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SYSTEMATIC INVENTIVE THINKING (SIT): A METHOD FOR INNOVATIVE PROBLEM SOLVING AND NEW PRODUCT DEVELOPMENT

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Globalization; Systematic Inventive Thinking; Method for innovative problem solving.

A B S T R A C T

In the era of globalization and rapid technological changes, companies are required to develop new products and services frequently in order to maintain their position in the competitive market. Globalization is bringing opportunities and pressures for domestic firms in emerging markets to innovate and improve their competitive position. In the past, it was common to develop new products and services based on market surveys, or the "consumer's voice." However, countless innovative technological inventions that had changed the economy and culture were born through the knowledge and creativity of scientists and engineers, and not because of a market survey. The present paper will shed light on the Systematic Inventive Thinking (SIT) method for innovative problem solving and new product development. The paper will present findings from three examples of teaching the SIT method to managers and product developers in industry, to science and technology teachers, and to engineers in an advanced technological company. Conclusions for using SIT for management, problem solving and new product development are also suggested.

1. INTRODUCTION

In the era of globalization and rapid technological changes, companies are required to develop new products and services frequently in order to maintain their position in the competitive market. Globalization is bringing opportunities and pressures for domestic firms in emerging markets to innovate and improve their competitive position (Gorodnichenko et al., 2008). In the past, it was common to develop new products and services based on market surveys, or the "consumer's voice." However, this approach is not enough in today's dynamic and competitive market. In this regard, let us be reminded of the famous saying by Henry Ford after the invention of the car: "If I had asked people what they wanted, they would have said faster horses." He expresses the opinion that most people cannot conceive of ideas that are total paradigm shifts from what they currently know exists. According to Goldenberg, Horowitz, Levav and Mazursky (2003), marketers might tell us that the best sources of new product ideas are customers, both current and potential. However, we are increasingly seeing that customers lack the imagination to envision innovative products that address their needs or desires. For example, participants in focus groups typically opt for product innovations that feature only minor changes in a current version. When these

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products hit the market, they often fizzle out because small improvements are not enough to alter customers' entrenched buying habits.

Historically, countless innovative technological inventions that had changed the economy and culture were born through the knowledge and creativity of scientists and engineers, and not because of a market survey. Take, for example, the invention of the cellphone and the development of today's smartphone. If people would have been asked 20 years ago what they needed, would anyone have asked for a phone that could be carried in a pocket and enable making calls to and from any place? Would anyone have askedfor a mobile device that would include the Internet, Facebook and road navigation software? All these inventions, born of the inventor's imagination and not based on consumer requests, created new markets and pushed the economy forward. This raises the question of how to encourage technological innovation among scientists, engineers and inventors in the context of problem solving and inventing new products and services, as discussed in the next section.

2. THE SYSTEMATIC INVENTIVE THINKING (SIT) METHOD FOR FOSTERING CREATIVITY IN PROBLEM SOLVING AND NEW PRODUCT DEVELOPMENT

The Systematic Inventive Thinking (SIT) methodology is a structured method for idea generating by making systematic manipulations with the components or attributes of a product or system, for example, shape, size, color, transparency or electrical conduction. The SIT method (Horowitz, 2001; Turner, 2009; Boyd & Goldenberg, 2013; Heo et al., 2016; Stern et al.,2006) was derived from the TRIZ theory of inventive problem solving developed by Altshuler (1988), who had examined thousands of inventions from which he extracted properties characterizing creative solutions.
SIT includes the following five principles or 'tools':

- ***Subtraction***: solving a problem by removing an object (with its main function) from the system;
- ***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;
- ***Task Unification***: solving a problem by assigning a new use or role to an existing object; and
- ***Attribute Dependency Change***: solving a problem by adding, removing or altering relationships between variables or attributes in a product or a system.

2.1. The 'closed world' principle

Horowitz (2001) defined the 'closed world' principle, according to which in inventive problem solving or new product development, one should strive to use only elements or resources already existing in the product/problem, or in the close environment, rather than "importing" new external resources for the solution. This principle also relates to the term "thinking inside the box."

2.2. An example of solving a quiz by SIT: the curved pipe problem

The first example in this paper is the curved pipe problem quiz, a famous example of problem solving using SIT (Horowitz & Maimon, 1997;Altshuller, 1988). A corn grain processing plant uses a curved pipe to guide grain flow via an air stream. The problem: the grains erode the pipe's surface at the bend, as illustrated in Figure 1.

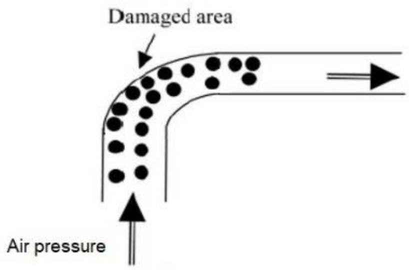

Figure 1. The problem of grains eroding the pipe.

An example of a customary solution is reinforcing the pipe by adding an erosion-resistant coating on the inside of the pipe. However, using the SIT method, we strive to solve the problem using components or resources that naturally exist in the system without significant use of additional resources. In this case, the components/resources in the system are: grains, pipe and air pressure.

According to the SIT 'task unification' principle, we try to solve the problem by assigning a new function or use to one or more components in the system. So, which of the three components in the system could help in solving the problem?

Figure 2 shows a solution in which the protection of the pipe is assigned to the grains by making a slight change in the pipe's shape.

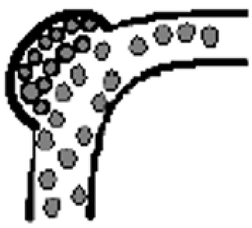

Figure 2. Using the grains to protect the pipe.

The reader is invited to think about how another component – air pressure – could be used to protect the pipe from abrasion. These solutions demonstrate the ‘closed world’ principle, or “thinking inside the box.”

2.3. A study on implementation of SIT in an industrial plant

All numbers and brackets in the text and formulas are to The second example of using SIT relates to the case of the Israeli KAPRO Industries company (Barak & Goffer, 2002). KAPRO has 30 years of experience in producing spirit levels, tape measures and other products for the construction industry, as illustrated in Figure 3.

Figure 3. A conventional spirit level

In the late 1990s, growing competition with cheap (but of constantly improving quality) products from developing countries posed a threat to the plant’s existence. The company realized that the main struggle with its competitors was not in the field of prices, but in the sphere of innovation, uniqueness and quality. Therefore, it exploited innovation as the main mechanism for strengthening the plant’s position and improving it in the end. Within these efforts, senior managers and engineers from KAPRO Industries participated in SIT workshops and consulted with SIT experts to develop new and innovative products, as illustrated in Figure 4.

The quest for innovation plays a key role in KAPRO Industries to date, and the company offers a range of innovative products to the construction industry, for example, laser-based levels.

A three-dimensional level.

A level for measuring slope angles in degrees or percentages.

Figure 4. Examples of innovative products developed by KAPRO Industries using the SIT method.

3. EXPLORING THE IMPACT OF PROVIDING A COURSE ON SIT TO MATHEMATICS, SCIENCE AND TECHNOLOGY TEACHERS

The third example of using SIT presented in this paper involves providing a course on inventive problem solving to mathematics, science and technology teachers studying towards master’s or doctoral degrees at Ben-Gurion University of the Negev (Barak, 2006). The course was run twice: in a pilot class involving 13 participants who studied the subject during five sessions of three academic hours each as part of a broader course on teaching science and technology; and in a second class, also comprising 13 students, who participated in a full-semester course (13 sessions, three academic hours each) entitled ‘Inventive Thinking in Science and Technology.’

The following problem presented to the participants demonstrates the approach of solving a problem by *Attribute Dependency Change*, namely, changing relationships between variables in a system. Horowitz (2001) called this principle ‘breaking symmetry.’

> In designing a traffic roundabout, there are often contradicting demands: if the road is too narrow (the internal circumference is too large), very large vehicles such as trucks and buses encounter difficulties crossing the junction; if the road is too wide, conventional cars might not slow down enough in passing through the junction. Suggest an inventive solution to this problem.

The students had learned in class that one way of overcoming this contradiction is by connecting between the two variables: road width and vehicle size. In other words, the roundabout will need to function like a narrow road (having a wide internal circumference) for small cars but also as a wide road (small circumference) for large vehicles. Other variables that must also be addressed are drivers’ habits. A solution to this problem is shown in Figure 5. While trucks and buses can easily travel over the small step of the intermediate circle, drivers of small vehicles usually avoid driving over this step.

Figure 5. A two-dimensional roundabout road.

The solution seen in Figure 5 creates dependency between two variables, road width and car size, as illustrated in Figure 6.

The idea of traffic lanes intended only for public transportation, as is common in large cities, is based on the same principle: making a connection between the lane location and the type of vehicle allowed to use each lane.

The solution seen in Figure 5 creates dependency between two variables, road width and car size, as illustrated in Figure 6.

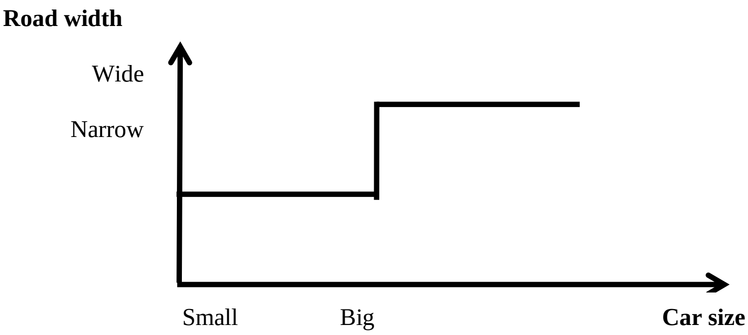

Figure 6. Creating dependency between two variables: road width and car size.

The idea of traffic lanes intended only for public transportation, as is common in large cities, is based on the same principle: making a connection between the lane location and the type of vehicle allowed to use each lane.

Goldenberg and Mazursky (2002) in their book *Creativity in Product Innovation* presented the principle of changing dependency between variables in the example of pizza delivery. Customers are often disappointed when a pizza they receive by delivery is not hot enough. Sellers would like to compensate their customers with a 50% discount if the pizza temperature is less than 60ºC. The solution is also based on connecting between two variables: pizza temperature and price per customer. We can show this by using a graph similar to the one in Figure 6. We can refine this idea further by placing a small temperature sensor in the pizza box that changes color continuously according to the pizza's temperature, for example, from red for a hot pizza to blue for a cold pizza. Accordingly, the pizza price will fall from 100% to 0%, as illustrated in Figure 7.

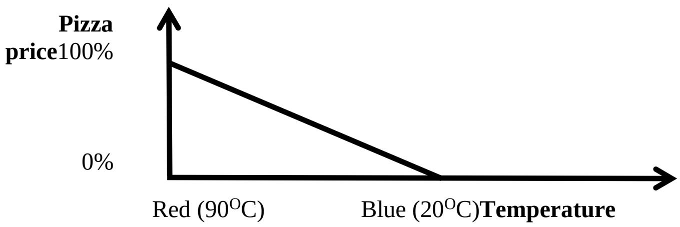

Figure 7. Linking pizza price to temperature.

This example also demonstrates the concept of solving a problem or inventing a new service by changing relationships between variables in a system.

3.1. Findings from the pre- and post-course inventive problem-solving exam

The participants in the two SIT courses mentioned above answered a six-question exam before and after learning the course (in different versions). Full information on the exam questions and the findings in this study are presented in an earlier publication (Barak, 2006). Here, we present only a partial example of the findings in this study. Figure 8 shows that the percentage of inventive ideas (versus conventional answers) the students wrote in the post-course exam was much higher in comparison to answers in the pre-course exam.

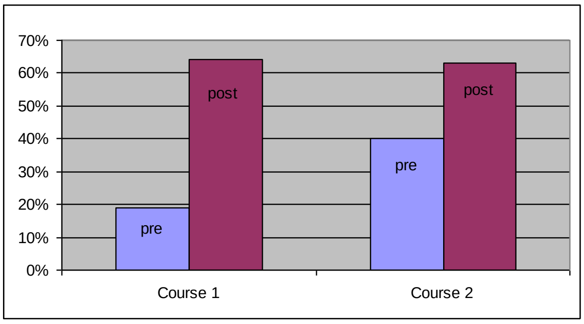

Figure 8: The rate of inventive ideas in students' answers in the post-course versus the pre-course exam

Following are examples of students' reflections during the course in the summative discussion and even several weeks later:

"The most important point I learned is that a good solution to a problem is often close by; you don't have to look far."
"Now I look at things differently; I see things on the street, at home or on TV and say, oh, this product is based on 'division,' that advertisement uses the 'multiplication' principle, and so on."
"I can identify how the simple principles or tricks we learned are used everywhere…"
"I am trying to teach these thinking methods to my children."

Naturally, some students expressed different views. For example:

"I am very creative, but in a spontaneous fashion; thinking systematically does not suit me."
"I don't see how these methods can help in mathematics."

In general, science and technology teachers, more than mathematics teachers, found great interest in the SIT method. Barak and Mesika (2007) conducted a two-year study on teaching SIT to junior high school students in the framework of science class. Data included pre- and post-course quizzes, interviews and observations of class activities. The findings indicated that the school-children significantly improved their achievements in suggesting original solutions to problems in comparison to the control group, and successfully utilized the method they had learned in their final projects in subjects such as an 'amusement park' and 'road safety.'

3.2. A study on cultivating Self-Regulated Learning (SRL) and Systematic Inventive Thinking (SIT) among engineering experts in industry

The third example relates to a study in fostering problem solving and inventive thinking among engineering experts (Barak & Albert, 2017). The program aimed at achieving two goals: first, fostering Self-Regulated Learning (SRL) comprised of cognition, meta-cognition and self-efficacy beliefs (Bandura, 1986; Barak, 2010); and second, teaching SIT methods for problem solving (Altshuler, 1988; Horowitz, 2001; Turner, 2009). In a pilot study, Barak and Albert (2017) conducted observations at industry sites to learn about experts' thinking while solving problems. In the main study, the researchers developed a 30-hour workshop on problem solving in the engineering context, which included teaching about SRL and the SIT method, including games, quizzes and practical tools of thinking and problem solving, as shown in Figure 9.

Figure 9. Examples of puzzles and games the engineers dealt with

The course was delivered to five groups of 20-25 engineering experts (total n=110). An additional group of 30 engineering experts from one of the organizations served as the control group. The study combined qualitative and quantitative methodologies, and data collection tools included questionnaires, interviews, tests, observations and documenting participants 'talking aloud' in problem solving.

The findings indicated that the engineers significantly improved their competencies regarding identifying problems in a given system or device and in suggesting more innovative solutions and less irrelevant solutions to those problems, as illustrated in Figure 10. They also reported that their thinking had changed, and they became more systematic and effective in carrying out in-depth examinations of situations and searching for solutions.

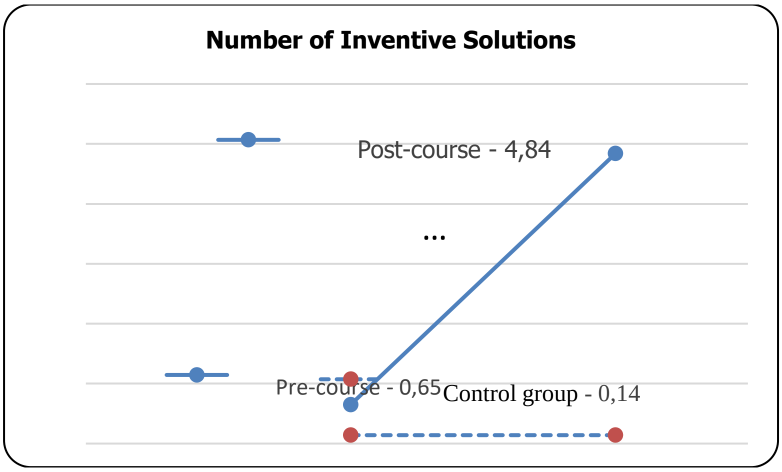

Figure 10. Number of inventive solutions engineers in the experimental and control groups suggested in the pre- and post-course exam (N=110).

4. APPLICATION OF SIT FOR NEW PRODUCT DEVELOPMENT: THE CONCEPT OF "FUNCTION FOLLOWS FORM"

The SIT method was developed and examined in two major applications: inventive problem solving and new product development. Many new inventive products that have dominated the market were born as a result of manipulating components of an existing product. For example, in the past, we had used a telephone connected to a wall socket with a wire; then the cordless phone was born; after that, the cellphone came along, followed by the smartphone. Another example: let us apply the SIT tools to a conventional chair, as illustrated in Figure 11.

Subtraction: If we remove the backrest, we get a stool; if we remove the chair legs, we get a beach chair.

Duplication: If we duplicate the seat, we get stairs.

		
Legs subtraction	Backrest subtraction	Seat multiplication

Figure 11. Outcomes of applying SIT tools subtraction and multiplication to a chair.

In their book entitled *Creativity in Product Innovation* (2002), Goldenberg and Mazursky use the term "creativity templates" to describe SIT and other systematic methods for thinking along inventive lines in order to target creative thoughts. These authors define this perspective as "Function Follows Form" (p. 41), in contrast to the conventional approach of "Form Follows Function." The notion of "Function Follows Form" has been associated with some of Apple's revolutionary products in which people were first surprised by a new product design but quickly learned to use and enjoy the product. Goldenberg and Mazursky (2002) proposed the concept of "the voice of the product" to describe the process in which new innovative products create a market, in contrast to the conventional approaches of "the voice of the customer" or "the voice of the market" in developing new products.

Boyd and Goldenberg (2013, p. 10) write that the "Function Follows Form" principle (just the opposite of "Form Follows Function") dates back to 1896 and the architect Louis Sullivan. These authors mention other psychologists who recognized in 1992 that people take one of two directions when thinking creatively: from the problem to the solution, or from the solution to the problem. Imagine being shown a baby's milk bottle that changes color as the temperature of the milk changes. Most people would instantly recognize that it would help to make sure that the milk for the baby is not too hot. Now imagine that you were asked the opposite question: how could we make sure that the baby's milk is not too hot? How long would it take you to come up with a color-changing milk bottle? Without a technique, you night never arrive at such an idea. Boyd and Goldenberg (2013, p.11) note that herein lies the key to using the method: apply one of the SIT techniques to create a “form” and then take that form and find a “function” it can perform, i.e., “Function Follows Form.”

SCAMPER and SIT

It is worth mentioning that the SIT method corresponds partially to the SCAMPER method (Eberly, 1972; Osborn (1963), consisting of the following techniques:
S—Substitute
C—Combine
A—Adapt
M—Magnify/Modify
P—Put to other uses
E—Eliminate
R—Rearrange/Reverse

Kaplan (2001) compared SIT to SCAMPER, and Horowitz claimed that SIT is better than SCAMPER because it is more restricting and therefore much more helpful to the problem solver.

5. IMPLICATIONS FOR SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) EDUCATION IN THE AGE OF GLOBALIZATION: ENTREPRENEURSHIP AND THE FACTOR OF CULTURE IN MODERN GLOBALIZATION

The term globalization is widely used to describe processes of worldwide development and transformation of scientific, technological, economic and cultural products, as well as scientific and technological innovations and ideas stretching out across the globe (Chiu & Duit, 2011; Carter, 2008). Developing universal methods for innovations in problem solving and developing innovative products and services can serve as a bridge to collaboration on STEM education between different countries worldwide.

The object of the study under consideration, due to its systemic socio-economic and resource-technological nature, requires a complex and interdisciplinary approach taking into account the views of various sciences (Bedianashvili, 1995). At the same time, we consider it important to touch upon the global context of the problem presented and its relation to the process of entrepreneurial activity. This aspect, makes it relevant to re-understand and develop entrepreneurship as a system, and entrepreneurial skills, as the most important component of this system (Acs et al., 2005; Bedianashvili, 2017b; Beugelsdijk, 2007; Hofstede et al., 2004; Papava, 2017).

In discussing the global context of entrepreneurship, it is necessary to consider the complexity of it as an ecosystem. The polistructural systems character of the entrepreneurial ecosystem is adequately represented in the Global Entrepreneurship Index, which includes 14 components in three categories, as descried in Table 1 (https://thegedi.org/tool/)

Table 1. Components in the Global Entrepreneurship Index

Entrepreneurial Attitudes	**1. Opportunity Perception**
	2. Startup Skills
	3. Risk Acceptance
	4. Networking
	5. Cultural Support
Entrepreneurial Abilities	**6. Opportunity Startup**
	7. Technology Absorption
	8. Human Capital
	9. Competition
Entrepreneurial Aspirations	**10. Product Innovation**
	11. Process Innovation
	12. High Growth
	13. Internationalization
	14. Risk Capital

For the format of our research,it is important from the indicators presented for entrepreneurial activities (Acs, Szerb, & Eloyd, 2018) on the essence of indicators:

- Startup Skills – Does the population have the skills necessary to start a business based on their own perceptions and the availability of tertiary education?;
- Technology Absorption - Is the technology sector large and can businesses rapidly absorb new technology? and
- Human Capital - Are entrepreneurs highly educated, well trained in business and able tomove freely in the labor market?

In addition to the above, the challenges of modern globalization, such as the cross-cultural characteristics of countries and the importance of their adequate reflection in entrepreneurship and all areas of activity should be considered as well (Bedianashvili, 2014; Bedianashvili, 2020).

The global differences in culture between countries are clearly reflected in the Hofstedean model of culture, according to which we can judge the attitude towards innovative thinking and habits in this or that national cultural values. Separate studies confirm that the cultural factor is crucial for the proper development of innovative activities (Hofstede, et al., 2004; Bedianashvili, 2014; Bedianashvili, 2020; Didero, et al., 2008; Beugelsdijk, 2007; Furman, porter, & Stern, 2002; Geertz, 1973; Inglehart & Welzel, 2005; Acs, 2006; Barnett, 1953; Beugelsdijk et al., 2014; Edler & Fagerberg, 2017).

The Hofstede Insights Culture Compass™ is a tool to understand the impact of cultural value preferences and potential behavioral pitfalls while working with people from selected countries. Figure 12 shows the comparative disposition of cultural values for Georgia, Israel, Switzerland and United States (Resource: https://www.hofstede-insights.com/country-comparison/georgia,israel,switzerland,the-usa/)

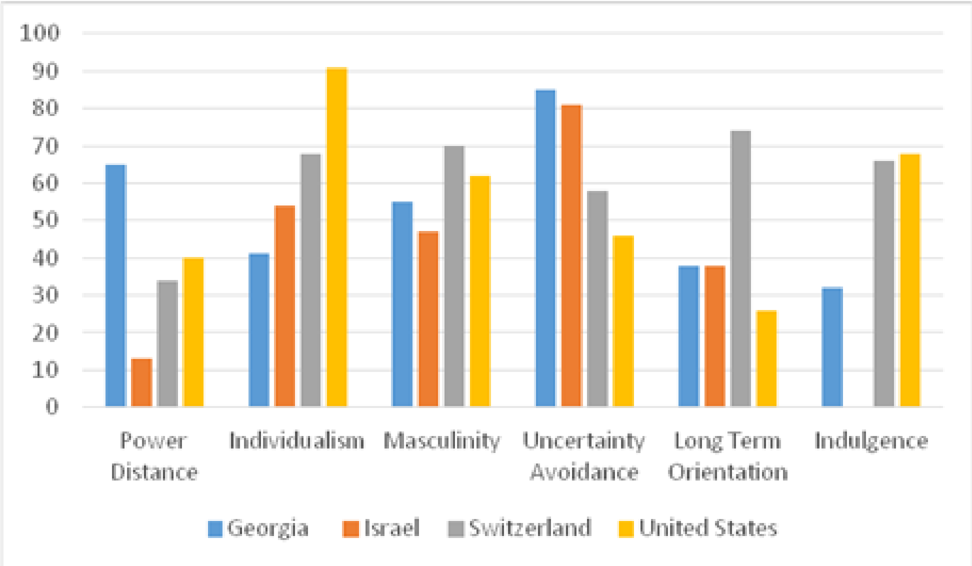

Figure 12. The comparative disposition of cultural values for Georgia, Israel, Switzerland and the United States

The Hofstede model of culture consists of the following six dimensions (https://hi.hofstede-insights.com/national-culture):

- **Power Distance**- this dimension expresses the degree to which the less powerful members of a society accept and expect that power is distributed unequally. The fundamental issue here is how a society handles inequalities among people;
- **Individualism Versus Collectivism**- the high side of this dimension, called Individualism, can be defined as a preference for a loosely-knit social framework in which individuals are expected to take care of only themselves and their immediate families;
- **Masculinity Versus Femininity**- the Masculinity side of this dimension represents a preference in society for achievement, heroism, assertiveness, and material rewards for success. Society is more competitive. Its opposite, Femininity, stands for a preference for cooperation, modesty, caring for the weak and quality of life. Society at large is more consensus-oriented;
- **Uncertainty Avoidance**- the Uncertainty Avoidance dimension expresses the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity. The fundamental issue here is how a society deals with the fact that the future can never be known: should we try to control the future or just let it happen?
- **Long Term Orientation Versus Short Term Normative Orientation**- Every society has to maintain some links with its own past while dealing with the challenges of the present and the future. Societies prioritize these two existential goals differently;
- **Indulgence Versus Restraint** - Indulgence stands for a society that allows relatively free gratification of basic and natural human drives related to enjoying life and having fun. Restraint stands for a society that suppresses gratification of needs and regulates it by means of strict social norms.

In the context of globalization, it is important for each country to follow the socio-economic and technological developments, to identify the changes that need to be made in the direction of the transformation of cultural values. For example, in the case of Georgia, based on the analysis of the current situation (Fig. 12), it is clear that this is a reduction in power distance and the development of individualism (Bedianashvili, 2016, 2017a). The modernization of business culture naturally requires the transformation of the paradigm of developing and implementing the country's economic (socio-economic) policy and its adjustment to the requirements of knowledge economy in the context of building a knowledge society (Bedianashvili, 2018). At the same time, the concept of the whole process of education, which focuses on the formation of innovative thinking and relevant skills in a person, acquires special significance.

6. CONCLUSIONS

In the present work, we introduced the Systematic Inventive Thinking (SIT) method for problem solving and new product development and presented findings from the application of this method in industry and education. SIT does not present a precise method, but a cluster of heuristics that may help in achieving innovative ideas and solutions. The main concept of SIT is the use of these heuristics for systematic thinking using resources that exist naturally in the problem's 'closed world' or 'thinking within the box,' in contrast to the conventional method of brainstorming, which is actually a random search for new ideas. Engineers, managers and product developers in technology companies could use this method to develop innovative products and services, which is a necessary need to survive and evolve in the global competition in technology and commerce today. SIT will help people acquire and refine their entrepreneurial skills in areas such as thought start-up of entrepreneurial activity, systematic perfection of human capital, creation of productive and technological innovations, their effective absorption.

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