**Chapter 9: Problem Solving**

**Learning Objectives**

* Explain the differences between the following pairs of opposites: directed versus undirected thinking, well-defined versus ill-defined problems, and productive versus reproductive thinking.
* Discuss how computer programs can simulate the way that human beings represent and search a problem space for a solution.
* Contrast algorithms with heuristics as a means for searching a problem space and define the heuristics of means-end analysis, working backward, and analogies.
* Discuss the stages of creativity and impediments to the creative process.

**Chapter 9: Problem Solving**

**Brief Summary**

The centrality of problems in everyday life has prompted psychologists to study extensively the domain of problem solving. Typically, humans approach problems in two ways using either directed thinking which is goal-directed and rational or undirected thinking which is wandering thought. Goal-directed thinking is useful for solving well-defined problems where the initial state, goal state, and intermediate states are known. Undirected thinking is useful for solving ill-defined problems that require insight and creativity. Artificial intelligence programs, which model human problem solving, have been developed to better understand the cognitive processes contributing to successful problem solving. Factors that have been found to be important components of problem solving are how the problem is represented, whether searching the problem space involves an algorithm or a heuristic, and the particular strategies that can be applied to the problem such as working backward, using analogies, and a means-end analysis. Individual differences in problem solving have also been identified with experts and novices using, respectively, forward and backward chaining strategies to solve problems.

The role of creativity in problem solving, though important in human history, has not been studied as extensively in the laboratory. Three criteria have been proposed by which a product of the human mind can be considered creative: It must be unique, useful in some context, and must have required special talent on the part of its creator to be realized. The creative process itself can be organized into four stages: Preparation or the development of knowledge in a particular domain, incubation or putting the problem aside for a period of time, illumination or the crucial insight that suggests the solution to the problem, and verification or checking to determine if the solution is acceptable. Studies of creative individuals suggest that creative products emerge from a winnowing process applied subsequently to a large number of ideas. Creativity can be blocked by past experiences related to the problem or fixation, as well as the inability to conceive of new uses for an object which is known as functional fixedness. Measures of fluid intelligence have been found to correlate with creativity. Furthermore, research has shown that an intensive working memory training regimen can significantly boost performance on fluid intelligence tests. Studies of individual differences in creativity have attempted to relate postmortem analyses of neural features in the brains of famously creative individuals to their unusual abilities. For example, a postmortem analysis of the brain of Albert Einstein suggests that peculiarities in parietal lobe structures may underlie his advanced visuo-spatial and mathematical abilities, while an enlarged prefrontal cortex may have contributed to his unusual problem-solving abilities.

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**Detailed Summary**

1. People think by manipulating mental representations of the world. Through the use of such representations, people can plan courses of action and simulate their effects prior to taking action. The study of problem solving has shed light on how people go about this. Often in solving a problem, one builds a model of the environment with a clear, well-defined goal in mind. One then tries to find a path that leads straight to the goal with little deviation. Such problem solving illustrates directed thinking. Undirected thinking refers to dreaming, daydreaming, and other forms of thought that meander without concern for attaining a goal. Undirected thinking is neither rational nor goal oriented.

2. A well-defined problem is characterized by an initial state, a goal state, and a set of operators. Each legal move from the initial state to intermediate states to the goal state is defined by an operator. All of the states and operators taken together define the problem space. To solve a well-defined problem, one must select a sequence of operators that follow a path through the problem space to the goal. An ill-defined problem is missing a clear initial state, goal state, and/or known operators. An ill-defined problem often calls for insight and creativity, what the Gestalt psychologists called productive thinking. Yet even some well-defined problems demand creative insights for solutions.

3. A general model of problem solving entails first representing the problem and then searching the problem space for a path to the goal. Finding a good representation of the problem space is critical and often demands as much insight as does the search process itself. Algorithms are rules for searching the problem space that are guaranteed to succeed, although often at prohibitive costs in time and effort. Heuristics are rules of thumb that may or may not lead to success, but they carry less cost than do algorithms. The General Problem Solver (GPS) is one of several artificial intelligence programs that simulate aspects of human problem solving. It is based on the premise that a general search heuristic called means-end analysis is powerful enough to solve a wide range of problems. Today, it is recognized that an adequate simulation of human problem solving must address the effects of domain-specific knowledge and metacognition, as well as general heuristics. Effective problem solving also requires adequate working memory. Attention is needed to maintain relevant representations in working memory while suppressing distractions. The larger the capacity of the central executive of working memory, the better one can solve novel problems.

4. Gestalt psychologists recognized that both perception and problem solving require the proper organization of elements. They identified two common obstacles to successful problem solving: fixation and functional fixedness. Fixation refers to the tendency to set the mind into a routine approach to problem solving. Thinkers who adopt an automatic or mindless approach to problems often overlook ways of representing and searching the problem space that are ideal. Functional fixedness refers to the tendency to see objects as having only a single typical use. Thinkers prematurely categorize the elements of a problem in accordance with their typical use, thus overlooking novel and useful alternatives.

5. Historical creativity refers to ideas that are novel within the context of cultural history. Few people are recognized as historically creative, yet all of us engage in cognitive processes that are creative, even if our creative products are not judged as novel, useful, or extraordinary. The stages of creativity begin with preparation of or working with a problem for an extended period of time. Incubation, or putting the problem aside, is the next stage. The third stage is illumination, or coming up with a crucial insight that leads to the solution of the problem. The fourth stage is verification, when the insight is implemented and tested. Creativity appears to follow a Darwinian process. First, ideas are conceptually combined to generate a large number of variations. Second, there is a variation-selection process in which most ideas are winnowed out as uninteresting. The high productivity rates of historical geniuses, then, are part of the secret of their success. They had good ideas as a consequence of having many ideas in the first place.

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**Topical Outline**

Types of Thinking

* Directed thinking is goal-directed and rational.
* Undirected thinking is wandering thought.

Well-Defined and Ill-Defined Problems

* + A well-defined problem is characterized by an initial state, a goal state, and intermediate states known as subgoals.
  + Legal moves through the problem space are accomplished by operators.
  + The Tower of Hanoi puzzle is used to study problem solving in the laboratory.
  + Ill-defined problems are those for which the goal state, the initial state, and/or the operators are not clearly defined.

Productive and Reproductive Problem Solving

* Reproductive thinking entails the application of tried-and-true paths to a solution.
  + Productive thinking requires insight and creativity.

Relations Among Terms

* Well-defined problems often require directed and reproductive thinking.
* Ill-defined problems often require undirected and productive thinking.

A General Model of Problem Solving

* Ernst and Newell’s (1966) General Problem Solver was an artificial intelligence (AI) program that attempted to solve a wide range of problems.

Representing Problems

Understand

* + A critical step in finding the solution to a problem is to first find a good way to represent the problem.

The MC Problem

* Stressing the importance of finding the right representation of a problem may not be helpful in solving the problem.

Searching the Problem Space

* An algorithm is a rule for solving a problem that always succeeds, given enough time and effort.
* A heuristic is a rule of thumb that may or may not lead to a solution, but has less computational cost than an algorithm.

Working Backward

* Working backward from the goal state to develop a solution is only viable when the goal state is uniquely defined.

Analogies

* An analogy heuristic looks for similarities between a current problem and one solved in the past.

Means-End Analysis

* Means-end analysis refers to comparing one’s current state to the goal state and then finding a means or an operator to reduce the difference.

Domain-Specific Knowledge and Metacognition

Knowledge and Power

* Knowing how to represent a problem and search the problem space is aided by domain-specific knowledge.
* The monitoring of cognitive processes and states of knowledge is called metacognition because it involves cognition about cognition, or thinking about thinking.

The Case of Physics

* Expertise in a specific domain aids problem solving in two ways. First, domain-specific knowledge supplements general procedures for representing and solving problems. Second, expertise provides metacognitive control over the processes of problem solving.
* Experts use forward chaining in solving problems, whereas novices use backward chaining.

Creativity

* Compared to other types of thinking, creativity has not been studied as extensively in the laboratory.
* Both the left and right hemispheres of the brain are required for creative thinking. The right hemisphere is biased toward the simultaneous processing of visual-spatial information, whereas the left hemisphere is biased toward the sequential processing of verbal information.

Historical Versus Process Creativity

* + Historical creativity refers to ideas that are novel within the context of the whole of human history.
  + A product of the human mind must satisfy three criteria to be considered creative: 1) It must be unique, 2) It must be judged as useful in some context, and 3) It must have demanded some special talent on the part of its creators.

Stages of Creativity

* + The process of creativity consists of four stages: Preparation, incubation, illumination, and verification.

Creativity Blocks

* + The structure or representation of the problem may impose unnecessary constraints that can hinder creative thought.

Fixation

* + - Fixation refers to the blocking of solution paths to a problem due to past experiences related to the problem.

Functional Fixedness

* + - Functional fixedness refers to the tendency to see objects as having only a single typical use.

Sources of Creativity

* + Creativity is fundamental to human nature and creators bring problem representations, search heuristics, and diverse forms of knowledge to their tasks.

Creative Production

* + - The process of creating involves first generating a large number of variations of ideas and second, winnowing out most ideas as uninteresting in a variation-selection process.

Fluid Intelligence

* Fluid intelligence refers to the ability to solve novel problems.
* Intelligence as problem-solving ability contrasts with crystallized intelligence, which refers to the breadth and depth of a person’s knowledge.

Role of Working Memory

* The executive functions of working memory that are served by prefrontal cortical regions play a role in general fluid intelligence, or the ability to solve new problems.

Einstein’s Brain

* Postmortem examination of Einstein’s brain revealed peculiarities in the parietal lobe region which are considered to underlie his visuo-spatial and mathematical genius.
* Einstein also possessed an unusually large prefrontal cortex and this may have contributed to his advanced problem-solving abilities.

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**Key Terms**

directed thinking

undirected thinking

well-defined problem

initial state

goal state

subgoals

operator

problem space

ill-defined problem

reproductive thinking

productive thinking

isomorphic problems

algorithm

heuristic

metacognition

backward chaining

forward chaining

historical creativity

preparation

incubation

illumination

verification

fixation

functional fixedness

fluid intelligence

crystallized intelligence

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**Discussion Questions**

Discussion Question #1

A regimen for training working memory has been found to increase fluid intelligence. List three occupations that involve a large component of working memory and three occupations that involve a small component of working memory. Do you think that working in either of these jobs would affect your fluid intelligence? Why or why not?

Discussion Question #2

Provide an example from your everyday life of a well-defined problem and an ill-defined problem. What techniques would you use to solve each of these? How would these techniques differ from one another?

Discussion Question #3

Do you think that social interaction can be a source of creativity? In what ways would social interaction benefit each of the stages of creativity? List three examples of creative products that have been created by groups rather than individuals.

Discussion Question #4

A creative product generally evokes a response from the particular audience for which it was intended. Critics are those individuals in such an audience who analyze, interpret, and evaluate the merit of the creative product. What role does criticism play in the creative process? Does criticism serve to benefit the creative product or does it act to constrain creativity?

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**Questions for Thought**

Consider a problem you have encountered and solved in the past week. Would you classify it as a well-defined or an ill-defined problem? What role was played by directed and undirected thought in arriving at the solution?

Can you provide examples of when you have used analogies and working backward as problem-solving heuristics? How about means-end analysis?

A test of creativity calls for people to think of as many uses for an object as they possibly can. For example, how many ways can you use a hammer? Why is this considered a measure of creativity?

Consider a time when incubation aided your ability to arrive at a creative insight. Why do you think that incubation helped in your case?

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**Web Resources**

[**The Elevator**](http://www.muller.co.il/riddle/Riddle.aspx?id=17)

The elevator riddle which demonstrates how hints can be helpful in solving insight problems.

[**Tower of Hanoi**](http://www.mazeworks.com/hanoi/)

An interactive demonstration of the Tower of Hanoi.

[**Creativity Test: Insight Problems**](http://www.indiana.edu/~bobweb/Handout/d4.ips.htm)

An interactive demonstration of verbal, mathematical, and spatial insight problems.

[**Creativity Test: Remote Association Task (Mednick, 1962)**](http://www.indiana.edu/~bobweb/Handout/d5.rat.htm)

An interactive demonstration of the Remote Association Task.

[**IQ Boost with Dual n-back Test**](http://dual-n-back.com/)

An interactive demonstration of the dual 2-back task similar to the task used in the Jaeggi et al. (2008) study to improve working memory through training.

[**Raven Test**](http://www.raventest.net/)

An interactive demonstration of the Raven’s Progressive Matrices Test of fluid intelligence.

[**METACOGNITION: Study Strategies, Monitoring, and Motivation**](http://academic.pgcc.edu/~wpeirce/MCCCTR/metacognition.htm)

Provides an overview of metacognition and highlights its application to student learning and studying practices.

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**SAGE Journal Articles**

Strough, J., Cheng, S., & Swenson, L.M. (2002). [Preferences for collaborative and individual everyday problem solving in later adulthood.](http://jbd.sagepub.com/cgi/reprint/26/1/26?ijkey=43YJXc9XbrrnQ&keytype=ref&siteid=spjbd) International Journal of Behavioral Development, 26, 26-35.

1. Discuss the pros and cons of solving everyday problems either alone or in groups.

2. In their article, the authors suggest that older adults attempt to “adjust their problem solving to best fit the resources available to them.” How does this reflect the idea of metacognition?

3. What evidence did the authors find regarding the role of domain-specific knowledge in older adults approaches to problem solving?

Lefebvre-Pinard, M. (1983). [Understanding and auto-control of cognitive functions: Implications for the relationship between cognition and behavior](http://jbd.sagepub.com/cgi/reprint/6/1/15?ijkey=XGwWQtRAh.jBo&keytype=ref&siteid=spjbd). International Journal of Behavioral Development, 6, 15-35.

1. Some individuals will talk to themselves while engaged in problem solving. What are the benefits of this self-talk in terms of problem solving efficiency?

2. How does the problem solving process differ for children compared to adults?

3. The author views metacognition as an ability that varies among individuals with some being high in private self-consciousness and others being low. Do you think it is possible to increase an individual’s level of self-consciousness in a given problem solving situation?

Norris, S. P. (1989). [Can we test validly for critical thinking?](http://edr.sagepub.com/cgi/reprint/18/9/21?ijkey=boWgrIR4qlVFs&keytype=ref&siteid=spedr) Educational Researcher, 18, 21-26.

1. How does the idea of critical thinking relate to metacognition?

2. What does the author mean by the term, “psychological generalizability?”

3. Do you think it is possible to develop a valid test that assesses critical thinking? What are some of the pros and cons of such a test?

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**Recommended Readings**

Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., & Mednick, S. C.(2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences, 106*, 10130–10134.

de Groot, A. D. (1965). *Thought and choice in chess*. The Hague, Netherlands: Mouton.

Gilhooly, K. J. (1996). *Thinking: Directed, undirected and creative*. (3rd ed.). London:

Academic Press.

Runco, M. A. (2004). Creativity. *Annual Review of Psychology*. 55, 657-687.

Sternberg, R. J. (Ed.). (1999). *Handbook of creativity.* New York: Cambridge University Press.