Journal of Turkish Science Education, 2023, *20*(1), 50-65.
DOI no: 10.36681/tused.2023.004

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

The Effects of a Systematic Approach to Solve Real-Life Inventive Problems in the Science Classroom

Nilüfer Demirci Saygı[1], Fatma Şahin[2]

[1] *Faculty of Science, Sakarya University, Türkiye, demirci@sakarya.edu.tr, ORCID ID: 0000-0002-9729-170X*
[2] *Atatürk Faculty of Education, Marmara University, Türkiye, ORCID ID: 0000-0002-6291-0013*

* *This study is derived from author's PhD dissertation.*

ABSTRACT
Nowadays, many education programmes claim to evolve according to present and future skills needed for sustainable development, and one of these skills is inventive problem-solving. Systematic-inventive problem solving (SIPS) is a systematic approach to problem-solving derived from engineering, technology, science, mathematics, and general problem-solving principles. This study presents findings from a SIPS-based methodology to enhance inventive problem-solving in school science for the Light topic. SIPS is an approach for innovative solutions with early judgment by exploring the problem's world or surroundings. This study was conducted with 78 seventh-grade pupils in Istanbul, Türkiye. Mixed methods were applied to determine the contribution of SIPS to developing their inventive problem-solving and to get their opinions about SIPS. The data were collected through the pre-post Inventive Problem-Test (IP-T), documentation of pupils' activities, and interviews. Statistical and descriptive analyses revealed that using inventive problem-solving tasks fostered pupils' inventive-problem solving skills. Also, using SIPS helped pupils solve real-life problems for which they might need information on different topics such as heat-temperature, electrostatics, or pressure. The study suggests that SIPS makes it possible to increase 7th grade pupils' interest in science, more comprehensive and focused thinking, and their realisation that what they learn at school is useful in everyday life.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
02.11.2021
Accepted:
31.10.2021

KEYWORDS:
Systematic inventive problem solving (SIPS), Inventive Problem, TRIZ, ASIT.

To cite this article: Demirci Saygı, N., & Şahin, F. (2023). The effects of a systematic approach to solve real-life inventive problems in the science classroom. *Journal of Turkish Science Education*, *20*(1), 50-65.

Introduction

Education plays an essential role in the development of nations (Nneji, 2022). The welfare of countries strongly depends on their pace of technological improvement and innovation, especially while natural sources are in decline (The Royal Society, 2010; Agbedahin, 2019). The education of individuals is essential to gain the necessary skills to achieve these tasks for society as a whole (Soldi et al., 2016). Creativity is one of the main driving forces of the modern world. Rapid economic and societal changes demand creative skills from employees. Therefore education decision makers have adapted the creative skills into their (Kim et al., 2019) education systems are responsible for developing innovative programmes to inculcate these skills (Hawkins, 2002; Lampa et al., 2013). In this context, many countries are applying new approaches in their educational strategies (Sanders, 2009; Thomas & Waters 2015). STEM (Science, Technology, Engineering, and Mathematics) is paramount within these approaches (Breiner et al., 2012; Bybee, 2010). STEM, a unification of mathematics, engineering, technology, and design fields in science education, has as its main goal to make learners build creative problem-solving skills (Breiner et al., 2012; Chen, 2009; Gonzalez & Kuenzi, 2012; Sanders, 2009). To achieve this, mixing knowledge areas, using problems and projects, and promoting skills such as group learning, problem-solving, project management and idea generation are proposed for the education agenda (Higuera Martínez et al., 2021).

Solving a problem requires connecting and treating different items of knowledge in a database (Wong & Siu, 2011). Inventive thinking is a way of problem-solving by searching related entries in the database and producing a unique solution in the final stage (Mumford et al., 2012; Öncü, 1992; Sternberg, 2006). This process is at least a two-step procedure, including divergent and convergent thinking (Cropley, 2006; Goodwin & Miller, 2013). A broadly accepted-traditional view on combining these two styles is that divergent thinking comes first and aims to produce as many ideas as possible. Later, convergent thinking takes the stage to review all possible statements and choose the most appropriate one (Barak, 2006). Goldenberg and Mazurski (2002) state that producing as many ideas as possible is not essential to solving a problem creatively and that postponing judgment does not necessarily increase the inventive value of the ideas. The critical thing in inventive thinking is quality rather than quantity. With well-determined criteria such as focused thinking and quick decision-making can be inventive problem-solving methods (Barak, 2003) without dealing with vast numbers of ideas (Barak, 2006). Because of these reasons, SIPS seems to be one of the present popular innovative problem-solving methods.

Systematic Inventive Problem Solving

Systematic Inventive Problem Solving (SIPS) stands on two pillars. One is being systematic, including regularity and following specific principles, and the other is being inventive, including new and original ideas. In SIPS, some specific progressive rules are followed to produce new and original ideas while using specific methods that are known to be successful. SIPS combines idea focusing (TRIZ/Inventive Problem Solving, ASIT/Advanced Systematic Inventive Thinking) and idea-generating (brainstorming, SCAMPER, CoRT/The Cognitive Research Trust Thinking Program) activities.

TRIZ is the abbreviation of "Teoriya Resheniya Izobreatatelskikh Zadatch" in Russian, which means the theory of inventive problem-solving. TRIZ is a technology-based approach to inventive problem solving (Mazur, 1995). TRIZ has been around for years, due to its innovative problem-solving capabilities in technology, design and engineering (Savransky, 2000). A study on engineering students in the university level investigating the effect of TRIZ on creativity found that TRIZ has a positive effect on creativity by increasing problem analysing, generating, selecting and executing a strategy (Chang et al., 2016; Liu et al., 2020). Researchers have been working to simply TRIZ for the school level (Turner, 2009). Systematic Inventive Thinking (SIT) or Advanced Systematic Inventive Thinking (ASIT) has arisen from the work of Horowitz (2001a). ASIT focuses on technology and design education in the class environment (Horowitz, 2001b, 2001c). ASIT simplifies the problem-solving process and employs the "Closed Worlds (CW)" and the "Five Idea Thinking Tools (FITT)". FITT includes following steps unification/use a thing with a new function, multiplication/provide a copy or a modification of a thing, division/disassemble a thing and reshape it from it parts, object removal/excluding a thing from the related system, breaking symmetry/changing the variables or symmetric-asymmetric relations between their functions in the related system. Closed World is a principle that indicates a solution to a problem should arise from the components, elements or resources which already exist in the problem or close environment (Horowitz, 2001a). SCAMPER, CoRT and brainstorming are idea-generating methods; brainstorming has become the cornerstone of the problem-solving process (Osborn, 2004). SCAMPER is an earlier version of systematic problem-solving for a technique developed by Eberle (1977), and it stands for Substitute, Combine, Adapt, Magnify, Modify, Put to other uses, Eliminate or divide, Rearrange, Reverse (Deacon, 2000).

SCAMPER is a method of asking questions about an object of interest to extend the horizon of consideration for the object (Glenn, 1997; Güven, 2008; Serrat, 2017; Silverstein et al., 2009). The Cognitive Research Trust (CoRT) Thinking Program was developed by Edward de Bono (De Bono, 1991). The CoRT programme consists of six parts comprising 60 lectures, each consisting of ten contents. Each content focuses on a single topic for example prediction, decision-making, problem identification (De Bono, 1976, 1983, 1991).

The essential components of ASIT are included in SIPS, which combines the idea-focusing and idea-generating tasks mentioned above. The main principle of SIPS is a "Closed World" (CW). According to this principle, an inventive solution to a problem relies on the "problem world" or its close environment components. In general, if the solution of the problem needs additional elements from outside of the problem world then these kind of solutions are not accepted as inventive solutions (Barak, 2003). In the problem-solving process with SIPS, the idea focusing activities are first considered. The first thing is to determine the system's components that consist of the CW of the problem Then, one or more FITT is/are applied to these components. Ideas generation techniques are considered when applying FITT to elements in the closed world. SIPS is a combination of many techniques and has an active structure. Number of techniques can increase or decrease depends on the characteristics of the group studied and the problem.

SIT has been applied in Technology Education by Turner (2009). Barak and Goffer (2002) organised a series of workshops based on SIT to the staff of a private company to improve their innovative thinking. Langley, Arieli, and Eylon (2010) researched the Physics and Industry programme, which is an elective, out-of-school activity and in close partnership with world-leading electro-optics enterprise to investigate the effect of SIT over the real-world technological problem. Barak (2006; 2009) investigated teaching based on SIPS by science and technology teachers and this study states that problem-solving abilities are improvable. Barak and Mesika (2007) investigated the effect of SIPS on junior high school pupils in which they observed an improvement on pupils that are given opportunities to develop their own thinking methods not just in school but also outside of the school. There isn't a lot of study on SIPS or inventive problem solving at the junior high school level, and much less research has been done on the integration of SIPS or inventive problem-solving activities into science curriculum.

In the present study, we infused the Light topic of 7^{th}-grade junior high school science with SIPS to determine the contribution of the method to the development of real-life inventive problem-solving. The infusion approach embeds inventive problem-solving techniques in a curriculum (McGuinness, 2005). The study's problem state is;

Does SIPS have an impact on 7^{th}-grade pupils' real-life inventive problem-solving?

Subproblems are listed in the following part.

1. Does SIPS affect the 7 th grade pupils' solving real-life problems that are unrelated to the light topic?

2. Do 7th-grade pupils use the basic processes (identifying components, using FITT) of SIPS? What is the frequency of the use of FITT, one of the components of SIPS, while students are solving problems?

Methods

We employed the mixed methods research design incorporating both qualitative and quantitative methods (Adnan & Gökçek, 2012; Çepni, 2014). In the quantitative part of the work, the quasi-experimental pattern, including pre-test, post-test, experiment, and control groups model, was employed by the researcher to determine the effect of SIPS on students' problem-solving. In the qualitative part of the work, the data from Inventive Problem Test IPT and interviews were analysed using descriptive analysis (Loeb et al., 2017). A group of junior pupils, two classes in total, from same high school taught by same teacher, were selected. One of the classes was randomly selected as the experimental group and taught using a programme including SIPS.

Participants

We have carried out the present work with 7th-grade students in Istanbul, Turkey. A junior high school and 78 students were chosen randomly. We have grouped the students into two parts. Each group consists of 39 pupils. Before this study, the pupils enrolled in this research had been taught by the same teacher during the term. We used the Student Recognition Survey (SRS). The SRS includes the questions related to personal information such as; gender, education level of their parents, the employment situation of their parents, number of siblings, whether they have a study room, etc. The analysis of the SRS revealed that the pupils had similar socioeconomic profiles. Then, it was examined whether there was a significant difference between the academic achievements of the pupils. We employed the one-way analysis of variance (ANOVA) test to determine whether the difference in achievement scores of the experimental and control groups was statistically significant. For this, mean score of science course Written Exam (WE) and scores of Level Determination Test (LDL- 6. Grade) which were compared (Table 1).

Table 1

ANOVA results for Academic Achievement Scores of the Experimental and Control Groups

		Sum of Squares	df	Mean of Square	F	p
LDL	Between Groups	7320,912	1	7320,912	1,566	0,215
(6. Grade)	Within Groups	355351,748	77	4675,681		
	Total	362672,66	78			
WE	Between Groups	18,513	1	18,513	0,044	0,834
	Within Groups	31786,821	77	418,248		
	Total	31805,334	78			

According to the analysis's findings in Table 1, there was no significant difference in the groups's science course WE scores ($p>.05$) or their LDL- 6. Grade scores ($p>.05$).

Pilot Study

A pilot study was carried out to observe the implementation of SIPS, make the lessons more effective, plan the time correctly, and research the validity-reliability of the data collection tools. Several activities have been added to the SIPS structure by considering the characteristics of the participants, the unit gains, and the literature review. However, a data collection tool with 18 problems was composed. Pilot study lessons for light topics conducted by the researcher were recorded visually. It was trialled with eight 7th-grade pupils studying in different schools in Istanbul. After the study, the time elapsed for each activity, the ideas produced by the pupils while solving the problems and the use of SIPS were analysed with the observations in the courses and the evaluation of the camera recordings. The data collection tool was examined by two scientists and two teachers for content and construct validity leading to the removal of some items, leaving 9 problems.

Data Collection Procedures

In order to collect data in the selected school, a permission letter numbered 50457 was obtained from the Istanbul Provincial Directorate of National Education through Marmara University, Istanbul, Türkiye. We applied the experimental method over four weeks (four 40-min periods per week). In addition to this time, we needed one week for the pre-test and post-test. We used one and a half weeks to explain the SIPS method to pupils in the experimental group. During this time, the components of the SIPS, Brainstorming, CoRT (Plus-Minus-Interest, Consider All Factors, Focus), SCAMPER, ASIT were explained using a different topic rather than Light. Then, by explaining the structure of SIPS, examples of problem solutions were made with SIPS. The researcher taught the light unit in both groups. This unit is made up of four main sections: light absorption and energy, colours, refraction and lenses.

SIPS Based Teaching

The researcher carried out SIPS-based lessons in the experimental group in this work. An example of a given Grade 7 Science course in the experimental and control groups is showed in the Table 2 below.

Table 2

An Example of the Application of SIPS to Light Topic

Topic	SIPS steps
Absorption of Light & Light Energy	*Informing:* Before starting the topic, a written research assignment was given about the importance, effects, advantages, and disadvantages of solar energy. Introductory Activities: The pupils were asked to express their opinions following their research. The researcher demonstrated a visual presentation of the news published in the newspapers about solar energy, including the subject's achievements. Later, students' opinion about the topic were noted by the researcher. The titles of a few of the news items used in the introduction are as follows: 1: Solar-powered cafe 2: Produce electricity with solar cells and sell it to the government 3: The world's first solar-powered stadium Idea generation: Brainstorming was carried out about light energy. The problem at this stage is Which tools we use daily can work with solar energy? ***The experimental group was also asked this question:* *A solar cooker that cooks with solar energy; List 3 positives, 3 negatives, and 3 exciting features.* Experiment Design: The pupils were asked to find a solution to one of the five problems in the laboratory environment; with the experimental setup they would design using whatever materials they have been given (coloured cloth, flashlights of different sizes, radiometers, thermometer...). A few problems are: Does the amount of light have an impact on the radiometer's rotational speed? Does the radiometer’s rotational speed depend on how far away the light source is? Does the amount of light have an impact on the temperature change caused by light on a surface? Sharing Experiences: Pupils were asked to share their experiences and explain the concepts in their own words. The researcher made explanations, and information about the subject and concepts was shared. The worksheet has been applied. Idea Focusing: At this stage, one of the problems answered in both groups: How should windows or curtains be designed to keep a sunny house warm in winter and cool it during summer, even when the electricity is cut off (without using electricity)? ***Real-life problem solved by experimental group students through SIPS*

The main difference of the SIPS-based course from the current program was producing solutions. In this last step, the students were asked to solve the inventive problem post-test, where the experimental group solved problems with SIPS.

In this work, the researcher also took the role of teaching two groups. The researcher has also organized the management of the SIPS activities in the experiment group, data collection from both groups, and checked the in-phase situation of SIPS with the Ministry of National Education curriculum, etc. This approach is often referred to as "participant as an observer" (Marshall & Rossman, 1989). Specific lessons materials for each section in the Light chapter have been equally used in both groups during the research. Some lecture materials include the radiometer, flip-flap, colour filters, colour wheels, lenses, and PowerPoint slides. Also, additional sources such as worksheets have been distributed to the students for extra activities and to efficiently use the class time.

Data Collection Instrument

In this study, an inventive-problem test was used to determine the contribution of SIPS to the development of pupils' inventive-problem solving. In addition, the interview technique was used to get the pupils' opinions about SIPS and its elements.

Inventive Problem Test

The researcher examined question styles in books provided by the Turkish Government and textbooks published by other publisher. Seventh grade level problems were written considering the gains related to the Light subject in the Current Science Curriculum. These were scrutinised by subject experts. The Inventive Problem-Test (IP-T) was applied to both groups before and after. IP-T comprises inventive problems defined as if they do not have a known solution method (Mazur 1995). Inventive problems are real-life problems and don't have solution manuals. Their solutions are not the first thing coming to mind and are usually uncommon, uncertain, inadequate and ridden with contradictions (Savransky 2000). IP-T has nine problems in total. While first seven problems are about the gains of Light chapter, the last two problems are not directly related to those gains. Two of the first seven problems (water curtain in steel mill and controlling wound under the bandage without removing dressing) were adopted from the work of Mazur (1995). The rest of these problems (air conditioning with window, cabinet sell in narrow shop, seeing small historical artifacts more clearly in museums, destroying cancerous cells without damaging healthy tissues with X-rays, reducing the reflection of lights on the shop window) were created by the authors. The last two problems (fish pool and airport balloons) unrelated to the light topic have been inherited from the work of Barak (2006) and they are adjusted to determine the effectiveness of the scientific knowledge during the inventive problem-solving process. The papers problems written on were given to the students at the end of each main section. The students were asked to type down their answers on this paper. These papers were collected at the end of the lesson for data analysis.

Interview

A structured interview technique was employed to determine the thoughts of experimental group pupils about the SIPS. It consisted of 15 questions. Five of them were adopted from Kapucu and Yıldırım (2007). These five questions were employed to learn what pupils' thoughts to TRIZ education. Ten of the fifteen questions aimed to determine pupils' views on SIPS (CoRT, SCAMPER, Brainstorming, and ASIT) activities.

Data Analysis

Problem solutions after the implementation of SIPS are considered as either "Traditional Solution (TS)" or "Systematic inventive solution (SIS)" (Barak, 2006). In this study, students' problem solutions were grouped in 7 categories given in Table 3: Idea Without Solution (IWS), Non-Related Idea (NRI), Wrong Idea (WI), Traditional Solution (TS), Good Traditional Solution (GTS), Systematic Solution (SS), Systematic Inventive Solution (SIS). GTS has been defined as an original solution that is not inherent in the problem but can be achieved by adding a new element. SS includes answers in which students focus on a component in the closed world of the problem but do not contain innovative elements.

Table 3

Inventive Problem Evaluation Scale (IP-ES)

Solution	Explanation
Idea Without Solution (IWS)	There is neither answer nor clear answer to the problem
Non-Related Idea (NRI)	Solution for a different problem
Wrong Idea (WI)	Gives opposite or wrong answer to the problem solution
Traditional Solution (TS)	Adding new element which is not from the CW
Good Traditional Solution (GTS)	Good solution with adding new elements that are not component of the CW
Systematic Solution (SS)	Focused on a component of the CW but idea is not inventive
Systematic Inventive Solution (SIS)	Focus on a component of the CW. Innovative solution by trying to change the physical properties (size, colour, shape, stiffness, etc.) of components, add a modified copy of a component to the system, remove a component from the system, or change its relationship or function with other components in the system

Descriptive analysis was employed to analyse the qualitative data obtained within the aim of the research. According to Loeb et al. (2017) when it comes to identifying and defining trends in a group, descriptive analysis is an essential part of almost every experimental work and report. In this study, descriptive analysis was employed to determine the experimental group's views regarding the use of the SIPS structure as well as the effect of SIPS on their inventive problem-solving. The data can be arranged according to predetermined themes and presented by considering the questions used in the interview and observation processes. In a study in which descriptive analysis is used, direct quotations from observed individuals are frequently included (Yıldırım & Şimşek, 2008). In this work, direct quotes from the students' interviews were included. These answers were grouped in three; yes, no, and uncertain. Later, the percentage of findings belonging to the interview was determined. Also, the interview results were investigated using descriptive analysis.

The answers of 20 randomly selected pupils from the experimental (n=10) and control groups (n=10), corresponding to 25% of whole group, were categorised and compared according to IP-ES by the researcher and two science experts for reliability.

Findings

In this section, the answers given by the students to the IP-T and the interview were examined. We have organized the findings according to themes built upon research problems: *the impact of SIPS on inventive problem solving, the learning of SIPS structure, the effect of SIPS on solving inventive problems which are not directly related light topics and students' examples and reflections on the method*. The findings obtained in this context are presented in line with the titles.

The Impact of SIPS on Inventive Problem Solving

In order to determine the impact of SIPS learning on pupils' inventive problem solving, IP-T results of the experimental and control groups were compared. The total percentages of answers for IP-T as pre-test and post-test classifying according to IP-ES are given in Table 4, summarising the result obtained from IP-T.

Table 4

Percentage Answers of Experimental and Control Group Pupils to Problems in the IP-T

Group-test	Idea without solution (%)	Non-related Idea (%)	Wrong idea (%)	Traditional Solution (%)	Good Traditional Solution (%)	Systematic Solution (%)	Systematic Inventive Solution (%)
Exp. Pre	18.3	3.6	5.4	28	7.4	27.5	9.8
Exp. Post	17.1	3.1	3.5	13.3	5.8	24.7	32.5
Control Pre	24.9	3.4	4.2	24.6	5.34	28.8	8.8
Control Post	35.8	3.8	3.6	20.4	5.3	23.6	7.6

The results of the pre-tests showed that both groups were at almost equal levels in producing inventive solutions. It is seen in the pre-test that the traditional and systematics solutions are employed mainly by both groups. This is consistent with Barak (2006). The experimental group preferred traditional solutions (28%) to systematic inventive solutions (9.8%) at the beginning. However, after the intervention the preference for traditional solutions had dropped (13%) in favour of systematic inventive solutions (33%). On the other hand, we do not observe such a change in the control group. We can accordingly comment that the current education programme does not considerably affect the development of systematic inventive solutions.

The Learning of SIPS Structure

Table 5 shows if the experimental group responded to problems or not, identifying the components of the CW, determining which of the FITT employed and the number of systematic inventive solutions obtained from the answers. Students provide more than single answer for some of the problems. Table 5 has all of the provided IPT answers in their entirety.

Table 5

Findings of the Experimental Group's Use of SIPS

Problem Number	No answer	Answer given	Total Number of Solutions	Pupils who wrote Components	Number of solutions to which tool used is written	Number of pupil systematic inventive solutions	Number of systematic inventive solutions
1	5	34	50	28	24	16	26
2	4	35	47	28	14	5	5
3	3	36	46	13	11	14	15
4	5	34	47	10	4	12	24
5	4	35	52	36	33	24	25
6	14	25	25	25	3	15	15
7	8	31	37	17	9	18	18
8	11	28	37	24	2	1	2
9	17	22	28	21	4	2	2

Although the experimental group was not instructed to write the components or FITT on the papers, the group showed a tendency to write about 72% of the components in total. The experimental group mainly determined the components of the problem. However, most did not outline which tool they used to solve the IP-T. The component writing or the tool writing ratio varied depending on the problem. The number of students shows a decline in answering problems related to an unknown topic

(8th and 9th problems) or a problem related to a technological application (4th and 6th problems) of known Light topic.

A few examples about components writing and using FITT are given below. The first example is about "component writing" for a problem in the IP-T. The problem is "A seller who wants to show each colour of a cabinet in his/her shop, however the shop is very narrow to do this. How can you help the seller solve this problem? Students from the experimental group extract components from the problem itself, which forms the CW as below;

Pupil 1: *Customer, seller, cabinet, shop*

Pupil 2: *Shop, cabinet, air, seller, board, colour, narrow, customer*

Another example is about "component writing" for a different problem of "How a seller can design his/her shop windows to reduce the reflection of daylight and streetlights that make it difficult for customers to see window products?"

Pupil 3: *Shop, window, stores, customer, light, street*

Pupil 4: *Stores, window, glass, light, streetlight, customer, products, eye*

An example about writing the FITT to the problem "The steel mill has a water curtain to protect workers from overheating. But this water curtain does not cut the light, what would you recommend for it?" (Mazur, 1995) is a few of them listed as below;

"*Unification of steel: The steel produced in the steel factory should be placed in front of and behind the water curtain, and then steel balances both heat and Light*"

"*Multiplication of water curtain: I change the colour of the water. The water curtain reflects Light back*"

"*Breaking the symmetry of the water curtain: I add too many different shape water curtains to the light's incoming direction*."

Another example of writing the FITT for a given problem of "Precious, small historical artifacts found in museums need to be preserved. For this, they are placed inside the glass bells. However, the writings and figures on them showing the characteristics of their periods do not look very well. What can be done to protect these valuable and small artifacts while making them look clearer?" is below;

"*Unification of glass bells: The glass bell's glass is made in the form of a thin-edged lens. Glass bell becomes a magnifying glass. The contents of the historical artifacts appear larger*."

"*Multiplication of historical artifacts: I substitute fake artifacts instead of a real one. I put it on a smaller glass bell. Thus, the artifact and the details on it are seen more easily*."

The third problem in IP-T is "controlling wound under the bandage without removing dressing". The answers for this problem were examined according to IP-ES. The systematic inventive solution rate was 24% in the pre-test and 46.2% in the post-test for the experimental group. In the control group, these rates were 14.6% and 15.4%, respectively. Some of the answers given to this problem and their category according to IP-ES are given below;

"*Use some types of rays, we can see if the wound has healed without removing the bandage*."

"*If this wound has not healed and there is inflammation, it will be blood sample can be taken*"

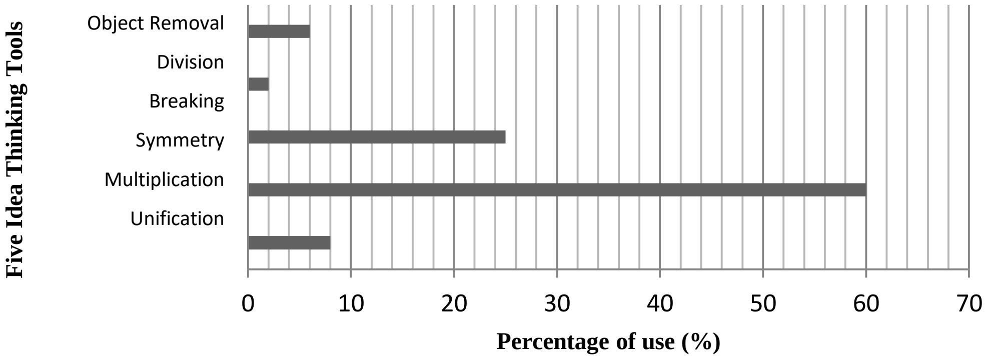
"*Let's make a tool, put the tool under the bandage and check the wound with a camera and see it.*"

Of course, these answers are not considered as innovative because the solutions proposed require introducing external components into the system. However, they may be regarded as "traditional" or "good traditional" solutions. These external components are not naturally present in "the world of the problem". Some of the answers given for this problem were "systematic solutions": *Could check if it hurts before removing the bandage/ I see if the bandage bleeds/ Touching*. The "*transparent bandage*" response for this problem is in the "systematic inventive solution" category. Because it added a modified copy of a component to the system by changing the physical properties of "bandage".

A subsidiary aim of this work is to determine the frequency of use of FITT. So, we have analysed the FITT's statistics, during the experimental group's solution process. Figure 1 shows the comparison of the FITT's used by the students while solving inventive problems, as a percentage.

Figure 1

Comparison of FITT's Used by students While Solving IP-T (%)



In our work, we have observed that the pupils mostly preferred "multiplication" (60%) to solve the problems and the least preferred one was "division" (2%).

The Effect of SIPS on Solving Inventive Problems Which Are Not Directly Related Light Topics

There are two problems in IP-T to determine the impact of SIPS on inventive solutions for an unknown topic. These problems do not directly involve the gain of the Light unit. One of these problems is the "Fish taken at sea are kept on fishing vessels in huge pools until they are brought ashore. The fish must be made to swim quickly inside the pools, much like they would in the open sea, to preserve their delicate flavour. Do you have any ideas for how to solve this issue?"(Barak, 2006). The experimental group presented no inventive solutions for this problem in the pre-test while the control group yielded one. The inventive solutions are given only by the experimental group in the post-test at the rate of 4.5%. Approximately 45% of the answers were given "systematic solution" in the post-test in both groups. "Traditional solution" examples for this problem are given below.

"I put mirrors in the pool. The fish get scared as they move toward the mirror; they keep moving in order to run away from each other."

"If we put a motor as in an aquarium into this pool, water in the pool would be fresh all the time so fish always stay alive and fresh during the transport."

These answers have been traditional because new items such as mirror and motors have been added outside the CW. Some of the typical "systematic answers" can be listed as follows:

"I put seawater in the pool"

"Increase the depth of the pool"

"I enlarge the pool"

"Pool should be narrow and long"

"Some sea plants can be placed into the pool and the fish feel like at sea"

These answers involve changes in the components of the system, but they do not include innovation. Hence these answers are in the category of systematic solutions. The answers "*Very small and fast fish should be put into the pool and the big fish would run after the small fish*" or "*Since big fish eat small fish I add big fish to the pool. Small fish try to escape from the big fish to avoid being eaten and then they must keep moving*." are accepted as "systematic inventive solution" because adding a modified copy of a CW of the problem.

In the IP post-tests, the experimental group produced more inventive solutions to the problems than the control group. Table 6 shows the answers to each problem found in IP-T.

Table 6

Findings of Experimental and Control Group Students' Responses to Each Problem in the IP-T

Problem	Group-Test	Idea without solution (%)	Non-related Idea (%)	Wrong idea (%)	Traditional Solution (%)	Good Traditional Solution (%)	Systematic Solution (%)	Systematic Inventive Solution (%)
1	Experimental Pre	10,2	15,4	2,6	48,7	2,6	2,6	17,9
	Experimental Post	9,1	7,3	3,6	18,2	7,3	7,3	47,2
	Control Pre	22,2	20	0	37,8	6,7	2,2	11,1
	Control Post	23,8	19	4,8	33,3	4,8	4,8	9,5
2	Experimental Pre	12,2	4,9	2,4	12,2	2,4	58,6	7,3
	Experimental Post	7,9	3,9	3,9	9,8	9,8	54,9	9,8
	Control Pre	17,9	5,1	2,6	17,9	0	53,9	2,6
	Control Post	35	2,5	5	17,5	2,5	37,5	0
3	Experimental Pre	5,2	0	0	25,6	7,7	41	20,5
	Experimental Post	6,1	0	0	16,3	8,2	38,8	30,6
	Control Pre	10	0	0	46	2	30	12
	Control Post	17,5	0	0	25	2,5	45	10
4	Experimental Pre	28,6	0	0	16,6	2,4	28,6	23,8
	Experimental Post	9,6	7,7	3,8	17,3	7,7	7,7	46,2
	Control Pre	29,3	0	0	4,9	4,9	46,3	14,6
	Control Post	41	0	0	15,4	5,1	23,1	15,4
5	Experimental Pre	7	0	14	18,6	23,2	18,6	18,6
	Experimental Post	7,1	0	10,8	7,1	12,5	17,9	44,6
	Control Pre	14,6	0	4,9	17,1	7,3	19,5	36,6
	Control Post	35,9	0	5,1	12,8	12,8	10,3	23,1
6	Experimental Pre	35,8	7,7	2,6	51,3	2,6	0	0
	Experimental Post	35,8	2,6	5,1	18	0	0	38,5
	Control Pre	51,3	5,1	12,8	28,2	2,6	0	0
	Control Post	64,1	5,1	7,7	15,4	0	2,6	5,1
7	Experimental Pre	17,1	0	12,2	19,5	12,2	39	0
	Experimental Post	17,8	0	0	11,1	2,2	28,9	40
	Control Pre	23,9	0	10,9	19,6	6,5	39,1	0
	Control Post	25	0	10	25	5	30	5
8	Experimental Pre	24,4	0	4,4	44,4	13,4	13,4	0
	Experimental Post	22,9	4,2	2,1	8,3	4,2	54,1	4,2
	Control Pre	31,8	0	2,3	34,1	13,6	18,2	0
	Control Post	45	5	0	25	12,5	12,5	0
9	Experimental Pre	23,9	4,3	10,9	15,2	0	45,7	0
	Experimental Post	37,8	2,2	2,2	13,3	0	40	4,5
	Control Pre	22,8	0	4,5	15,9	4,5	50	2,3
	Control Post	34,9	2,3	0	14	2,3	46,5	0

The first seven problems differed from the last two problems in terms of both the number of systematic inventive solutions and the number of pupil who produce inventive solutions. The experimental group produced a greater number of inventive solutions to a problem related to the light than the control group. The percentage of systematic inventive solution to the last two problems was quite low.

Pupils' Examples and Reflections on the Method

Table 7 shows that the quantitative findings obtained from the interview in which the opinions of the students in the experimental group about the program and components of the SIPS were obtained.

Table 7

The Interview Questions and The Responds of the Experimental Group

Questions	No %	Not Sure %	Yes %
Did you like the way this topic was taught?	15	9	76
Do you think you can make independent decisions easier after this topic?	6	31	63
Do you trust your feelings and abilities rather than the advice of others?	12	24	64
Do you think to try of new inventions?	25	41	34
Do you think your communication skill did improve?	12	23	65
Do you believe that the activities you learn in the lessons will help you solve any problems you encounter in your daily life?	6	23	71
Do you think now that you can easily solve a problem you encounter?	6	28	66
Do you think it is easier for you to come up with ideas about a given topic?	13	23	64
Do you think you can now feel more comprehensively about a given topic?	3	19.5	77.5
Do you think you can now focus more on what you think?	3	19.5	77.5
Do you think the best solution is the most practical for a given problem?	6	32	62
Do you think an object can be multifunctional?	7	10	83
Do you think the subjects taught at school are helpful in everyday life?	6	24	70
Do you think you are now able to consider a topic from different perspectives?	3	33	64

In addition to these answers written by the pupils, a camera recording was also taken so that they had the opportunity to express their answers more clearly. The interviews revealed that of the pupils in the experimental group, 76% of the whole group enjoyed how the unit was taught. In relation to this, some of the answers to one of the questions, "Did you like the way this topic was taught?" from the interview are:

"*Solving these questions (IP-T) may have helped me develop my self-confidence*."

"*I enjoyed the lesson. The questions were very developing*."

"*I think it was a very good work, it was sometimes hard to follow*."

"*I believe it was worth our time, and I learned a lot thanks to them*."

It is seen from the table that 78% of the group think that they can be more comprehensive and focused on a given problem. 70% of the group think that what they learned at school could help them in daily life. One answer given to the question "Do you believe that the activities you learn in the lessons will help you solve any problems you encounter in your daily life?" is

"*Yes, I think it helps. For example, I used the plus-minus-interesting tool, one of the methods we learned while deciding to go to our village with my family this summer holiday. The plus of going to the town; is on the way to the village, I will see new places and get fresh air. The minus aspect; as I thought I would be alone when I went there because all my friends are in Istanbul. The interesting aspects, I will be in touch with nature, and I am interested in seeing new things. I considered these when making our decision*."

Eighty-three percent of the students think an object can be used multifunctional rather than one function. Although most of the pupils think that they are not able to invent (65% of the group say either "no" or "not sure"). We believe that this could be improved if this way teaches them in a wider time interval. The students thought that the study contributes to their inventiveness abilities.

Conclusion and Recommendation

In this work, we investigated the effect of SIPS on the development of the inventive problem-solving skills of junior high school pupils. We employed SIPS in infusion mode, combining SIPS with the current programme based on the national curriculum. From the pre-test we observed that the pupils were not good at producing inventive solutions to given problems. The analysis of the findings from the current study revealed that the experimental group showed progress in the development of systematic inventive problem solving, which is in good agreement with the existing literature (Barak, 2013; Belski, 2009; Demirci-Saygı & Şahin, 2017; Kapucu & Yıldırım, 2007; Karataş & Özcan, 2010; Kurtuluş, 2012; Moon, Ha & Yang, 2012; Stern, Biton & Ma'or, 2006). On the other hand, the control group was taught according to the official curriculum without SIPS, and we did not observe any considerable improvement in their systematic inventive problem-solving. From the experimental group, it is seen that SIPS is an efficient way to produce inventive solutions. Pupils devise answers drawing on not only the topic at hand but others also (e.g., motion, energy, lifting force, electricity..). However, this has not been the case for the control group. So, we can conclude that field knowledge is not enough to produce inventive solutions, although it is necessary.

When considering the use of SIPS, the pupils generally determine the components of a problem's CW. The second step of SIPS is applying FITT to the problem's components. At this stage, it was examined which principles the pupils mostly used in solving the problems and whether they use a single principle or more. The pupils mostly used the "multiplication" strategy to produce inventive solutions. After multiplication, it was apparent that the breaking symmetry, unification, object removal, and division tools, respectively, were used by the pupils. This result differs from FITT in patents (Savransky, 2000). This ranking tends to differ in different studies and shows that there is no single prescription for FITT which applies in all cases (Moon et al., 2012). Each tool has a key role in inventive problem solving, depending on problems and groups. The pupils employed FITT one by one while producing inventive solutions in our work. However, it can also be considered as a combination of all FITT to create inventive ideas (Barak, 2006). Due to the limited time of application, this development was not observed in the pupils. However, results suggest that they had internalised the fundamentals of SIPS, and they noticed that the inventive solution is already embedded inside a problem and could be extracted by variations occurring in some components of the problem.

The structure of SIPS is based on engineering, technology and design and it is adopted activities for the classroom environment (Barak, 2004). This work also demonstrates those activities have effects on students' inventive problem solving (Uzel & Bilici, 2022; Ergül & Çalış, 2021).

While the systematic inventive solution rates in the experimental and control groups were 10% and 9% before the intervention, these rates became 33% and 8% respectively after the intervention. This result is important because it shows that inventive problem-solving ability can be improved and will affect the consideration of educators, various job groups, families, and students about inventive thinking. We believe that this will lead teachers and school administrators to develop positive attitudes toward improving their programmes and push them to encourage inventive thinking performance in schools. Besides, it will increase the internal motivation of inventive idea generation, which is important for inventive problem-solving.

References

Adnan, B., & Gökçek, T. (2012). Karma yöntem araştırmalarına genel bir bakış. *Elektronik Sosyal Bilimler Dergisi*, *11*(42), 1-21. https://dergipark.org.tr/tr/pub/esosder/issue/6156/82721

Agbedahin, A. V. (2019). Sustainable development, education for sustainable development, and the 2030 agenda for sustainable development: Emergence, efficacy, eminence, and future. *Sustainable Development*, *27*(4), 669-680.

Barak, M., & Mesika, P. (2007). Teaching methods for inventive problem-solving in junior high school. *Thinking Skills and Creativity*, *2*, 19–29.

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.

Barak, M. (2003). Impacts of Learning Systematic Inventive Thinking Methods. In J. R. Dakers and M. J. de VriesPupils (Ed.), *PATT-13) International Research Conference 3003* (pp. 170-174). https://www.iteea.org/File.aspx?id=40485&v=e17b5085

Barak, M. (2004). Systematic approaches for inventive thinking and problem-solving: implications for engineering education. *Int. J. Engng Ed*., *20*(4), 612-618.

Barak, M. (2006). Teaching methods for systematic inventive problem-solving: evaluation of a course for teachers. *Research in Science & Technological Education, 24*(2), 237–254. https://doi.org/10.1080/02635140600811668

Barak, M. (2009). Idea focusing versus idea generating: A course for teachers on inventive problem solving. *Innovations in Education and Teaching International*, *46*(4), 345-356.

Barak, M. (2013). Impacts of learning inventive problem-solving principles: students' transition from systematic searching to heuristic problem solving. *Instructional Science*, *41*(4), 657–679. https://doi.org/10.1007/s11251-012-9250-5

Belski, I. (2009). Teaching thinking and problem solving at university: a course on TRIZ. *Creativity and Innovation Management, 18*(2), 101-108. https://doi.org/10.1111/j.1467-8691.2009.00518.x

Breiner, J., Harkness, M., Johnson, C.C., & Koehler, C. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Bybee, R. (2010). Advancing STEM education: a 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35. https://eric.ed.gov/?id=EJ898909

Çepni, S. (2014). *Araştırma ve proje çalışmalarına giriş* (7. ed.). Celepler Matbaacılık.

Chang, Y-S., Chien, Y-H., Yu, K-C., Chu, Y-H., & Chen, M. Y-C. (2016). Effect of TRIZ on the creativity of engineering students. *Thinking Skills and Creativity*, *19*, 112-122. https://doi.org/10.1016/j.tsc.2015.10.003.

Chen, X. (2009). *Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education.* (NCES No. 2009-161). Washington, DC: U.S. Department of Education, National Center for Education Statistics. https://nces.ed.gov/pubs2009/2009161.pdf

Cropley, A.J. (2006). In praise of convergent thinking. *Creativity Research Journal*, *18*(3), 391-404. https://doi.org/10.1207/s15326934crj1803_13

De Bono, E. (1991). The cognitive research trust (CoRT) thinking program. *The International Journal of Creativity & Problem Solving, 1*(2), 105-117.

De Bono, E. (1976). *Teaching thinking.* Maurice Temple Smith.

De Bono, E. (1983). *De Bono's thinking course*. London: BBC.

Deacon, S.A. (2000). Using divergent thinking exercises within supervision to enhance therapist creativity. *Journal of Family Psychotherapy, 11*(2), 67-73.

Demirci Sayğı, N., & Şahin, F. (2017). The effects of systematic inventive problem solving activities on theoretical, experimental and real life problem solving. *Sakarya University Journal of Education* *7*(2), 268-281. https://doi.org/10.19126/suje.335785

Eberle, B. F. (1997). *SCAMPER.* Waco, TX: Prufrock.

Ergül, N. R., & Çalış, S. (2021). Examination of high school students' engineering design skills: Example of electromagnetism. *Journal of Turkish Science Education*, *18*(4), 765-780.

Glenn, R.E. (1997). SCAMPER for student creativity. *Education Digest*, *62*(6), 67-69.

Goldenberg, J., & Mazurski, D. (2002). *Creativity in product innovation.* Cambridge University Press.

Gonzalez, H. B., & Kuenzi, J. J. (2012). *Science, technology, engineering, and mathematics (STEM) education: A primer.* Washington Congressional Research Service (CRS) report for congress, R42642. http://www.stemedcoalition.org/wp-content/uploads/2010/05/STEM-Education-Primer.pdf

Goodwin, B., & Miller, K. (2013). Creativity requires a mix of skills. *Educational Leadership*, *70*(5), 80-83. http://www.ascd.org/publications/educational-leadership/feb13/vol70/num05/Creativity-Requires-a-Mix-of-Skills.aspx

Güven, Y. (2008). *Farklı düşünme etkinlikleri (SCAMPER)*. Kök Yayıncılık.

Hawkins, R. (2002). Ten lessons for ICT and education in the developing world. In G. S. Kirkman, P. K. Corneliuous, J. Sachs, and K. Schwab. (Ed.), *The Global Information Technology Report 2001-2002 Readiness for the Networked World* (pp. 38–45). Oxford University Press.

Higuera Martínez, O.I., Fernández-Samacá, L., & Serrano Cárdenas, L.F. (2021) Trends and opportunities by fostering creativity in science and engineering: a systematic review. *European Journal of Engineering Education, 46*(6), 1117-1140. https://doi.org/10.1080/03043797.2021.1974350

Horowitz, R. (2001a). From TRIZ to ASIT in 4 steps. *TRIZ Journal.* Retrieved 18.11.2014 from https://triz-journal.com/triz-asit-4-steps/

Horowitz, R. (2001b). ASIT's five thinking tools with examples. *TRIZ Journal.* Retrieved 18.11.2014 from https://triz-journal.com/asits-five-thinking-tools-examples/

Horowitz, R. (2001c). Using ASIT to develop new products. *TRIZ Journal.* Retrieved 18.11.2014 from https://triz-journal.com/using-asit-develop-new-products/

Kapucu, S., & Yıldırım, N. (2007). Mühendislik öğrencilerine TRIZ yenilikçi problem çözme tekniklerinin öğretilmesi. *Mühendis ve Makine Dergisi*, *572*(48), 23-27.

Karataş, S., & Özcan, S. (2010). Yaratıcı düşünme etkinliklerinin öğrencilerin yaratıcı düşünmelerine ve proje geliştirmelerine etkisi. *Ahi Evran Üniversitesi Eğitim Fakültesi Dergisi, 11*(1), 225-243.

Kim, A. M., Speed, C. J., & Macaulay, J. O. (2019). Why don't students recognize creative learning opportunities in a biomedical science program? *Biochemistry and Molecular Biology Education*, *47*(6), 656-668. https://doi.org/10.1002/bmb.21295

Kurtuluş, N. (2012). *Yaratıcı düşünmeye dayalı öğretim uygulamalarının bilimsel yaratıcılık bilimsel süreç becerileri ve akademik başarıya etkisi* (Unpublished master's thesis). Karadeniz Technical University.

Lampă, I., Greculescu, A., & Todorescu, L. L. (2013). Education for sustainable development–training the young generation for the future. *Procedia-Social and Behavioral Sciences*, *78,* 120-124.

Langley, D., Arieli, R., & Eylon, B.S. (2010, August, 23-26*). Enhancing four science learning dimensions: the physics & industry experience.* Girep Conference, Reims, France.

Liu, W., Tan, R., Peng, Q., Li, H., Li, Z.,Yang, B. (2020). Impact of TRIZ learning on performance in biologically inspired design. *International Journal of Engineering Education*, *36*(3), 974-987.

Loeb, S., Dynarski, S., McFarland, D., Morris, P., Reardon, S., & Reber, S. (2017). *Descriptive analysis in education: a guide for researchers* (NCEE 2017-4023). U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance. https://files.eric.ed.gov/fulltext/ED573325.pdf

Marshall, C., & Rossman, G. B. (1989). *Designing qualitative research.* Sage Publications.

Mazur, G. (1995). *Theory of inventive problem solving TRIZ*. Mazur. Retireved 20.04.2010 from http://www.Mazur.Net/Triz/

McGuinness, C. (2005). Teaching thinking: theory and practice. *British Journal of Educational Psychology, Special Monograph Series, Pedagogy – Learning for Teaching*, *3,* 107– 126.

Moon, S., Ha. C., & Yang, J. (2012). Structured idea creation for improving the value of construction design. *Journal of Construction Engineering and Management*, *138*(7), 841-853.

Mumford, M.D., Medeiros, K.E., & Partlow, P.J. (2012). Creative thinking: processes, strategies and knowledge. *The Journal of Creative Behavior*, *46*(1), 30–47. https://doi.org/10.1002/jocb.003

Nneji B. (2022). Why education systems should build environmental ethics into every subject. *The conversation.* Retrieved 17.09.2022 from (https://theconversation.com/why-education-systems-should-build-environmental-ethics-into-every-subject-173078).

Öncü, T. (1992). Yaratıcılığın betimlenmesi ve yaratıcılık üzerine çevresel etkiler. *Ankara Üniversitesi Dergisi*, *14*, 255-264.

Osborn, J. (2004). Biography: Alex F. Osborn. *Journal of Creative Behavior*, *38*(1), 70-72.

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20–26.

Savransky, S.D. (2000). *Engineering of creativity: introduction to TRIZ methodology of inventive problem solving*. CRC Press.

Serrat, O. (2017). *The SCAMPER technique*. Knowledge Solutions (pp. 311–314). Springer.

Silverstein, D., Samuel, P., & Decarlo, N. (2009). *The innovators toolkit 50+ techniques for predictable and sustainable organic growth*. Breakthrough Management Group International.

Stern, Y., Biton, I., & Ma'or, Z. (2006). Systematically creating coincidental product evolution case studies of the application of the systematic inventive thinking (SIT) method in the chemical industry. *Journal of Business Chemistry*, *3*(1), 13-21.

Sternberg, R.J. (2006). The nature of creativity. *Creativity Research Journal, 18*(1), 87–98. http://dx.doi.org/10.1207/s15326934crj1801_10

Soldi, R., Cavallini, S., Friedl, J., Volpe, M., Zuccaro, C. (2016). *A new skills agenda for Europe*. European Commission: Brussels, Belgium. DOI:10.2863/708323.

The Royal Society (Great Britain) (2010). *The scientific century: securing our future prosperity*. The Royal Society. http://royalsociety.org/the-scientific-century/

Thomas, B., & Watters, J. (2015). Perspectives on Australian, Indian and Malaysian approaches to STEM education. *International Journal of Educational Development, 45,* 42–53. https://doi.org/10.1016/j.ijedudev.2015.08.002

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

Uzel, L., & Bilici, S. C. (2022). Engineering design-based activities: investigation of middle school students' problem solving and design skills. *Journal of Turkish Science Education*, *19*(1), 163-179.

Wong, Y.L., & Siu, K.W.M. (2011). A model of creative design process for fostering creativity of students in design education. *International Journal of Technology and Design Education, 22*(4), 437-450. http://dx.doi.org/10.1007/s10798-011-9162-8

Yıldırım, A., & Şimşek H. (2008). *Sosyal bilimlerde nitel araştırma yöntemleri*. Seçkin.