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Teaching methods for systematic inventive problem-solving: evaluation of a course for teachers

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Systematic inventive problem-solving is an approach for finding original and useful ideas by systematically examining alterations in existing components within a system, their attributes, functions or internal relationships. This method, which aims at complementing divergent thinking in problem-solving and design, is gaining increased attention in industrial and academic frameworks. The current study examined how science and technology teachers learn, internalize and use the method within an academic course. Data were collected through pre-course and post-course quizzes and questionnaires, documentation of students' activities, and interviews. The results showed that individuals can improve their problem-solving abilities by combining methods based on 'ordered thinking' and 'disordered thinking,' and that none of these approaches has preference over the other. Considerable additional work is required, however, to investigate how the proposed approach could be used to foster creative thinking in science and technology studies at school.

Introduction

How, and to what extent, can education foster pupils' competencies in inventive problem-solving? Creativity is generally believed to be the result of the confluence of cognitive processes, knowledge, thinking style, personality, motivation and social environment (Cropley, 2000). Creativity is often defined as the ability to produce work that is both novel (original, unexpected, imaginative) and appropriate (useful, adaptive concerning task constraints) (Guilford, 1967; Simonton, 1988, 1997; Sternberg & Lubert, 1996). Torrance (1969) defined creativity broadly as the process of sensing a problem, seeking possible solutions, drawing hypotheses, testing and evaluating, and communicating the results to others. Creativity, according to Torrance, includes original ideas, a different point of view, breaking out of the mold, recombining ideas or seeing new relationships among ideas.

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Sternberg and Lubert (1996) point out that creativity is a topic of broad scope that is important at individual, societal and economical levels. Despite the broad recognition as to the importance of fostering the creative thinking of individuals, and children in particular, relatively little experience or research evidence exists regarding the promotion of creative thinking at school, for several reasons. First, the term creativity is rather vague. Since many people associate creativity with the free flow of thoughts, disordered thinking or 'out of the box' thinking, there seems to be an inherent contradiction in attempts to teach people how to think creatively: How can we teach individuals to think in an unusual way or arrive at unexpected ideas? Second, traditional teaching methods, especially in mathematics and science, often impede the fostering of pupils' creative thinking since teachers tend to praise pupils for finding the 'right' solution or solving a problem using the 'right method' rather than for originality, inventiveness or risk-taking. Finally, creativity is fostered by internal motivation rather than external reward (Amabile, 1996). Lately, educators have made efforts to improve learning by applying instructional methods such as project-based learning, problem-based learning and the use of computer technologies for teaching and learning (Marx *et al.*, 1997; Barak & Deppelt, 1999). However, the mere creation of good conditions for creative thinking does not necessarily promote creativity at school. Rather than hoping that creative thinking will flourish spontaneously, there is room for teaching pupils innovative problem-solving methods in scientific and technological contexts, as is done increasingly in fields such as engineering and management.

The current study deals with a course aimed at fostering inventive thinking in problem-solving offered to mathematics, science and technology teachers. Beyond the customary methods for fostering creative thinking, such as brainstorming, the course addressed a range of systematic inventive thinking principles in solving problems and designing new artifacts, derived from methods used increasingly in industrial and academic frameworks. The importance of this study lies in the fact that the participants were experienced science and technology teachers. There is broad agreement that the teacher's subject matter knowledge and pedagogical knowledge are central factors in any educational improvement (Shulman, 1986; Darling-Hammond, 1998). Subject matter knowledge, in terms of fostering problem-solving abilities in the class, means knowledge about issues such as learning and cognition theories, definitions of creativity, or cognitive and social factors that support or impede creative thinking in school. Pedagogical knowledge, in this regard, means knowledge about how to overcome the 'mysterious' perceptions towards creative thinking and problem-solving, how to teach pupils to think creatively in solving problems, how to engage them in thinking tasks and how to encourage pupils to present and explain their ideas (Tishman *et al.*, 1995; Zohar, 2004). Imparting instructional approaches related to creating a culture of openness and original thinking in schools to mathematics and science teachers is especially important, since the traditional view about teaching these subjects has focused almost exclusively on conventional subject matter rather than on inventiveness and originality in problem-solving. Therefore, the main questions that guided this study were: How do teachers learn, internalize and use systematic inventive problem-solving methods? How does such an experience influence teachers' attitudes regarding learning methods for creative problem-solving? In the Conclusions section, other related works are mentioned and an agenda for further research is suggested.

Theoretical background

Perkins (1987) stresses that human thinking is complex and multi-faceted, and instruction designed to foster thinking and learning must consider thinking skills as an aspect of intelligence. Perkins (1987, p. 45) suggests the following equation: Intelligence = *Power* + *Tactics* + *Content*, as illustrated in Figure 1.

The *Power* component, according to Perkins, relates to those elements of intelligence that depend on neurological efficiency of the brain as an 'information processing device.' Learning does not affect this ability, although nutrition and mental simulation over a period of many years may have some impact. The *Content* component of intelligence indicates that intelligence depends primarily on a rich knowledge base in the discussed domain, such as mathematics, physics or social domains. The *Tactics* component is the most interesting for this discussion. Tactical intelligence, according to Perkins, is comprised of a range of strategies, techniques, methods, heuristics or 'tricks' used in solving a problem or seeking the design of an innovative product. Both Perkins (1987) and Cropley (1999) stress the importance of control mechanisms such as styles, strategies or tactics that guide the thinking process and affect its results. For example, when teaching individuals who are classified as being slightly retarded or slow learners, strategies for particular tasks such as memorizing, reading or problem-solving can improve their performance dramatically. Creative individuals require not only a knowledge of heuristics for generating novel ideas but also tools for handling counterintuitive solutions to problems (Amabile, 1996). Creative problem-solvers must have wide enough expanses of knowledge to generate and identify useful chance combinations that lead to solutions and change current solutions into alternate products or procedures (Brophy, 1998). Campbell (1960) suggested the notion that 'blind variations' in science discovery should not be considered as 'random variations' since an experienced scientist has a problem to be solved in mind and a history of prior attempts to find a solution.

Perkins (1987) uses the term 'thinking frames' to describe a collection of thinking methods, strategies, tactics or routines helpful in a specific context, and stresses that only few people naturally possess this kind of tactical intelligence. A thinking frame,

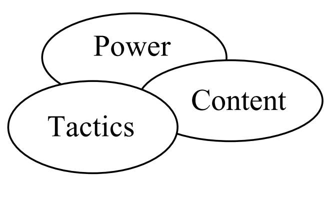

Figure 1. Intelligence

according to this approach, is 'a guide to organizing and supporting thought processes' (Perkins, 1987, p. 47). Similarly, De Bono (1991) uses the term 'thinking pattern' to describe thinking that moves from one point to another through a path that is directed in some manner, or has some repeating motives rather than through an occasional course. When well practiced, a thinking frame needs not be conscious and it includes information not only about how to proceed but when to proceed in that way. Like any other learning, thinking frames are obtained through:

- acquisition—direct learning;
- internalization—practicing it enough so that one becomes fluent and spontaneous with it;
- transfer—using the frame extensively beyond its context of learning.

The educational literature, however, widely agrees that the transfer of thinking skills is limited to closely related situations, and that we must teach individuals to transfer and not to expect its natural occurrence (Perkins & Salomon, 1989; Salomon & Perkins, 1989).

Several methods or programs for fostering creative thinking that have been suggested over recent years are actually aimed at teaching people a variety of thinking frames that could help them find innovative solutions to problems in such areas as science, engineering, management, marketing or advertising. Some of these programs are: De Bono's (1990, 1991) Cognitive Research Trust (CoRT) program; the Creative Problem Solving model proposed by Isaksen *et al.* (1994); the Eight-Dimensional Methodology suggested by Raviv (2003) and SCAMPER, developed by Osborn (1963) and Eberle (1977). The latter framework, for example, consists of seven techniques for solving a problem by changing components or functions in a system: *Substitute*, *Combine*, *Adapt*, *Magnify*, *Put into Other Use*, *Eliminate* and *Reverse*. The above-mentioned methods overlap one other to a certain extent, and all aim at fostering divergent thinking and convergent thinking in problem-solving. A further discussion on using these two thinking approaches in problem-solving follows.

'Idea generating' versus 'idea focusing'

Guilford's (1963) differentiation between divergent thinking and convergent thinking was a milestone in research on creativity. Although Guilford pointed out that both types of thinking are essential in the creative process, many psychologists and educators mainly associate the term creative thinking with divergent thinking. The frequent perception is that in design and problem-solving, first comes divergent thinking aimed at creating as many ideas as possible, and only later comes convergent thinking intended at examining these ideas or solutions and choosing the optimal one. In science and technology, however, convergent thinking is just an analytical analysis based on mathematics and related scientific-technological areas such as physics, electronics and computer sciences. Examples of methods aimed mainly at idea generating are Synectics (Gordon, 1961), Mind-Mapping (Wycoff, 1991) and Brainstorming (Osborn, 1963). These methods adopt a range of common principles, such as facilitating the free flow of thought, triggering imagination, using associations, using analogies, avoiding internal and external criticism, postponing judgment, borrowing ideas and paying attention to outrageous ideas (Plsek, 1997).

The convergent-after-divergent model for creative problem-solving has been criticized lately since problem-solving and design are not linear processes. Furthermore, there is growing awareness that methods such as brainstorming or variations thereof may not be as productive as predicted, and brainstorming groups do not always generate more or better ideas than individuals working independently (Simonton, 1988; Goldenberg *et al*., 1999).

'Idea focusing'

Over recent years, there has been increasing knowledge that innovative solutions to problems can be arrived at by focused thinking and early judgment of ideas rather than by checking a large number of ideas. Barlow (2001) suggests the notion of better 'in-box thinking' as an alternative to the production of ideas. One of the well-known approaches for systematic inventive problem-solving in engineering contexts is TRIZ, a Russian acronym for the Theory of Inventive Problem-Solving. This method was developed in the 1960s by Altshuller (1988) and his colleagues, who studied over a million patents and identified a range of principles and knowledge that define the process of inventive solutions for engineering problems. The method, which is not easy to describe or learn, is often presented by the '40 Techniques for Overcoming System Conflicts,' such as : *Segmentation*, *Extraction*, *Local Quality*, *Asymmetry*, *Combining*, *Universality*, *Nesting*, *Counterweight* and *Prior Counter-Action*. The TRIZ method and variations thereof are gaining increased attention in areas such as car and electronics industries, the management of modern organizations and the design of advertising campaigns (Helfman, 1992; Savransky, 2000; Goldenberg & Mazurski, 2002). Barak and Nizzan (2002) studied the impact of introducing workshops for systematic inventive thinking (Horowitz & Maimon, 1997; Horowitz, 2001) into a medium-size Israeli tool manufacturer for the construction industry. It was found that these workshops not only contributed to the development of a range of innovative products that were highly successful on the international market, but also raised the interest of the company's management, designers and technical staff in designing innovative products and new services. Some examples of utilizing the 'idea focusing' approach in finding inventive solutions to problems are presented later in this paper.

In conclusion, it should be emphasized that thinking in general and creative thinking in particular is a complex process that cannot be segregated into specific actions or procedures. Teaching innovative design methods is aimed at helping individuals increase their repertoire of thinking frames, consisting of techniques, tactics, strategies or heuristics in problem-solving on the one hand, and divergent thinking methods on the other. These frames are flexible, not always defined precisely and partially overlap. The ability to relate simultaneously to several thinking frames or to move easily between different modes of thinking is a key factor in innovative reasoning (Sternberg & Lubert, 1991; Noppe, 1996; Brophy, 1998; Howard-Jones, 2002).

According to Sternberg (1987, p. 253): 'Virtually no problems can be solved by single processes or thoughts in isolation, so one must learn to combine these processes in a way that gets things done effectively.' Additional research is required, however, to identify different types of thinking frames useful in creative problem-solving, and to determine how individuals acquire thinking methods, internalize them and utilize them in different contexts and situations.

The study

Framework and participants

This study deals with a course aimed at fostering inventive problem-solving competencies by learning 'idea generating' and 'idea focusing' methods derived from programs such as Brainstorming (Osborn, 1963); CoRT (De Bono, 1991); TRIZ (Altshuller, 1988) and SCAMPER (Eberle, 1977). The course consisted of class exercises, home assignments and discussions through an on-line forum. At the heart of the course was learning a range of 'inventive principles' in problem-solving, as demonstrated later in this article.

The participants were mathematics, science or technology teachers studying towards Master's or doctoral degrees at the Ben-Gurion University of the Negev. The course was run twice: a pilot class involving 13 participants who studied the subject during five meetings (three academic hours each) as part of a broader course on teaching science and technology; the second class, also consisting of 13 students, participated in a full-semester course (13 meetings, three academic hours each) entitled 'Inventive Thinking in Science and Technology.'

Data collection and analysis

The study combined qualitative and quantitative techniques aimed at collecting as much information as possible on the participants' activities, achievements and attitudes during and after the course (Guba & Lincoln, 1994). The data were obtained in diverse ways:

1. A six-item quiz was administrated in the first and last course lessons (different versions).
2. The students filled in a nine-item Likert-type questionnaire about their attitudes to creative thinking, also administrated in the first and last course lessons.
3. Most of the discussions during the class meetings were documented or recapitulated.
4. The second course was accompanied by an on-line forum, which became a source of authentic information about students' learning and attitudes. A total of 45 questions and quizzes were presented in the forum by the instructor and the students, and 138 solutions or other comments relating to these quizzes were recorded.
5. Each student submitted a mid-semester assignment containing mainly his/her experience in using the inventive problem-solving methods learned in

different contexts. The participants cited a total of 74 examples that were analyzed carefully.

6. Many informal talks were held with individual students or pairs of students. For example, discussions held while consulting with them on their course assignments were documented.
7. Several students made reference to the course weeks and even months after it had ended. This information was also recorded and addressed later during data analysis.

Data collection and analysis were carried out by the instructor together with the course assistant, who participated as a student in the pilot class and accompanied all of the activities in the second class. This approach is often called 'participant as observer' (Marshall & Rossman, 1989). As is common in qualitative inquiry, the data analysis was aimed at identifying, coding and categorizing patterns found in the data into meaningful themes (Bogdan & Biklen, 1982). Patton (1990) used the term thematic analysis to describe the process of paring, sieving and reorganizing data. Some of the outcomes of the pilot course were used to upgrade the second course; other understandings were re-examined by carrying out additional discussions in the class or individual talks with the participants. The main findings are presented in the following section.

Findings

Learning principles for inventive problem-solving

The course started with a theoretical review, and continued with learning methods for divergent and convergent thinking such as brainstorming and lateral thinking. At the center of the course, however, was the learning of principles for systematic inventive problem-solving derived from TRIZ and other methods reviewed earlier in this article. An example of the types of questions and tasks presented to the students in this part of the course and the approach to solve them follows.

> Huge pools located on fishing vessels are used to store fish caught at sea while they are being transported ashore. In order to preserve their delicate taste, the fish must be forced to swim quickly inside the pools, just like in the open sea. Can you suggest a solution to this problem?

This question appeared on the pre-course quiz that the students in both groups filled in. Students' solutions were discussed later in the class. Some common answers were to add a pump to the pool that would circulate the water, or add food or other chemicals to the pool that would make the fish swim faster. These answers, however, are not considered innovative because the solutions proposed require introducing new elements into the system that are not naturally present in 'the world of the problem.'

One of the 'systematic inventive problem-solving' approaches focuses each time on one component of the system or its closed environment. In the case under discussion, these components include the vessel, the pool, the fish, the water and the sea. The solver tries to change each component's physical attributes (size, color, shape, hardness, etc.), add slightly modified copies of a component to the system, remove a component from the system or change its relationships or functions with other components in the system. This approach help pupils to find, for example, that an innovative solution to the fish problem is adding a baby shark, which is just another type of fish often found in fishermen's nets, to the pool.

As mentioned, the fish problem was one of the items that appeared in the pre-course quiz that the students from both courses answered. Not one of the students in the first group and only two students in the second group suggested this type of solution.

Each of the pre-course and post-course quizzes given to the students comprised six questions, which the students solved within 30–40 minutes (unlimited time was provided). In both courses, while the students were solving the pre-course quiz, one could hear comments of the following nature in the class:

> The questions are very difficult.
> My mind is blocked.
> I feel stupid.
> At my age, don't expect too much from me.

These quotes indicated students' perceptions about thinking creatively or their skepticism about improving their problem-solving abilities. One week after the fish example was discussed in the class, one of the participants said:

> I asked the fish question in my class (junior high school), just for fun. Before I had even completed presenting the question, a pupil from the back seats shouted 'Add a shark…a shark…' The kids are so clever…how come I didn't think of this before?

While the pre-course quiz was aimed at provoking students' interest in inventive thinking, the aim of the summative quiz was to provide the students with some feedback about their learning. The quizzes were administrated anonymously, and were not used for any kind of personal evaluation or grading.

The following question appeared in the summative quiz that the students in both courses solved:

> A seller of helium balloons at an airport arrivals hall noticed that many balloons were released unintentionally from people's hands and collected on the very high ceiling. The seller wants to retrieve the balloons from the ceiling every night in order to resell them the next day. What could the seller do to retrieve the balloons?

Conventional solutions to this question, as some of the students proposed, were to use a high ladder or a long stick. These methods, however, are not considered inventive because a ladder and a stick do not belong naturally to 'the world of the problem.' As previously mentioned, in order to seek an inventive solution to a problem it is useful to make a list of the system's components and examine different manipulations of each of these components or their internal relationships. In this case, the components include the balloon, the helium, the cord, the ceiling, the air surrounding the balloon, the light, the balloon seller and the balloon buyers. Following are examples of student's responses to this question in the summative quiz. The number in brackets indicates the frequency of the specific solution that appeared in the students' answers (some students suggested more than one solution):

- Change the tie in the balloon to cause the gas to escape gradually (4).
- Use a balloon or a gas that gets heavier over time (3).
- Cool down the balloon/heat up the air around the balloon (3).
- Make the cord extend in length over time (2).
- Use a gas that gets heavy when the light is turned off (2).
- Use another balloon with a long cord and place a little glue or a strip of double-sided glue tape on its top (1).

Although some of students' suggestions are incorrect physically (a common phenomenon in the first stage of seeking a solution), the assortment of students' answers reveals that they grasped the notion of solving a problem by manipulating the system's components. The latter solution appearing in the above list, as illustrated in Figure 2, looks like the simplest one. It utilized the principle of solving a problem by using existing components or slightly modified copies thereof (often called the 'duplication principle').

In the data analysis, students' answers to the pre-course and post-course quizzes in both courses were graded on two levels: conventional solutions (or no solution) and inventive solutions. The results indicated that the rate of inventive ideas in students' answers in the pre-course and post-course quizzes increased from 32% to 64% in the first course, and from 40% to 63% in second course, respectively (some of the items were modified in the quizzes given in the second course). These results, as presented in Figure 3, indicate an increase in students' success in finding inventive solutions to the type of problems addressed in the course.

Integration of diverse 'inventive principles' in problem-solving

In the first lessons, the students focused each time on exercising another inventive problem-solving principle in the order they had learned them. Gradually, as the

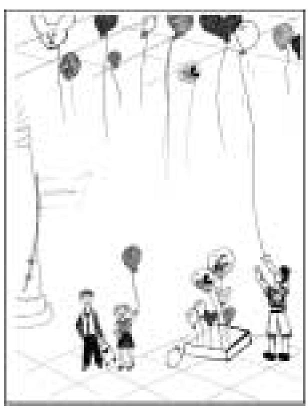

Figure 2. A balloon seller uses a balloon with a long cord to retrieve balloons stacked on the high ceiling

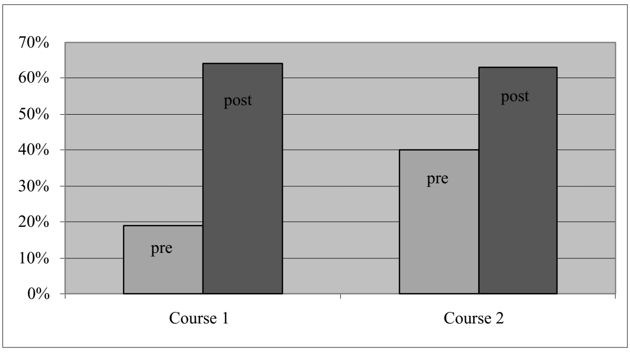

Figure 3. The rate of inventive ideas in students' answers in the pre-course and post-course quizzes

participants became familiar with more techniques and increased their confidence in utilizing the method, they started to combine different problem-solving techniques. Furthermore, students who suggested an interesting solution to a problem rarely tended to indicate the specific principle they had used in finding this solution. In talks with the students and during class discussions, the followings comments were made:

> In the beginning, I tried each principle separately. Now everything is mixed up.
>
> I can't say whether I used the principle of 'division,' 'duplication' or 'change properties'; they all merged together.
>
> The important point is getting a good idea.
>
> Sometimes I first think about a solution and then try to identify which principle fits the solution. At other times, the process moves in the opposite direction.

The above-mentioned quotations clearly reflect the perception expressed in the two courses that learning 'inventive principles' and exercising them discretely is helpful mostly in the first stages of learning the inventing problem-solving method. Nevertheless, after gaining experience in using the method, people observed that they could arrive at similar solutions by using different inventive principles or by combining different approaches. Moreover, the participants shifted their attention increasingly towards finding a good idea, while the question as to what inventive principle helps best in finding such an idea became less and less important. Another indication of this viewpoint about inventive problem-solving was found in the results of the mid-semester assignment submitted by students from the second course, in which they were required to mark next to each solution the principle or technique they had used in solving a particular problem. Out of the 68 examples the students included in their assignments, only half could be considered as innovative, and in only about half of these did the students indicate a pertinent solving principle (in the evaluators' eyes). Similar signs of this approach were found in the summative quiz, in which the participants were also requested to mark the principle they had used in solving each of the six questions. In this case too, some students ignored this request while others wrote down several principles next to each answer. The students explained that they often found a solution spontaneously using different inventive principles; they did not deem it important to emphasize a specific method or the best problem-solving approach they had used.

Students' own examples and reflections on the method

The students presented a variety of examples or quizzes in the class and course forum that could be solved using the method learned. For example: how to improve the supply of hot water in a high-rise apartment building having a poor central-heating system; how to prevent rodents from damaging plastic pipes of an irrigation system in agricultural areas; how to design experiments intensifying diffusion in biological processes (in a school biology lab); how to protect one's fingers when using a kitchen grater. While most of the examples related to scientific-technological issues or real-life problems, some were for fun. For example, a student presented this question in the forum:

> A Bedouin wants to climb onto a tall camel, but doesn't have a ladder. Can you help him?

Below are some solutions to this problem, based on inventive problem-solving principles:

- Change the camel: make it bend over.
- Change the environment: take the camel to a nearby hill.
- Duplicate the camel: first climb onto a shorter camel, then onto the tall one.
- Duplicate the man: first climb onto a friend's shoulders, then onto the camel.

The following problem presented by the instructor demonstrates the approach of solving a problem by changing relationships between variables in a system. Horowitz (2001) termed this principle 'breaking symmetry.'

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

The students had learned that one way of overcoming this type of contradiction is by adding relationships between two (or more) variables, such as road width and vehicle size. In other words, the roundabout will need to function like a narrow road (large internal diameter) for small cars, but also as a wide road (small internal diameter) for large vehicles. Another variable that must also be addressed is that of drivers' habits. A solution to this problem is shown in Figure 4. 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 4. A roundabout that functions like a narrow road for small cars but also as a wide road for large vehicles

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.

Several weeks after the roundabout example was discussed in class, the students commented as follows:

> I've crossed a junction that has a small step around its internal circle a hundred times, but only now do I understand how clever this solution is.
>
> Now, every time I cross a roundabout of this type, I think about the 'change connection' principle.

One of the course participants, an electronics teacher, presented an example of solving a problem by eliminating an existing connection between variables in a system.

> Religious people do not turn electrical devices on or off during Shabbat. Extremely Orthodox Jews even avoid using electrical devices controlled automatically by a thermostat during the High Holidays because this action might cause the switching of electrical circuits. In heating a room by air-conditioning, for example, if the door is opened, this action decreases room temperature and thus the air-conditioner turns on. Suggest an inventive system to this problem.

One possible solution is to replace the thermostat with a timer that switches the air-conditioner on and off for fixed periods of time, for example for a duration of five minutes every quarter of an hour. This arrangement applies the principle of changing (removing) relationships between two variables: room temperature and air-conditioner state. However, since this type of system works without feedback, the room temperature might get too high or too low. A more sophisticated solution, as the student suggested, is by controlling the air-conditioner with four thermostats located in different places in the room, as illustrated in Figure 5.

In this system, the air-conditioner is switched on or off only when the temperature is identical at different points in the room, and thus no direct connection exists

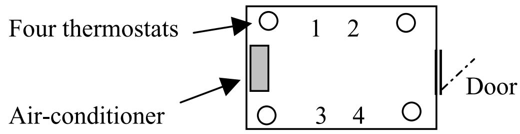

Figure 5. The air-conditioner is controlled by four thermostats simultaneously. Thus, no direct linkage exists between opening the door and the air-conditioner switching on or off

between the specific opening of the door and the air-conditioner's operation (heat also escapes through windows or walls). Therefore, this system is approved even by strict Shabbat observers. One could also arrive at this idea by asking questions like: What component in the system could be duplicated? Which relationships between system components could be added or eliminated?

After presenting his example, the student said:

> I knew about this problem and its solution from a project I had recently been involved in. However, only now can I clearly see that the solution is based on simple principles that can be useful in solving other technological problems as well.

Other examples of students' reflections during the course in the summative discussion and even after a few weeks were:

> 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.

Discussion

The evaluation of teachers' learning in the course indicates that the proposed approach has several advantages in fostering inventive problem-solving. First, the students learn that an inventive solution to a scientific or technological problem is often based on using resources or ingredients that exist naturally in 'the world of the problem' or its close environment, rather than on introducing external elements into the system. Second, such an experience causes people to look around and identify how inventive solutions to problems utilize a range of simple principles that can be learned and used in new situations. The phrase 'Why didn't I think about it before?', as was often heard throughout the course, proves this idea. Third, learning simple strategies, techniques and tactics for innovative design, and experiencing almost immediate success in finding solutions to problems, is likely to raise people's confidence in their abilities to think creatively and suggest interesting ideas in solving problems. Finally, in such a course, individuals can come to learn that concentrating on a problem (e.g. identifying contradicting demands) and closely analyzing a system's components and their internal relationships is often more productive than randomly searching for new ideas.

Perkins's (1987) view on thinking as being organized by thinking frames that can be learned, internalized and used in different situations is helpful in the discussion about teaching people how to think creatively in solving a problem. In Figure 6, 'ordered' and 'disordered' thinking are presented as parts of one frame.

While experienced designers and good problem-solvers are likely to use intuitively and unconsciously diverse thinking approaches, novices can benefit from learning methods for systematic inventive thinking in problem-solving. According to Dreyfus and Dreyfus (1986), novice problem-solvers tend to follow roles or methods they have learned, and only experts in a certain field are likely to apply intuition, utilize 'rules of thumb' or develop their own methods and techniques for coping with challenging tasks. Howard-Jones (2002) claims that experienced problem-solvers are characterized as being able to use lateral thinking and analytical thinking simultaneously or move easily between these two thinking modes. Consequently, when learners in a course start combining methods or principles they have learned, or find it redundant to identify the principle or technique they have utilized in solving a specific problem, this indicates that they have moved to some extent from being novices to 'advanced beginners' or 'competent,' according to the terms suggested by Dreyfus and Dreyfus (1986).

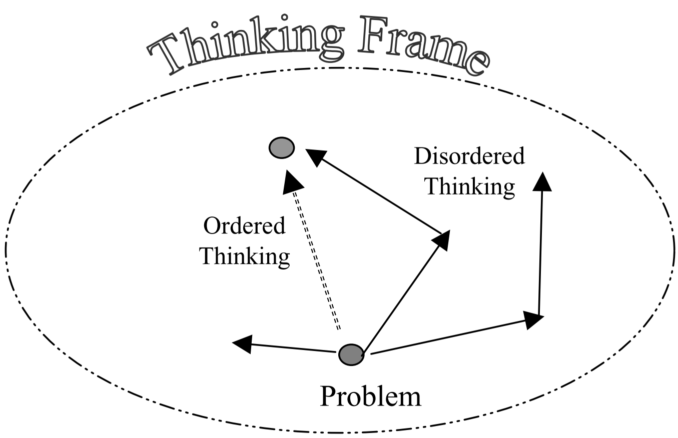

Figure 6. Inventive thinking in problem-solving as a combination of ordered and disordered thinking. A creative problem-solver is capable of effectively using the two thinking approaches and moves easily between them

Three factors contributed to the students' learning of the inventive problem-solving principles. The first factor is the emphasis on contextual learning, which means relating the learning to students' daily life contexts and experiences. Many of the questions and examples presented by the instructor and the students themselves in the course concerned matters that were significant to the participants, or to actual events discussed in the media during the course. For example, the case of the helium balloon discussed previously was presented in the course after seeing a balloon seller at Ben-Gurion Airport using a balloon with a long cord to collect other balloons stacked on the high ceiling. No one knows whether this idea had sparked in the seller's mind or whether he had made efforts to find a practical solution to his problem, since the ceiling was too high to use a ladder or a long stick, as some people had suggested. Using this example, however, proved to the participants that inventive ideas can be achieved by anyone, and that creative problem-solving is not aimed exclusively at inventors, engineers or professional designers. The second factor that significantly helped students' learning was basing the course on participants' activities rather than on the instructor's delivery. Requiring the students to present their own examples in the class, in the course forum and in the assignments they prepared was crucial for keeping the course dynamic and significant for the students. The notion of 'learning by doing' is especially important in teaching problem-solving methods because of the vague nature of this field. The third factor that helped in achieving the course goals was the consideration of reflection in the class, not only by requesting the students to indicate the inventive principles they used in solving a problem, but also by frequent discussions on the advantages and limitations of using the systematic inventive problem-solving method in comparison to 'disordered thinking' or brainstorming.

Stressing the principles of contextual learning, active learning and learning through reflective practice, as discussed above, is particularly important in courses aimed at teachers since it is well known in the educational literature that the methods teachers learn strongly influence their teaching in class.

Concluding remarks and research agenda

The proposed approach is novel in that it claims that people can improve their problem-solving abilities by combining methods based on 'ordered thinking' and 'disordered thinking,' and not one of these approaches has preference over the other. It is important to emphasize that while searching systematically for an inventive solution, one should not ignore unexpected ideas that suddenly appear. After all, surprising discoveries and blind variations played an important role in the history of science and technology (Campbell, 1960). The present study touched only slightly on the application of the proposed approach in teaching a specific science and technology curriculum, and additional work is required in this regard.

Although this study was limited in scope, teachers' positive response to the course and the fact that many expressed interest in the subject months after completing their university studies are encouraging. In this context, it is useful to mention here other efforts for teaching inventive problem-solving to Israeli pupils. In the program entitled 'Physics and Industry' (Eylon, 2003), launched in 1999, high school pupils preparing final projects in electro-optics learn a course on inventive problem-solving given by an expert in the field (Helfman, 1992). These pupils demonstrated effective use of the inventive problem-solving method in their project design, troubleshooting and improvement. The recently published book entitled *Systematic Inventive Thinking* (Helfman, 2005), intended for pupils and educators, is one example of a selection of learning materials on the subject that have been used in Israel since the 1980s. Hundreds of pupils all over the country participate in extra-curricular 'systematic inventive thinking' courses and take part in regional and national competitions on inventing new products. The research on the teaching–learning processes in these programs, however, is still in its infant stage.

The course discussed in this paper differs from other programs mentioned above in two points: firstly, the course suggests a simplified approach for teaching the basics of inventive problem-solving to young children in comparison, for example, with TRIZ (Altshuller, 1988); secondly, the course trains teachers to teach inventive problem-solving, rather than basing instruction to pupils on experts coming from industry, as is often found in the field. As a result of these courses for teachers, two teachers, for example, who recently graduated from the program ran a course for inventive problem-solving aimed at three groups of junior high school pupils from two different schools within their science and technology studies (Barak *et al.*, 2005). Initial observations about pupils' participation in the class and in the course's on-line forum indicate high motivation among many of the pupils to learn the method. However, much more work is required to explore to what extent children internalize the inventive problem-solving methods they are learning, how they integrate the notions of 'idea focusing' and 'idea generating' in different contexts and whether such a course affects pupils' confidence in problem-solving.

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