TEACHING AND LEARNING PROCESS: THINKING AND PROBLEM SOLVING

Wasis Djoko Dwiyogo
Faculty of Sport Science, Universitas Negeri Malang
Address: Jl. Semarang No. 5, Malang 65145, Indonesia
wasisdd@gmail.com

Abstract: The highest capability level in thinking and intellectual skills is problem solving. This is to say that educational activities should be directed not only to increase knowledge acquisition but also to develop the skill of problem solving. Problem solving is defined as seeking ways out from difficulties and challenges. The process of problem solving includes identifying problem, planning strategies in order to solve the problem, determining the right strategy, implementing the problem solving action, and evaluating the overall process and result of the action.

INTRODUCTION

Nowadays, the world has come to the knowledge era. This era marks the shifts of time from the era of agriculture (before 1880), the era of industrial revolution (1880 – 1985), the era of information (1955 – 2000), to the era of knowledge (1995 – present). In facing the new era, the skills needed to survive in the 21th century are different with those needed in the era of industrial revolution. According to Galbreth (1999), among the vital skills are skills of thinking and problem solving. Thus, a question comes up as to why thinking and problem solving skills are considered necessary in the world of education as produced from a series teaching process carried out by teachers and learning process carried out by learners?

Education directed to welcome the future must be able to develop thinking abilities and desire in analyzing and understanding problems scientifically (Joni, 1989). As stated by Ardhana (1992), giving learning experiences in rational, critical, and abstract thinking is the direction of future education. Educational experts in general admit that problem solving ability is one of many important objectives of school instructional programs because problem solving is the highest ability in thinking skills and intellectual skills (Gagne, R.M., 1975; Gagne, Briggs, & Wager, 1992; Resnick & Klopfer, 1989; Barba & Rubba, 1992; Marzano, Pickering, & McTighe, 1993). The fore, school education goals must not only increase knowledge acquisition, but must be able to develop thinking ability and problem solving (Tenyson, 1989 as quoted by Simonson & Frey, 1989), because problem solving ability is the highest mental activities (Polya, 1981).

Thinking and problem solving instructional topics have received more attention by psychological researches in 1980s. This attention is based on the rapid changes and challenges in the society which needs people to have problem solving abilities (Bransford, et.al., 1986; Marzano, et.al., 1988; Maezano, Pickering, & McTighe, 1993). When the problem solving ability has been processed, one is not only able to solve similar problems, but is also expected to be able to solve different problems in daily life (Gagne, E.D., 1985; Gagne, R.M., 1977; 1985; Bransford, Sherwood, and Reiser, 1986; Sieger, 1991).

UNDERSTANDING PROBLEM

According to Tennyson (1989), a problem is a condition where knowledge stored in the memory is not ready to do a problem-solving task. In other words, a problem-solving task is new, although knowledge already possessed can be used to solve a problem (Bell-Gredler, 1986; Travers, 1982). Gagne' (1985) argues that a problem is when there is an objective but the way to attain the objective is not yet identified. Hayes (1989) gives an example about a problem like this: someone is on one side of a river and wants to cross the river, but he cannot cross it. Frederickson (1984) classifies a problem into two types, namely, well-structured problem and ill-structured problem. A well-structured problem is a problem in which the objective, solving algorithm, and the information needed to solve the problem are available. For example, a well-structured problem in completing the width of a triangle: the triangle formulas, the length of the side, and the height have been known. Whereas an ill-structured problem has the following characteristics: the objective going to be attained is more complex and less definite, the information needed is blank or vague, and there is no formula that can be used to solve the problem (Simon, 1978). Problem solving, according to Polya (1981), is finding a way out for every difficulty and it is full of obstacle to achieve the objective. When someone is solving a problem, he is not merely learning to apply all the knowledge and principles, and controlling the thinking process (Gagne', E.D., 1985; Gagne', R.M. 1977; 1985; Marzano, 1980, et al., 1988). The key factor in problem solving is the application of the various parts of the experiences already possessed in order to come to the solution (Deighton, 1974).

PROBLEM SOLVING

A problem solving is a process of how knowledge is organized and represented symbolically in the long-term memory in order to be activated efficiently when problem solving occurs (Reif and Heller, 1982). Problem solving process contains: (1) understanding the problem to be solved, (2) classifying various actions that will be taken, (3) selecting in action, (4) identifying obstacles, (5) conducting an action, (6) evaluating what has been done (Gagne', Briggs, and Wager, 1988) and Hayes (1986) classify the strategy of problem solving into two phases, namely problem representation and solution.

Problem solving occurs in all subjects (Gagne', 1985); in natural sciences it is called inquiry approach, and in social sciences the term role play is used (Walter, 1980). Arithmetic is one of the subjects that focuses on mathematics in the elementary school and emphasizes problem-solving (Walter, 1980; Brewer, 1992). A report from commission by the Conference Board of Mathematical Science (1966) in England emphasizes the importance of problem solving in learning mathematics because it speeds up the students' independence and thinking. Publication by the National Council of Teacher of Mathematics (NCTM) in 1980 stated that in North America and Canada, the curriculum and mathematics learning in elementary school have given attention to problem solving. International Congress on Mathematics Education (ICME) in 1984 in Adelaide (Australia) has selected problem solving as the main topic discussed. Countries such as Brazil, Japan, Italy, Portuguese, Sweden, and England have been emphasizing problem solving as an important and principal part in mathematics learning (Lester, 1994).

Through problem solving, students are expected to be able to transfer the various knowledge possessed to face various problems. Transfer occurs when the knowledge already learned can be used to solve a new problem (Travers, Pikaart, & Reunion, 1977). The research findings conducted by Vesta and Walls (1967) and Witrock and Cook (1975) show that Robert Gagne' learning hierarchy is an example of positive transfer of the relationship between prerequisites tasks and super ordinate tasks (Glaser, 1976; White, 1976; Gagne', R.M., 1974: Travers, 1982).

According to Hayes (1989), representations in problem solving consist of two types, namely internal and external representations. An internal representation is a medium for someone in thinking that consists of comprehending a problem, relating the problem with the knowledge already possessed, and constructing the solving strategy. The external representations are an activity done to comprehend the problem and its strategy through pictures, sketch, diagrams, writing symbol, and constructing equivalence through other media outside one's self. Doing external representations may help to solve problems. Sometimes, problems can be solved by internal representations, for example to calculate 10 x 10 for certain students, it is not necessary to do external representations, but is needed for others. Many problems need internal and external representation at the same time to solve. In the study of problem solving process, researches are directed to see the see comparison done by problem solvers who are categorized as expert and beginner. Experts having richer are able to construct more difficult problems by doing chunks (Atkinson, Atkinson, and Hilgard, 1983), to automatically size the capacity of the higher cognitive awareness process (Glaser, 1990) and to use less steps (Barba & Ruba, 1992). Experts work forward strategy and novices work backward. Experts and novices are not different in using general strategies, but very different in using specific cognitive domains (Gagne', E.D., 1985; Alexander & Judy, 1988).

Therefore, the strategy used to solve a problem in a certain domain will be different from that used to solve a problem in another domain. The following are examples of the researches that revealed problem solving in various specific domains, such as physics (Reif & Heller, 1982; Zajchowski & Martin, 1993), biology (Smith & Sims, 1992; Lavoie, 1993), chemistry (Bunce, Gabel, & Samuel, 1991), health (Kagan, 1988), language (Palumbo, 1990; Lundsteen, 1970), ill-defined (Klein & Weitzenfeld, 1978), and mathematics (Kilpatrick, 1969; Polya, 1981; Riley, Greeno, & Heller, 1983).

There are five different characteristics between experts and novices in solving problem, namely, (1) experts' schemata is richer; (2) experts emphasize more on problem structure, whereas beginners emphasize more on surface feature; (3) experts are more aware of the strengths and the weakness as a problem solver; (4) experts are better in monitoring and arranging the efforts of problem solving; and (5) experts give more attention to finding out the solution of problems (Lester, 1994). According to Foshay (1991), problem-solving researches conducted by instructional designers must always be related to the representation of knowledge and strategy done by expert and novice problem solvers. Kilpatrik's research finding (1969) about students' problem solving process and Lester's (1994) about characteristics of experts and novices will contribute important benefit to designing instructional strategy, especially the strategy of content organization. Through the instructional strategy that is relevant to the condition of learning, such as the student's individual characteristics, and the characteristics of the subject, the instruction will be more effective, efficient, and interesting (Reigeluth, 1983).

Based on the above discussion, problem-solving achievement is very important for students. Therefore, with problem solving skills, students are expected to be able to transfer their knowledge acquired in one subject to another subject. In addition, students are expected to be able to solve problems in their daily life. Anyhow, research on problem solving is not much found, also, as well as research on students' process of problem solving. Therefore, it is important to conduct research related to problem solving process and the different characteristics between expert problem solvers and beginner problem solvers.

LEARNING CAPABILITIES

Learning capabilities is an ability or capability obtained through learning (Gagne, 1975). Some experts present concepts and description of learning achievement. Gagne (1975) calls it human capabilities, and other experts call it as taxonomy of education objectives (Bloom, 1979), level of performance (Merrill, 1983), and intellectual structures (Guilford, 1967 as quoted by Martin & Briggs, 1986).

Based on the idea stated by Gagne' (1975), Bloom (1979), Merril (1983), and Guildord (1967), there is a similar idea that learning achievement of intellectual skill is a hierarchy, starting from simple to complex. The most complex learning capability is problem solving because this capability needs various prerequisites concepts and principles as the subordinates.

Among the four ideas stated above only Gagne' (1975) who explicitly stated that problem solving capability is the highest hierarchy. Nevertheless, in the level of performance, problem-solving capability is not mentioned explicitly. "Find" performance is the highest hierarchy capability (Reigeluth, 1983). Similarly in the Bloom's taxonomy, in the level of application, analysis, synthesis, and evaluation concern with problem solving aspects. Whereas in Guilford' cognitive structure, in the content, systems, transformation, and implication are as the intellectual structure which concern with problem solving aspects.

HOW DO WE PROCESS INFORMATION?

The main assumption that underlies information-processing theory is the principle of information flowing system and knowledge representation in the human memory. Human memory is an active system in selecting, organizing, and changing information into information code, and storing it in the memory. Information obtained in an environment is transformed from one structure to another structure, through receptor, register sensory, short-term memory, long-term memory, response generator, and effectors (Gagne', R.M., 1975; Gagne, E.D., 1985). According to Gagne' (1985), information processing flow starts from an environment and is then received by a receptor. The receptor sends a code in the form of electro-chemistry impulse to brain. From the receptor, the information is then enters the nerve system through sensory register. The information is encoded by the sensory register in the structured form. The information is stored in a short time. According to Bell-Gredler (1991), the data are stored for about 0.5 – 2.0 seconds to be analyzed. The information selected to be analyzed then enters the short-term memory. Some meaningful information is then sent to the long-term memory to be stored permanently.

In short-term memory, the information is endured for 10 – 20 seconds, more or less the same with two pieces of information (Gagne', E.D., 1985; Bell-Gredler, 1991). Encoding and sending information to the long-term memory which can be send back to the short-term memory is called working memory. The short-term memory emphasizes the length of time when the information is stored and the working of conscious memory, whereas the working memory emphasizes the functions. For example, someone who must recall something which has been learned before, must take the thing from long term memory and then send it to the short term memory as the working memory, the information then reappears.

The information that reappears from the short-term memory as well as from the long-term memory is done through response generator that functions to transform the information into action. The neural message will move the effectors, which then produces a performance. To move or change the needed information needs the role of executive control and expectancies. For example, a student who has expectancy about what stimulus from outside he will perceive, encodes it in the memory, and transforms it into an action.

HOW KNOWLEDGE WORKS TO SOLVE PROBLEM

Gagne' and White (1978) and Gagne' (1978, 1985) stated that principally knowledge is described mentality in the form of proposition, production, and image. Proposition is as a basic unit of information, an idea, or a concept. The same propositions form a propositional network. Production is a relationship among the proposition that form a causal relationship (if …. then …..). The form of proposition is used to describe declarative knowledge, whereas production is used to describe procedural knowledge. Impression is used to store information that cannot be formulated in the form of proposition or production. There have been many studies related to how to increase declarative and procedural knowledge, and problem solving strategies. The finding showed that the declarative and procedural knowledge do not belong to two exclusive forms of knowledge but are interrelated (Gagne', 1985).

In problem solving, there is an interactive relationship between declarative and procedural knowledge. Someone who is solving a problem before doing procedural action (comprehending the problem and finding the solution), must first organize the knowledge possessed related to the problem to solve. Organizing knowledge possessed is to activate the declarative knowledge, whereas sequencing actions consisting of representing a problem, finding the solution, and evaluating the solution is procedural knowledge (Riley, Greeno, and Heller, 1983).

DIFFERENT PERSONS, DIFFERENT PROBLEM-SOLVING STRATEGIES

Many studies related to word problem have been conducted. Meta-analysis conducted by Kilpatrik (1969) and Lester (1994) showed that researchers on mathematics problem solving principally can be classified into five kinds, namely problem solving ability, problem solving tasks, problem solving process, problem solving instructional programs, and teachers' influence towards students' problem solving abilities. Studies on problem solving abilities are directed to see the comparisons of process done by expert problem solvers and novice problem solvers.

The finding showed that there is a difference between experts and novices in solving problems (Atkinson, Atkinson & Hilgard, 1983; Swanson, O'Connor, & Cooney, 1990). Experts are faster in representing the problems based on principles, whereas novices are superficial for certain attributes. An expert has rich schemata in solving problems compared to a novice. The difference between an expert and a novice lies on the procedures of problem solving efforts. Novices tend to focus on strategy, whereas experts are able to find an effective way, generalize, and evaluate the steps of alternative ways that will be conducted (driven by schemata). Many studied conducted describe the differences of problem solving strategies between experts and novices. The differences discussed focus on the schemata relevant to the problem solving. The experts schemata are based on the principles of problem solving ways using more principles and procedural knowledge. Simon and Simon (in Gick, 1986) differentiate the strategy used by experts called as working forward, and the novices as working backward.
Dewey (as quoted by Rich, 1972) describes problem solving process as "a complete act of though: (1) a felt difficulty, (2) its location and definition, (3) suggestion of possible solution, (4) development by reasoning of the bearing of the suggestions, and (5) further observation and experiment leading to its acceptance of rejection". Marzano et al. (1988) state that problem is as a process, namely thinking process and the application of the acquired knowledge.

Problem solving process is described by Newel and Simon (1972) through a computer simulation called General Problem Solving (GPS) which consist of (1) stating a problem, (2) what has been known and its legal operator, (3) deciding objectives and sub-objectives, and beginning to solve sub-problems, (4) using objectives as a means of evaluations progresses, if possible the sub-objectives must be formulated again. Gagne', R.M., Briggs, & Wager (1988) state that a number of processes done in solving problems contains of deciding the concepts of problems which will be solved, classifying the action sequences, choosing an action, identifying obstacles, solving problems, and checking again the statements of objectives. Whereas according to Tennyson (1989), the cognitive process in problem solving consists of analyzing the given situation, arranging a conceptualization of situation, confirming the specific objectives used to handle the situation, and arranging a possible solution. Finally, Gick (1986) states that steps in solving problems principally consist of two steps, namely representing the problem and the problem solving actions. Polya (1981) states that problem solving is finding the way out for something difficult and full of obstacles to attain the predetermined objectives. Problem solving process in mathematics, according to Polya, consists of four steps of seeing, planning, doing, and checking. More specifically, Eicholz (1989) suggested five steps which need to be done, namely, comprehending what is being asked, finding data needed, planning what must be done, finding the answer by computation and correction the answer again.

Talking about solving problems delivered through question, Dwiyogo (2001) conducted a research on categorizing learners based on their academic achievement by using protocol method of thinking aloud and clinical interview. The achievement group of learners consist of those with high, intermediate, and low achievements. Through the algorithm of solving the problems, it was concluded that there were five steps of problem solving carried out by students of third grade, that is, (1) understanding the problem, (2) representing the problem, (3) determining the operation model, (4) calculating, and (5) concluding the answer. Figure 1 shows a clear picture of thinking process in problem solving carried out by third graders.

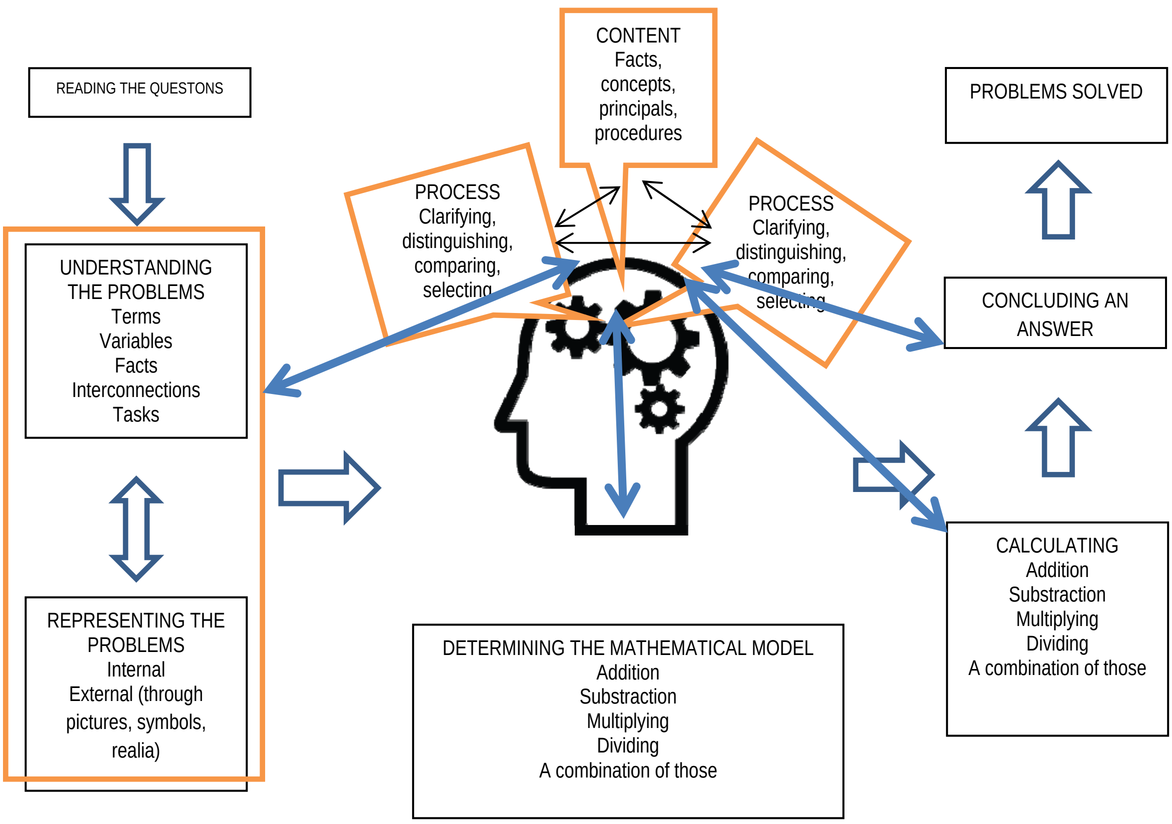

Figure 1. A theoretic model of learning process in solving problems in the form of story for third graders (Dwiyogo, 2001).

Based on the five process of problem solving, the following findings are obtained: (1) learners with high achievement are always able to obtain higher percentage of correct answer than those with intermediate and low achievements; (2) learners with intermediate achievement are sometimes able to obtain higher percentage of correct answer than those with low achievement; (3) learners with high achievement are always quicker in finding the correct answer than those with intermediate and low achievements; (4) learners with intermediate achievement are sometimes quicker in finding the correct answer than those with low achievements; (5) learners with high achievement are always able to use the shortest way to find the correct answer than those with intermediate and low achievements; (6) learners with intermediate achievement are sometimes able to use the shortest way to find the correct answer than those with low achievements; (7) learners with high achievement are able to select the most accurate and more varied operational model and use mathematical principals well, while those with low achievements hardly find the accurate operational model and use less varied model; and (8) learners with high achievement always check their answers by substituting the found numbers back into the questions, while those with low achievement hardly do that.

CONCLUSION

From the finding above, it can be concluded that there is a consistent difference between learners with high achievement and those with low learners in terms of the process of problem solving. The difference lies on the number of steps to solve the problem. The high achievers are able to solve problems more effectively, rapidly, and in a way that mathematical principals have given.

This finding is considered beneficial to instructors in designing a teaching and learning process that puts the emphasis on the learners. In order to design a problem solving learning process by using questions in the form of story, one needs to take into account programs and materials in the form of algorithm. That way, there will be options for learners who both are able and not able to answer the question to select from.

REFERENCES

Alexander, P.C. & Judy, J.E. 1988. The interaction of domain-specific and strategic knowledge in academic performance. Review of Education Research 58(4), 375-404

Ardhana, W. 1992. Sistim pendidikan nasional, realisasi, permasalahan, dan pemecahannya. Presented for Konvensi Nasional Pendidikan Indonesia II, Medan, February 4-8.

Atkinson, R.T., Atkinson, R.C., and Hilgard, E.R. 1983. Introduction to psychology. London: Harcourt Brace Jovanovich, Inc.

Barba, R.H. and Rubba, P.A. 1992. A comparison of pre-service and in-service and space science teacher general mental abilities, content knowledge, and problem solving skills. Journal of Research in Science Teaching, 29(10), 1021-1035

Bloom, B.S. (Ed.). 1979. Taxonomy of educational objectives. London: Longman Group Ltd

Bransford, J., Sherwood, R., Vey, N., and Reiser, J. 1986. Teaching thinking and problem solving research foundation. American Psychologist, 41(10), 1078-1089.

Dwiyogo, W.D. 2001. Pemecahan Masalah Soal Cerita Siswa Sekolah Dasar Kelas Tiga. Unpublished Dissertation. School of Graduate Studies, Universitas Negeri Malang.

Foshay, W.R. 1991. What we know (and what we don't know) about training of cognitive

strategies for technical problem-solving. In G.J, Anglin (Ed). 1991. Instructional Technology: Past, Present, and Future. Englewood, Colorado: Libraries Unlimited, Inc.
Gagne', E.D. 1978. Long-term retention of information following learning from prose. Review of Education Research. 48(4) 629-665.
Gagne', E.D. 1985. The cognitive psychology of school learning. Toronto: Little Brown & Company (Canada) Limited.
Gagne', R.M., Briggs, L.J., Wager, W.W. 1992. Principles of instructional design. New York: Holt, Rinehart and Winston.
Gagne', R.M. 1975. Essentials of learning for instruction. New York: Holt, Rinehart and Winston
Gagne', R.M. 1985. The condition of learning and theory of instruction. Four Edition. New York: Holt, Rinehart and Winston
Gagne', R.M. & White, R.T. 1978. Memory structures and learning outcome. Review of Education Research. 48(2) 187-222.
Galbreth, J. 1999. Preparing the 21st Century Worker: The Link Between Computer-Based Technology and Future Skill Set. *Educational Technology*, Vol XXXIX, Number 6, November-Desember 1999.
Gick, M.L. 1986. Problem-solving Strategies. Educational Psychologist, Volume 21, Issue 1-2, page 99-120.
Gredler, B.M.E. 1991. Belajar dan Membelajarkan. Terjemahan oleh Munandir. 1991. Jakarta: CV. Rajawali.
Hayes, J.R. 1989. The complete problem solver. New Jersey: Lawrence Erlbaum Associate Inc.
Kilpatrick, J. 1969. Problem solving in mathematics. Review of Educational Research, 39(4), 523-533.
Klein, G.A. & Weitzenfeld, J. 1978. Improvement of skill for solving ill-defined problems. Educational Psychologist. 13, 31-41.
Lavoie, D.R. 1993. The development, theory, and application of a cognitive-network model of prediction problem solving in biology. Journal of Research in Science Teaching. 30(7), 767-785.
Marzano, R.J., Brant, R.S., Hughes, C.S., Jones, V.F., Presseicion, B.Z., Rankin, S.C., and Suhor, C. 1988. Dimension of thinking: A framework for curriculum and instruction. Alexandria: Association for Supervision and Curriculum Development.
Marzano, R.J., Pickering, D., McTighe, J. 1993. Assessing student outcomes: Performance assessment using the dimension of learning model. Alexandria: Association for Supervision and Curriculum Development.
Merril, M.D. 1983. Component display theory. In Reugeluth, C.M. (Ed), 1983. Instructional design theories and models: An overview of their current status. Hilsdale, New Jersey: Lawrence Erlbaum Associate Publisher.
Palumbo, D.B. 1990. Programming language problem-solving research: A review of relevant issues. Review of Educational Research, 60(1), 65-89.
Polya, G. 1981. Mathematical discovery: On understanding, learning, and teaching problem-solving. New York: John Willey & Sons, Inc.
Joni, R.T. 1989. Mereka masa depan sekarang: Tantangan dalam pendidikan dalam menyongsong abad informasi. Delivered in Ceramah Ilmiah Dies Natalis IKIP Malang XXXV, October 18, 1989.
Reigeluth, C.M. (Ed). 1983. Instructional-design theories and models: An overview of they current status. Hilsdale, New Jersey: Lawrence Erlbaum Associate Publisher.
Rich, J.M. 1972. Conflict and decision: Analyzing educational issues. New York: Harper & Row Publisher.

Reif, F., and Heller, J.I. 1982. Knowledge structure and problem solving in physics. Educational Psychologist, 17(2), 102-127.

Riley, M.S., Greeno, J.G., and Heller, J.I. 1983. Development of children' problem-solving ability in arithmetic. In Ginsburg, H.P. (Ed). 1983. The development of mathematical thinking. Orlando, Florida: Academic Press, Inc.

Sieger, R.S. 1991. Children's thinking. Second Edition. Englewood Cliffs. New Jersey: Prentice Hall.

Simon, H.A. 1978. Information-processing theory of human problem solving. In Estes, W.K. (Ed). 1978. Hand book of learning and cognitive process: human information processing. Vol. 5. New Jersey: Lawrence Erlbaum Associate Publisher.

Smith, M.U. & Sims, O.S. Cognitive development, genetics problem solving, and genetic instruction: a critical review. Journal of Research in Science Teaching. 29(7), 701-713.

Swanson, H.L., O'Connor, J.E., & Cooney, J.B. 1990. An information processing analysis of expert and novice teacher' problem solving. American Educational Research Journal. 27(3), 533-556.

Tennyson, R.D. 1989. Cognitive science and instructional technology: Improvement in higher order thinking strategies. In Simonson, M.R. & Frey, D. (Ed). 1989. Proceeding of selected Research Paper Presentation at the 1989 Convention the Association for Educational Communication and Technology in Dallas (Texas).

Travers, R.M.W. 1982. Essentials of learning. 5th Edition. New York: Macmillan Publishing Coy, Inc.

Travers, K.J., Pikaart, L., and Runion, G.E. 1977. Mathematical teaching. New York: Harper & Row.

Vesta, V.J., & Walls, R.T. 1967. Transfer of object-function in problem solving. American Educational Research Journal. 4(3), 207-215.

White, R.T. 1976. Research into learning hierarchies. Review of Education Research, 43(3), 361-376.

Zajchowski, R., & Martin, J. 1993. Differences in the problem solving of stronger and weaker novices in physics: knowledge, strategies, or knowledge structure. Journal of Research in Science Teaching. 30(5), 459-470.

