Creative Problem Solving

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Abstract

This paper describes an undergraduate course prepared and delivered by the author aimed at developing creative problem-solving skills. The course is based on intensive problem-solving exercises that illustrate various creative problem-solving strategies. Students gain practical experience in finding useful analogies, combinatorial thinking, problem reforming, and state space search methods. They compare incremental and transformative problem-solving, and analyze various obstacles that prevent the problem-solver from perceiving either the problem itself or the information necessary to solve it: such as stereotyping, imposing unnecessary restrictions, and the fear of thinking in a different way. The paper discusses some issues in problem solving typology, what types of skills are necessary for creative problem solving, and what kind of problems enhance the development of such skills.

Introduction

The need for helping undergraduate students develop creative problem solving skills has been widely acknowledged. However, few courses if any in the Computer Science curriculum address this need. What we actually teach is how to use already known methods and how to apply already developed algorithms to solve particular problems. Generally, the majority of students fail to solve problems that have not been discussed in class, or whose solutions are not described in the textbook, even when such problems are much easier than the ones students know how to solve. On the other hand, there are various books that discuss strategies for creative problem solving as well as various educational centers that make use of such books, and have programs and support events (courses, seminars and workshops) to teach problem-solving skills. However, undergraduate students are seldom involved in such programs while in college and there is experimental evidence that their creative problem-solving skills tend to decrease instead of to increase.

The course described in the paper exposes the students to creative problem solving experience and enhances the ability to view problems in a non-traditional way: to escape the trap of well-known procedures and solutions. The paper describes the types of strategies discussed, and the types of assignments. The course has no prerequisites. The domain of the problems is chosen so that students majoring in various disciplines can attend the course. Problems consist of puzzles and tasks that are not explicitly related to any science discipline.

The course has been delivered as a 3-credit three-week course (meets for three hours every day) and as an independent study for students majoring in elementary education. The paper also describes how elements of this course can be incorporated in regular computer science courses.

Problem Solving Issues

The literature is abundant with guidelines and prescriptions about how to be a successful problem solver. The issue is given a consideration from mainly two perspectives: how to solve mathematical problems, and how to solve business and management problems. How to solve mathematical problems is mainly discussed within the framework of deductive reasoning, i.e. how to choose the appropriate theoretical model and how to apply it to a given problem. The guidelines for business managers focus mainly on how to manage organizational activities.

Problem solving in computer science has its own specifics. It differs from solving math problems in that the students are required to modify and adapt a given theoretical model to solve the problem at hand. In general, such modifications and adaptations involve designing an algorithm with unique components, i.e. the students have to invent the solution rather than apply a prescribed sequence of steps to solve the problem. This is where the students face the greatest difficulties. Providing detailed guidelines for each assignment helps. However, it is not sufficient to build problem solving skills. The problem that the instructors face is how to effectively teach the various problem solving strategies and how to promote development of cognitive skills necessary for creative problem solving.

In order to gain a better picture of these skills, we need first to delve into the content of the concept "problem solving strategy".

Problem Solving Theories

There has been a lot of research done in scholarly work on higher education and teaching, cognitive sciences, as well as in artificial intelligence on problem solving methods. Various classification schemes have been proposed with respect to types of problems, types of problem solving strategies, and types of cognitive skills ([6], [8]).

Types of Problems

In psychology, problems are characterized by 4 aspects:

- goal: state toward which problem solving is directed
- givens: conditions and constraints present (explicitly or implicitly) in the problem
- means of transforming conditions
- obstacles

Currently a widely accepted taxonomy of problems is well-structured (well-defined) problems and ill-structured problems. In well-structured problems the four aspects are completely specified, while in ill-structured problems this is not so. Typical examples of well-structured problems are mathematical and algorithmic problems. The prevailing view is that well-structured problems and ill-structured problems require different cognitive skills. In this paper we are concerned mainly with creative problem solving for well-structured problems.

Types of Problem Solving

Currently two basic theories are used:

- Gestalt theory, which considers two aspects of problem solving: productive and reproductive. According to the theory, productive problem solving involves creativity based on "insight" into the problem solution. The theory claims that in order to gain insight, the problem has to be restructured. Reproductive problem solving involves known methods and routines based on previous experience. An important concept in the theory is the so called "functional fixedness" referring to the situation when previous experience prevents the problem solver from seeing new ways to solve the problem at hand.

- Problem solving through information processing, based on Newell and Simon's work [4], [5]. The basic assumption in this theory is that humans are essentially symbol manipulators that perform operations serially and represent knowledge as production rules. Problem solving is viewed as search in the problem space. The problem space is represented as an oriented graph with one initial state and one or more goal states. The edges correspond to applicable operators that transform the initial state to the goal state by going through a series of intermediate states. Thus, problem solving is a search for the best path from the initial state to a goal state.

The latter theory has been elaborated mainly within the research in artificial intelligence, and several problem-solving strategies have been formulated with the purpose of being used in development of artificial intelligent agents:

- State space search - search for a path from the initial state to the goal state
- Means-Ends analysis - reduce the difference between the goal and the initial state
- Problem decomposition
- Problem transformation, e.g. Divide-and-conquer
- Rule-based problem solving - deductive approach
- Analogy-based problem solving - inductive approach

While for their computer implementation we need to have well-structured problems, the strategies are generally used by humans for solving both well-structured and ill-structured problems.

Problem Solving Theories, Problems, and Creative Problem Solving

In general, a distinction is made between mathematical problem solving and algorithmic problem solving on one side, and creative problem solving on the other side. The opinion widely adopted is that mathematical and algorithmic problem solving involves applying known procedures and rules and thus the notion of creativity is not present. Creative problem solving is generally defined as "producing a new, individually or socially useful product, which cannot be produced by means of routine procedures" [1]. The assumption that well-structured problems do not involve creative problem solving can be debated. Certainly there are mathematical and algorithmic problems whose solution requires creative problem solving skills: consider for example the work of Einstein, Turing, Gödel, Dijkstra -just to mention a few. Let us see how the theories treat creative problem solving in well-structured problems.

Gestalt theory states that we need a restructuring of problem representations, and such restructuring occurs as a result of the problem solver's insight. The "problem solving as search" theory is based on the notion of initial state, goal state, and operators. At first sight it may seem that it does not refer to creative problem solving. However, we may consider the initial state to be the problem as given, and the goal state to be the problem restructured. Then, the issue to be resolved is how to find the operators to transform the initial state into the goal state. Thus the theory does not exclude creative problem solving for both well-structured and ill-structured problems.

So, why do some people have insights and others do not? In order to answer this question we have to look at two other questions:

(1) Where do the insights come from?
(2) Can we articulate specific obstacles to creative problem solving?

The answer to the second question can be found in the Gestalt theory, which has shown that relying on past experience can often hide the path to success, and results in failure. Furthermore, answers can be found in the work of Ellen J. Langer, Psychology professor at Harvard [2]. Langer introduces two concepts: mindlessness and mindfulness, and she examines their role in the problem solving process. Mindlessness is revealed in automatic behavior resulting from doing actions repeatedly; in acting from a single perspective, which results from sticking to a theory or to a model and being incapable of seeing other alternatives and keeping a fixed view of the world in general. An unexpected but plausible conclusion is that mindlessness may develop as a result of rigid education. We teach students the "correct" way to do things, and with this we implicitly imply that there is no other way to do things. Students, concerned mainly with the question "what does the professor want from us?" don't even attempt to think differently, and many of them completely block out any creative thought that might occasionally come to them.

Mindfulness is a way to view the world in its variety and in its interconnectedness. A mindful perspective to problem solving is the ability to approach the problem form different angles, to see long-distance relations between the given problem and other problems, and other situations in general.

Mindfulness is the key to answering the question "Where do insights come from?" According to David Perkins - a professor at the Harvard Graduate School of Education, insights are generated through exploring alternatives; through applying methods from other domains; through abandoning unnecessary restrictions arising from the single perspective view [7]. His book Archimedes' Bathtub: The Art and Logic of Breakthrough Thinking [7] has been chosen as a textbook for the course "Breakthrough Thinking" described in the next section.

How to Teach Mindfulness

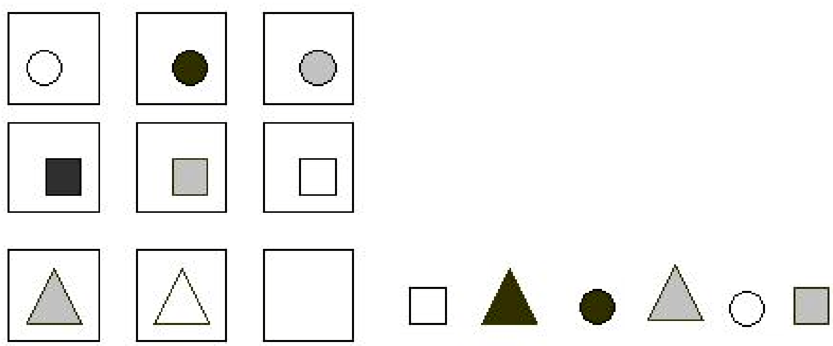
The course "Breakthrough Thinking" offered at Simpson College as a three-week May term course is aimed at exposing the students to creative problem solving experience. Its goal is to enhance the ability of viewing problems in a non-traditional way and of escaping the trap of well-known procedures and solutions.

The underlying assumption when developing this course was that creative problem solving involves problem restructuring. Based on the findings in [7] we have focused on four basic cognitive skills:

- Reasoning by analogy
- Combinatorial thinking
- Causal thinking, based on logic.
- Multidimensional thinking

Reasoning by Analogy

Problems that focus on this skill involve using distant analogies. An example of such a problem is to find 20 ways of using a shoe, which should not include it original purpose (foot protection). Furthermore, the students have to articulate the properties that make each usage possible. Another set of problems consists of finding the missing block in a set of images. The purpose of the homework assignment is to practice identifying and describing relations among objects. Students are given a set of puzzles. Each puzzle consists of nine squares put in a table 3 x 3. Eight of the squares contain some figures, and the last square is blank. The task is to fill in the blank square with an object chosen from the listed objects on the right side. The figures in the eight squares are in some relation. Students have to choose an object that is in the same relation with the other objects. Here is an example:



Finding the missing term in non-numerical sequences is another challenge to the students: for example o, t, t, f, f, s, s, ….. A good problem is to use numerical sequences in different number systems.

Combinatorial Thinking

Several groups of problems are used to develop combinatorial thinking:

a. Word transformation problems, e.g. how to obtain *cart* from *bold* by changing only a single letter at each step.
b. Constructing words out of the letters of a given word, e.g. to find 100 words built out of the letters in the word "constellation".
c. Solving cryptograms, such as

```
   LOAN          WEEK
   LOAN          WEEK
 + LOAN       +  WEEK
   LOAN          WEEK
   --------   -----------
   DEBT         MONTH
```

   Here is a more complex one:

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   ABCB  /  DC =  CED
    -        -     +
   FBGB  – EB = FBDH
   ------------------
   CGCG +   D = BGBG
```

d. Writing stories is an essential component since it provokes imagination. A typical assignment is to give a set of pictures (usually about 4) and ask the students to write two different stories based on the pictures.
e. The mastermind game with digits: an activity enjoyed by all students.

Causal Thinking and Logical Inference

Various logical puzzles that involve causal thinking and logical inference have been solved in class. Causal thinking is very important to problem solving in general. Experience has shown that even when students can correctly apply a procedure to solve a problem, they do not necessarily perceive the causal relations in the problem. For example, if the assignment is formulated as, "Write a program that reads three numbers, finds the average and prints the result," it is generally correctly done. However, if formulated as "Write a program that computes the average of three numbers. The numbers have to be read from the keyboard and the result has to be printed on the screen," there are students that would first write the code to compute the average and then write the input statement.

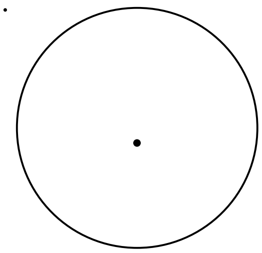
Multidimensional Thinking

Multidimensional thinking involves employing different perspectives, abandoning implicit restrictions, and modifying the initial settings of a problem. The nine-dot problem is a typical example. Other problems of that type are:

a. Here is a line: ______________
Without doing anything to the line, make it shorter.

b. A woman has 7 children. Half of them are boys. How is this possible?

c. Here is a picture:



Draw the picture (with the dot inside) without lifting the pencil from the paper.

Conclusion

The course was very well accepted by the students. Often they did not want to leave the classroom after the last period had ended. It is unreasonable to believe that a three-week experience will greatly enhance the students' problem solving skills. However, there is certain evidence that the students have attained a likeliness to similar problems. After the course ended, several students continued to look for such problems and actually started to enjoy problem solving. Some students even offered their problem collection to be used in the next issues of this course.

Certain elements of the course have been incorporated in some of the traditional computer science courses:

a. Open-ended assignments, with at least two different solutions of the problem.
b. Warm-up exercises at the beginning of each class period, with problems/puzzles as described above.

In a paper on instructional design [3] the following statement has been made:
"There is a body of knowledge and skill that has been developed and archived by generations of scholars, scientists, technologists, artists, and others. The purpose of instruction is to enable students (novices) to acquire this knowledge and skill. The purpose of instructional design is to develop experiences and environments which facilitate the student's acquisition of this knowledge and skill."

Instruction should be more than that. If we limit ourselves to conveying only the knowledge and skills that have been developed, how would new knowledge be created? We need to teach our students how to be creative thinkers, and the proposed course is a step toward this goal.

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