"Systematic Inventive Thinking" in Junior High School Study of Science and Technology: Development, Implementation and Evaluation of an Innovative Approach to Problem Solving

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By: Jacob Helfman

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Abstract

Systematic inventive thinking is an innovative topic in the syllabus of science and technology studies in Junior High School in Israel (Ministry of Education, 1996). The project reported in this thesis deals with the development, implementation and evaluation of a curriculum for this topic. The outcomes of this project provide the necessary background for teaching the topic in classrooms and in-service teacher courses (INSET) throughout Israel.

The principle findings of the curriculum implementation and evaluation show that it can be successfully learned and taught. Teachers can be trained in the topic by using the learning materials and the teaching methods developed in the project. The curriculum provided ninth-grade students structured and systematic thinking modes for problem-solving and contributed to improving their creative thinking skills. Moreover, the model was received with great enthusiasm and interest by students and teachers alike, and generated a creative atmosphere in the classroom.

The study is based on the premise that inventive thinking can be acquired in a systematic manner. Our approach was developed on the basis of various methods in the domain of problem-solving and creativity, especially the work of Altshuller (Altshuller, 1985). The project builds on previous developments carried out for adults in the Open University of Israel (Helfman,1990).

The approach that was developed enables learners to conduct the thinking process in a controlled, organized, and conscious manner. The inventive ideas are developed on two levels: An abstract level (development of models and solution concepts) and a concrete level (development of specific solutions).

The search for solutions consists of a three-stage method:

The first stage consists of applying the imagination in a divergent thinking mode, leading to possible thought directions that may lead to the desired solution.

This stage culminates in a large number of models and solution concepts.

In the second stage logical considerations are applied to proposed abstract solutions in order to sort them out by examining relevant conditions, constraints and properties. As a result a subset of solution concepts are chosen for further consideration (convergent thinking).

In the third stage the abstract solutions chosen in the second stage are transformed into concrete solutions by identifying actual resources that have the characteristics outlined by the abstract solution. In the process, materials, artifacts and procedures are found for solving the problem in several alternative and usually inventive ways.

The method of "inventive thinking" provides the problem solver with well defined thinking tools that accompany each of the stages described above. For instance, the "amazing dwarfs" are often used in the solution process as a useful thinking tool enabling the problem-solver to view systems microscopically. These "dwarfs" are not constrained by physical reality and thus enable the problem-solver to use the imagination without prohibition. The use of these dwarfs together with a method for analyzing the relevant systems functionally lead to many alterative solution concepts of problems. These solution concepts are then transformed into actual solutions. In the dissertation 23 creative thinking tools are described. Each tool has a specific role in the design of the solution.

The general heuristics offered by the method of "inventive thinking" together with the well defined thinking tools form the basis for the systematic nature of the solution process.

The project yielded the following outcomes:

- Two textbooks were written for students, two for teachers and s training guide for INSET (Helfman,2000).
- A formative evaluation of the learning materials and teaching methods was carried out, leading to the changes and improvements in the model's contents, learning methods, and teaching methods.
- The learning materials were used in studies held over two consecutive years – 1994 and 1995 – and were studied in seven ninth-grade classes (N=169). The detailed results are presented in the dissertation.
- Thirty-two INSET courses were held throughout Israel, following which the model was applied (fully or partially) in dozens of 7th , 8th and 9th grade classrooms from 1996 to 2000.

Since no previos research has been performed on the topic, we attempted to address the following questions:

1. How, and to what extent, does studying the "systematic inventive thinking" method contribute to ninth-graders' ability to solve problems in science and technology?
2. What are the attitudes of ninth-graders, and of teachers attending INSET courses, towards learning the topic of "systematic inventive thinking?"
3. Which problems are entailed in implementing "systematic inventive thinking" in science and technology curricula in Junior High Schools?

The study was carried out in two parts.

1. A detailed study was carried out with 103 ninth grade students from 5 classes who studied the topic for an average of 50 hours during the school year. The performance of these students (experimental group) was compared with that of 117 students from 5 classes from the same school with similar background who did not study the topic (comparison group.(
2. A study focused on students' and teachers' views and attitudes was carried out by using questionnaires, interviews and informal observations.

Following is a summary of the research results:

1. The detailed study of the students in the experimental group shows that they learned to organize their thinking in a systematic and conscious manner, and improved their ability to solve technological-scientific problems in a creative-methodical way. The process of searching for and discovering solutions generally took place at two levels: the abstract level (developing thought directions), followed by the concrete level (discovering specific solutions.(
2. Performance of the experimental group was compared with that of the comparison group, using three criteria (Guilford, 1959, 1967): thinking fluency, flexibility and originality. In order to evaluate hundreds of solutions, a methodology was developed for characterizing them according to the identity of the subsystems treated in the solution and the specific actions leading to the desired results. The choice of a given set of subsystems and specific actions lead to a well defined "thought direction" for solving the problem. This analysis led to three different measures associated with the previously mentioned criteria:
    a) The overall number of solutions that were proposed for the problem (thinking fluency)
    b) the number of thought directions that were developed for solving the problem (thinking flexibility)
    c) the number of abundant, original and unique solutions (thinking originality)

The methodology was also used for diagnosis, enabling students and teachers to receive individual feedback about the thinking process and its outcomes.

The students in both groups solved many problems in the course of the study. To gauge the effect of teaching method, three central problems (case-studies) were analyzed in detail. Each problem was solved both by individual students, and by teams. The analysis shows that the performance of the experimental students was significantly higher than that of the comparison students, in the criteria examined.

In each of three problems, both in individual work and team work, the experimental group developed dozens of thought directions and dozens of unique solutions, which students in the comparison group had no considered. This fact indicates that students in the experimental group expressed more openness and flexibility of thinking.

Fifty to seventy percents of the total thought directions developed by the experimental students were unique directions, while no unique directions were developed in the comparison group. This indicates that originality was significantly higher in the experimental group than in the comparison group.

The number of solutions (fluency) proposed by the experimental students, in individual work, was higher than that of the comparison students, constituting from 25% to 70% more solutions to the problems studied. On the average, students in the experimental group developed 191 solutions for the three case studies vs. 142 by the comparison group. In team work, relatively greater time was devoted to dividing the experimental group into sub-groups and to organizing their work. When we measured fluency among the experimental group, at the end of the technical arrangements, it was 46% higher than the fluency developed by the comparison group over a similar period, although the overall number of solutions was similar in both groups.

3. The study shows that the model met most of the expectations expressed by students and teachers, and was received with substantial interest, enthusiasm and appreciation by most of them. The method and the thinking tools that were developed were highly appreciated by students and teachers alike, in terms of their importance and contribution to fostering autonomous learners possessing original thinking. Observations showed that an atmosphere had been created that encouraged and nurtured creativity (freedom of action and self-expression, lacking preconceptions, substantial use of imagination, reinforcement and encouragement for using alternative thinking models, and so on).

Applying the topic of systematic inventive thinking in Junior High Schools raised two central problems: a. how to train the teachers, and b. how to introduce the method into schools on a wide scale. The second problem results from the lack of formal time for studying thinking skills, and the lack of learning materials to introduce the model into the contents of the new science and technology syllabus. In order to cope with these problems, the following approaches have been developed:

1. Teacher training: An unorthodox approach and teaching method for studying the topic at teach INSET courses: teachers gain experience in the material like the students, in particular they get to know their own thinking (meta-cognition), study how to teach thinking – not just what to think, and understand that they do not possess all the solutions, ideas and the multi-disciplinary knowledge required, and so on.
2. Implementation: Two forms of teaching the topic: a. Teaching the method of systematic inventive thinking as a special subject throughout the year, parallel with the subjects taught in "science and technology". The relationship between the content areas and the method of inventive thinking is created by solving several complex problems in the content area by using the method. b. Teaching the content area and inventive thinking in an integrated manner.

Learning materials for carrying out the two forms of teaching were prepared in several topics of the "science and technology" syllabus.