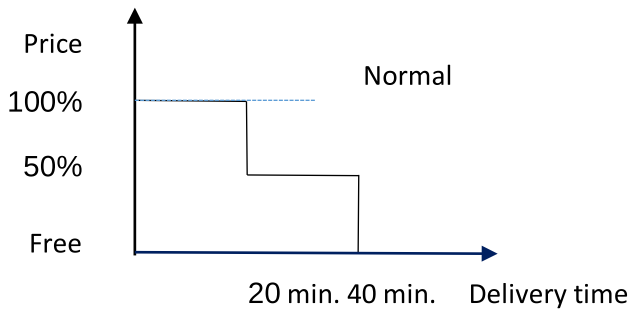


Figure 1: Linking pizza price with delivery time.

Goldenberg and Mazursky (2002) call the method illustrated in Figure 2 a change of *attribute dependency*, and show an additional solution of linking the pizza price with its temperature. Barak and Goffer (2002), and Barak and Mesika (2007) show more examples of teaching the SIT method to engineers and junior high school pupils. Drew and Goldenberg (2014) use the term thinking *Inside the box* as an alternative approach to inventive thinking. More studies on the SIT method are presented by Reich, Hatchuel, Shai, and Subrahmanian (2012), Turner (2009), and Moon, Ha and Yang (2012).

Self-Regulated Learning (SRL)

In recent years, educators have recognized increasingly that the cognitive side of learning and problem solving relates closely to the meta-cognitive side, that is, a learner’s self-awareness of his thinking. At the heart of the current research lies the concept of Self-Regulated Learning (SRL), which combines the cognitive, meta-cognitive and motivational aspects of learning and problem solving (Barak, 2010; Zimmerman & Schunk, 1989). While a great deal of knowledge about meta-cognition in learning among children is available, relatively little research exists regarding meta-cognitive thinking among engineering experts in industry within the context of troubleshooting and problem-solving processes.

The origin of the term Self-Regulated Learning (SRL) lies in Bandura’s social-cognitive theory (Bandura, 1986), which focuses on a learner’s self-observation, self-judgment and response. The theory emphasizes responsibility to the learning process (Schraw, Crippen, & Hartley, 2006), recognition and use of thinking strategies and skills, and motivation to succeed (Pintrich & DeGroot, 1990). In the present study, we examined troubleshooting and problem-solving processes among industry experts, focusing on the following aspects:

- *Cognition*: thinking patterns of industry experts; identification of non-procedural thinking processes such as heuristics, analogies and intuition regarding professional problems in industry;
- Meta-cognition: how experts in industry build a thinking strategy for troubleshooting and problem solving; and
- Self-efficacy: the perception of self-confidence and a sense of ability to succeed in carrying out a task.

Phase I: Pilot Study

The pilot study was intended to identify how engineering experts such as engineers and technicians deal with troubleshooting and problem solving at the workplace, with emphasis on the aspects of cognition, meta-cognition, and the use of Declarative, Procedural, Conceptual and Qualitative (DPCQ) knowledge in problem solving.

Data collection method

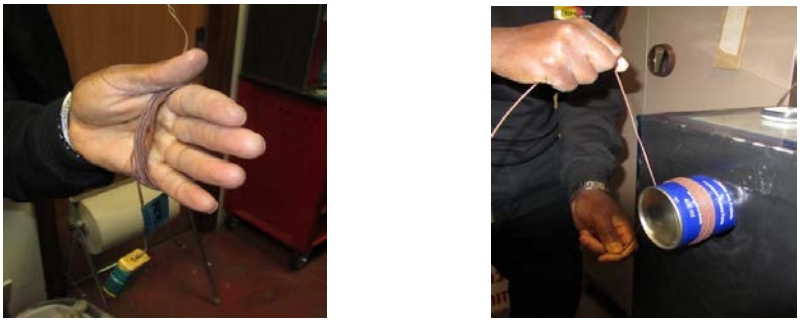
In the pilot study, one of the researchers studied the process of troubleshooting and improving machines and production lines in a food plant. He closely followed the work of 22 experts (engineers, technicians and heads of production lines), and fully documented 12 cases of identifying problems and making attempts to solve them in order to learn aspects such as identifying or comparing components, variables, processes, or checking a hypothesis.

During this phase, we also conducted the pilot round of the SIT/SRL workshop described below, which comprised 10 meetings of three hours each (total 30 hours). Due to the limited scope of this paper, we present only one example from the findings of the pilot study.

Example from pilot study: Prevention of temperature measurement deviations

The temperature of a specific machine in a production line was measured using a thermocouple temperature sensor. This is an electrical device comprised of two different conductors that produces a temperature-dependent voltage as a result of the thermoelectric effect. An external quality expert who reviewed the plant's production lines identified that in one of the machines, the workers used to fold the thermocouple wires, as illustrated in Figure 2a.

The expert pointed out that folding the wires in this way might produce micro-cracks in the wires, which could influence the wires' electrical resistance and cause a deviation in the temperature measurement accuracy. A simple solution was implemented by wrapping the electrical wire around an empty spray can, as illustrated in Figure 2b.



a b

Figure 2: Wrapping an electric wire around the palm of a hand (a) or around empty spray can b).

To troubleshoot and solve this problem, the expert had to possess conceptual knowledge about electrical circuits and temperature measurements using a thermocouple, as well as qualitative knowledge about frequent faults in measuring devices. In this example, the expert deliberately searched for things that could negatively affect the accuracy or reliability of the system tested. He proposed a simple solution that used devices already existing in the close environment, with no need for adding significant resources to the system. This is one of the characteristics of inventive problem solving, as was learned in the SIT/SRL course developed in this research.

Phase II: The Main Research

The main research involved the development, implementation and evaluation of the 30-hour SIT/SRL workshop which dealt with two main subjects:

1. Problem-solving methods, including the Systematic Inventive Thinking (SIT) method; and
2. Self-regulated learning in problem solving: cognition, meta-cognition and motivation in problem solving.

The updated version of the workshop comprised five class meetings of six hours each (total of 30 hours), which included lectures, discussions, games and quiz solutions that require different thinking strategies and skills, such as spatial vision, logic, induction, deduction and mathematical calculations.

The workshop was delivered to five groups of 20-25 engineering experts each (total n=110) The participants worked in small groups and dealt with more than 50 tasks and quizzes that were taken from the broad literature existing in this regard: for example, by Dudeney (2016) and Gardner (1987). However, the most important part of the workshop was the analysis of practical examples of authentic engineering problem solving that the participants' presented from their experience in the workplace. At the end of solving each task, each group discussed the process that took place in the group, for example, the role each participant took, thinking patterns and problem solving methods the groups used, and the application of SIT principles or other strategies in solving the task. At the end of the internal discussion in the groups, the entire class held a summative discussion in which each group presented their solution and working process. Finally, each participant wrote a short reflection of his work in the group in the form of answering questions such as How did I feel? How did I perform in the group? What did I learn about myself as a problem solver and as a group member?

The process described above, which was held four or five times in each class, was a central part of the present research. As already noted, the program under discussion intended to combine teaching the Systematic Inventive Thinking (SIT) method with fostering Self-Regulated Learning (SRL) among engineering experts.

Data collection methods

Data were collected in the following ways:

1. Fully documenting students' activities in the class:
2. Administering the Problems and Solutions (P&S) test (see details in the following section):
3. Holding interviews with participants in the class; and
4. Carrying out a repeated examination of the workshop's influence on the work of seven participants in their workplaces about three months after learning the course.

As previously mentioned, the core of the SIT method involves solving a problem or inventing a new product by using one or a combination of the following principles: Unification, Multiplication, Division, Change relationships between variables, Removal and Inversion. During the course under discussion, the engineers discussed a range of examples of the application of these principles, such as the pizza delivery cases mentioned above. In the class, the participants presented examples of using these principles to solve problems of design issues at their work. For example, one of the participants presented the case of finding a root cause for an engineering problem using a 'fish-bone diagram' (Yazdani & Tavakkoli-Moghaddam, 2012) to identify all possible reasons for causing unequal thickness in aircraft parts made of composite materials (carbon and epoxy). By analyzing each of the possibilities, the root cause was detected and a proper solution was developed. Another example was the case of improving a mechanical device aimed at locking a mechanical system. In order to provide an indication that the system is locked, an electrical switch was placed under the locking pin. This had to do with the Unification principle – assigning a new function to a component already existing in the system.

The nails puzzle

Some of the examples and exercises presented in the course were games and puzzles that could be found in books or on the Internet. One example is the nails puzzle shown in Figure 3, where the task is to hang all 10 nails from the table on the vertical nail without using any extra devices or materials.

Figure 3: The nails puzzle starting point.

Figure 4: The nails puzzle main solution stage.

Figure 5: The nails puzzle final solution.

The participants received the nails puzzle towards the end of the workshop. They worked in groups for about 60 minutes in class. Only three out of 20 groups managed to solve the problem, as shown in Figures 4 and 5. Data on how the participants coped with the problem were obtained using the *thinking aloud* method. We asked the participants to say in their own words what they were doing at each stage, their considerations, thoughts and trials. Three participants were recorded for 40-60 minutes each.

One of the participants in the workshop who solved the nails puzzle was a mechanical engineer who had a good record of inventiveness and problem solving in his job. Following are some comments from this engineer while working on the problem:

- The solution must follow the laws of physics;
- It has to do with equilibrium… with symmetry;
- There must be a construction that holds the nails;
- A construction always includes a skeleton and supporting elements;
- First I will create a construction and then see how to attach it to the nail;
- I will probably use two nails for the skeleton and eight [four + four] for the body [symmetry];
- It must be based on action and reaction forces… the nails press against each other; and
- The nails are already connected together and pressing against each other.

Aside from his thoughts on how to solve the problem, this participant also expressed meta-cognitive ideas, such as:

- I carried out many trials and felt that the solution was slipping through my fingers;
- I did not have a solution in mind… I built it step by step;
- I had a wide spectrum of thoughts… some of them were against the laws of physics; and
- I need logical thinking… how to obtain equilibrium.

The nails puzzle example demonstrates how a combination of *conceptual knowledge* in the related fields of physics and mechanics and *meta-cognitive knowledge* about problem solving play a central role in the problem-solving process. The SIT method is also relevant in solving this puzzle because SIT directs the problem solvers to use resources existing naturally in the system in a new way. In the present case, the gravity force acting on the nails is also used to press the nails together.

Findings from the Problems and Solution (P&S) test

This test intended to measure participants' abilities in *identifying problems* or dangers in using a specific tool or equipment at home or at the workplace and *suggesting solutions* to these problems.

For example, in using a samovar, as illustrated in Figure 6, there are dangers of being burned from the hot water, an electric shock or starting a fire.

Figure 6: An example from the Problems and Solutions test:

a. Point out as many **problems or dangers** as possible in using the instrument.

b. Suggest as many **solutions** as possible to each problem you have mentioned.

The test items related to the following categories were heating equipment, turning equipment, poisonous materials, spray work, electrical cutting tools, water reservoir, wet environment, transportation, seating, Illumination and radiation. As seen in Figure 6, a typical instruction in the test was:

a. Point out as many **problems or dangers** as possible in using the instrument.
b. Suggest as many **solutions** as possible to each problem you have mentioned.

Participants' answers were analyzed in terms of the following two aspects:

a. The **number of problems** identified for each device or tool; and
b. The number of **inventive solutions**, **conventional solutions** and **irrelevant solutions** proposed for each question. This method was developed in a previous study on teaching "Systematic Inventive Thinking" to children (Barak & Mesika, 2007).

The test was prepared in two versions containing 20 items each, which were used as pre-and post-course exams. Half of the participants answered version 1 before completing the course and version 2 at the end of the course, and the other half answered the same exams in reverse order. Since no significant differences were observed between students' mean scores in the two versions either in the pre- or post-course exams, the two versions could be considered as identical.

Due to the limited scope of this paper, we only present findings for questions a and b mentioned above, as shown in Table 1 and Figures 6-8.

Table 1: Number of problems, irrelevant solutions, and inventive solutions the participants suggested in the Problems and Solution (P&S) test

		Experimental Group (N=87)				Control Group (N=24)	
		Pre-course		Post-course			
		Mean	SD	Mean	SD	Mean	SD
TP	Number of problems identified	31.38	18.52	44.42	24.56	32.38	17.54
TC	Number of irrelevant solutions suggested	10.95	8.76	0.15	0.45	1.21	2.54

TI	Number of inventive solutions suggested	0.65	1.23	4.84	4.83	0.14	0.44

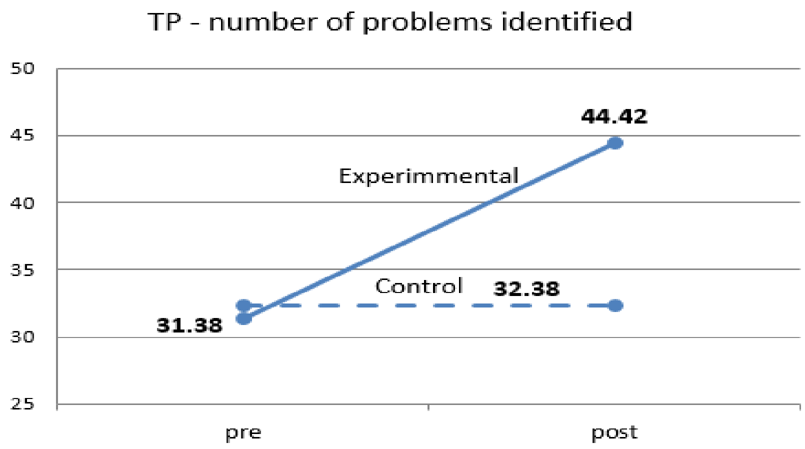


Figure 7: TP - Number of problems identified by the experimental and control groups.

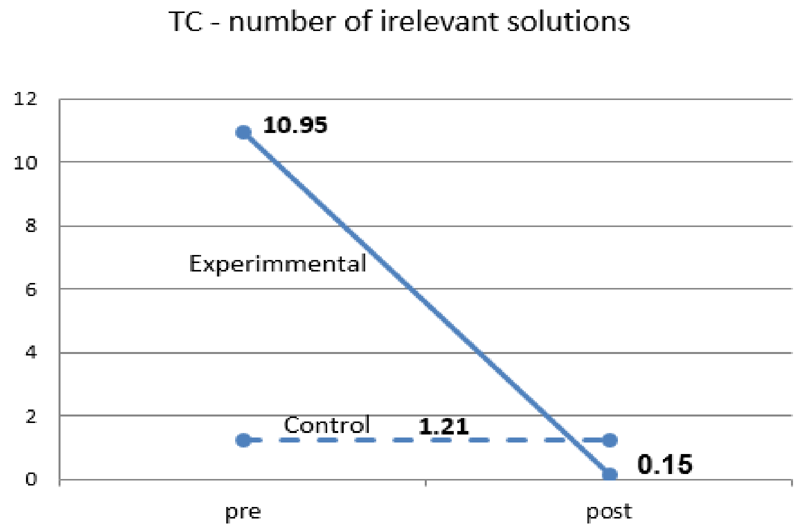


Figure 8: TC - Number of Irrelevant solutions suggested by the experimental and control groups.

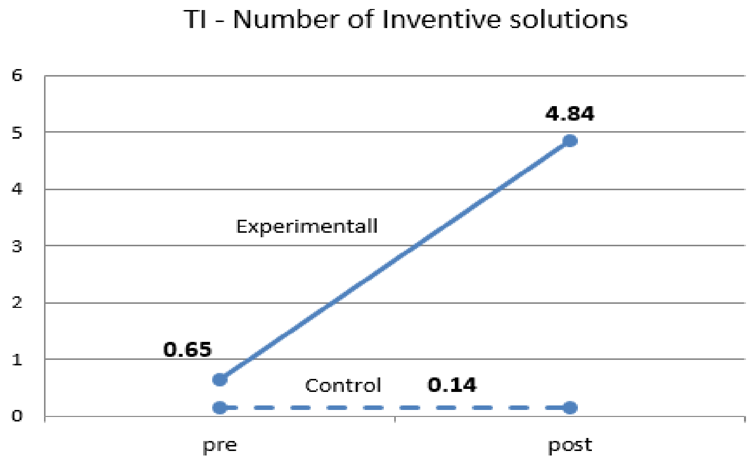


Figure 9: TI - Number of inventive solutions suggested by the experimental control groups.

To identify whether the participants' performance in the problem and solutions (P&S) test (TP, TC, and TI - dependent variables) were significantly affected by the test data (pre/post course - independent variable), a one-way MANOVA analysis was carried out on the raw data presented in Table 1. The findings $F(df=3)=201.198$ $p<0.000$) indicate a significant effect.

Since one-way MANOVA is an omnibus test statistic that does not tell which specific variables were significantly different from each other, it is common to follow this analysis by t-tests involving individual dependent variables separately. The findings, which are also illustrated in Figures 7, 8 and 9, are detailed below:

- TP - the mean number of problems the students in the experimental groups identified increased significantly from 31.38 to 44.42 ($t(df=164)=3.875$, $p<0.040$);
- TC - the mean number of irrelevant solutions the students suggested decreased significantly from 10.95 to 0.15 ($t(df=164) = 11.080$, $p<0.000$); and
- TI - the mean number of inventive solutions the students suggested increased significantly from 0.65 to 4.84 ($t(df=164)=7.75$, $p<0.000$).

In summary, the findings described above show that after completing the course, the participants in the experimental groups excelled in the final exam in all of the three parameters measured. In comparison to the control group, the course graduates identified more problems, suggested a higher number of inventive solutions and wrote fewer irrelevant solutions to these problems.

Repeated examination of the workshop's effects on participants' performance in their workplaces three months after learning the course

Three months after the completion of each workshop, we randomly selected four participants from each of the five groups that had participated in the workshop (total n=20) and asked them to meet the researcher at their workplace for a personal interview, to discuss how and to what extent learning from the SIT/SRL workshop affected the participant in his/her work. Twelve of the 20 engineers who were invited accepted the invitation, but in the end, the interview was held with only four, and three others sent written feedback letters of 4-6 pages. The reviewer conducted in-depth open-ended interviews, in which the interviewees selected the topics or examples they wanted to discuss. All the four oral interviews were recorded and transcribed.

In the first round of the data analysis, we identified the main categories the participants related to either in the interview or in the feedback letter. In the second round, we counted the number of participants who mentioned each category, as displayed in Table 2.

Table 2: Main categories from the subjects raised by the participants in the interviews or feedback letters three months after learning the SIT/SRL workshop.

Category	Frequency
Being proud of the self-change	7
Gaining sound knowledge of ideas and concepts	7
Checking problems from different directions	7
Using thinking strategies	7
Becoming confident in self-efficacy	6
Changing ways of thinking	6
Wishing to influence the workplace	5
Willing to study deeper	3

Table 2 shows that participants marked significant effects of the workshop regarding their competences and self-confidence in coping with problem solving and inventive thinking in their jobs in the workplace.

Discussion and Conclusions

The present study addressed two unique aspects of fostering problem solving and inventive thinking among engineering experts: first, teaching Systematic Inventive Thinking (SIT) methods for problem solving; second, teaching about Self-Regulated Learning (SRL) comprised of cognition, meta-cognition and self-efficacy beliefs. Encouraging results were obtained in providing the SIT/SRL workshop to five groups of engineering experts. The participants significantly improved their competencies regarding identifying problems in a given system or tool, and suggesting more innovative solutions and fewer irrelevant solutions to these problems. The participants reported that their thinking had changed to become more systematic in carrying out in-depth examinations of situations, and they were more effective in searching for solutions, extracting thinking methods and taking a panoramic view of the situation.

The findings of the present study replicate and extend the outcomes of prior studies that examined the effectiveness of teaching the Systematic Inventive Thinking (SIT) method to engineers (Barak & Goffer, 2002; Barak, 2004), mathematics and science teachers (Barak, 2006) and school children (Barak & Mesika, 2007). The present research, however, advanced this notion one step further by also integrating the teaching of Self-Regulated Learning (SRL), and meta-cognition in particular, in the problem-solving course. The training workshop that was developed and tested in this study could serve as a model for professional development programs not only for engineering experts but also for school students and teachers.

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References

Altshuller, G. S. (1988). *Creativity as an exact science*. New York, NY: Gordon and Breach. doi:10.1590/S1806-11172005000200004.

Bandura, A. (1986). *Social foundation of thought and action*. Englewood Cliffs, NJ: Prentice Hall.

Barak, M. (2004). Systematic approaches for inventive thinking and problem solving: Implications for engineering education. *International Journal of Engineering Education*, *20*(4), 612-618.

Barak, M. (2006). Teaching methods for systematic inventive problem solving: Evaluation of a course for teachers. *Research in Science and Technological Education*, *24*(2), 237–254

Barak, M. (2010). Motivating self-regulated learning in technology education. *International Journal of Technology and Design Education*, *20*(4), 381-401. doi:10.1007/s10798-009

Barak, M., & Goffer, N. (2002). Fostering systematic innovative thinking and problem solving: Lessons education can learn from industry. *International Journal of Technology and Design Education*, *12*(3), 227-247. doi:10.1023/A:1020259623483

Barak, M., & Mesika, P. (2007). Teaching methods for inventive problem-solving in junior high school. *Thinking Skills and Creativity*, *2*(1), 19-29. http://dx.doi.org/10.1016/j.tsc.2006.10.002 9092-x

Boyd, D., & Goldenberg, J. (2014). *Inside the box: A proven system of creativity for breakthrough results*. New York, NY: Simon & Schuster. http://dx.doi.org/10.7469/JKSQM.2015.43.1.001

De Bono, E. (1992). *The use of lateral thinking.* London, UK: Penguin. doi:10.1007/s10551-007-9422-4.

Boyd, D., & Goldenberg, J. (2014). *Inside the box: Why the best business innovations are right in front of you*. London, England: Profile Books

Dudeney, H. E. (2016). 536 puzzles and curious problems. Mineola, NY: Dover Publications. http://dx.doi.org/10.1017/S0025557200121783.

Gardner, M. (1987). *The second scientific American book of mathematical puzzles*. Chicago, IL: University of Chicago.

Goldenberg, J. & Mazursky, D. (2002). *Creativity in product innovation*. Cambridge, UK: Cambridge University. https://doi.org/10.1017/CBO9780511674464

Horowitz, R. (2001). ASIT's five thinking tools with examples. *TRIZ Journal*, 21, *September*. https://triz-journal.com/asits-five-thinking-tools-examples/

Moon, S., Ha, C., & Yang, J. (2012). Structured idea creation for improving the value of construction design. *Journal of Construction Engineering & Management*, *138*(7), 841-853. Doi:10.1061/(ASCE)CO.1943-7862.0000491#sthash.NGjtyCXP.dpuf

Osborn, A.F. (1963). *Applied imagination: Principles and procedures of creative problem solving* (3rd ed.). New York, NY: Charles Scribner's Sons

Pintrich, R. R,. & DeGroot, E. F. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82*, 33-40. Doi: 10.1037//0022-0663.82.1.33

Reich, Y., Hatchuel, A., Shai, O., & Subrahmanian, E. (2012). A theoretical analysis of creativity methods in engineering design: Casting and improving ASIT within C–K theory. *Journal of Engineering Design*, *23*(2), 137-158. doi:10.1080/09544828.2010.493505

Runco, M. A. (2015). Meta-creativity: Being creative about creativity. *Creativity Research Journal*, *27*(3), 295-298. doi:10.1080/10400419.2015.1065134

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*, 111-139. doi:10.1007/s11165-005-3917-8

Turner, S. (2009). ASIT: A problem solving strategy for education and eco-friendly sustainable design. *International Journal of Technology and Design Education*, *19*(2), 221-235. doi:10.1007/s10798-008-9080-6.

Van de Kamp, M., Admiraal, W., van Drie, J., & Rijlaarsdam, G. (2015). Enhancing divergent thinking in visual arts education: Effects of explicit instruction of meta-cognition. *British Journal of Educational Psychology*, *85*(1), 47-58. doi:10.1111/bjep.12061

Yazdani, A., & Tavakkoli-Moghaddam, R. (2012). Integration of the fish bone diagram, brainstorming, and AHP method for problem solving and decision making: A case study. *International Journal of Advanced Manufacturing Technology*, *63*(5-8), 651-657. Do:10.1007/s00170-012-3916-7

Zimmerman, B. J. & Schunk, D. H. (1989). *Self-regulated learning and academic achievement: Theory research, and practice*. New York, NY: Springer. doi:10.1007/978-1-4612-3618-4