THINKING SKILLS IN SCIENCE EDUCATION*

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Introduction

In recent years, Singapore Ministry of Education has placed a great deal of emphasis on teaching thinking skills in schools. Commitment to promoting thinking skills has been spreading throughout the nation. Literature shows that teachers ranked improvement in thinking as one of the most important educational goals (Gallup, 1985). Thinking skills that are marked for emphasis in science instruction include, among others, such processes as observing, classifying, describing, formulating questions/hypothesis, controlling variables, interpreting data, experimenting, and drawing conclusions. Science teachers are in an ideal position to promote the development of thinking skills, especially the higher-order ones, in students. This development can be facilitated by the teachers' instructional techniques, and affected by their attitudes and confidence level, the methods of assessments, and the learning environments. Teachers can help develop the thinking skills in students both through domain-specific and domain-general strategies.

The purpose of this paper is to review the literature with emphasis on some of the important scientific thinking skills and what research says about the teaching of thinking skills in terms of content, methods, effects of explicit teaching of thinking skills, and difficulties in teaching/learning thinking skills. Some implications for teaching thinking skills will also be discussed.

Some Important Thinking Skills

There are many fundamental thinking skills that are needed for successful scientific reasoning. A general list of such skills includes:

- understanding how cause is determined,
- recognizing and criticizing assumptions,
- analyzing means-goals relationships,
- assessing degrees of likelihood and uncertainty,
- incorporating isolated data into a wider framework, and
- using analogies to solve problems
  (Halpern, 1987a, 1987b, 1989, 1992)

Thinking skills can be viewed as a single, unitary intellectual ability or as a collection of smaller, component skills (e.g. observing). The thinking skills are developmental in nature with higher level skills building on more basic ones. There

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* Paper presented at the 1997 Annual Conference of the Educational Research Association, Singapore, 24th - 26th November, 1997.

are thinking skills that students can learn to recognize and apply appropriately. If these skills are recognized and applied, students become more effective thinkers (Halpern, 1992). Mayer (1992) shares the same view: better thinkers are those "students who are better able to take what they have learnt and successfully use it in new situation. These students are better able to transfer knowledge about solving problems to new problems that they were not taught about". Students can make cognitive gains by expanding and elaborating on a skills repertoire.

In the 20[th] century, a few important thinking skills such as problem-solving skills, higher-order thinking skills, critical thinking skills and creative thinking skills have attracted a great deal of attention among researchers in the field of science education. The meanings of these thinking skills are briefly discussed here.

Garrett (1984) argues that problem solving can be regarded as an element of thinking but that it is probably more properly considered as a complex learning activity that involves thinking. To solve problems a repertoire of thinking skills are needed. Problem-solving skills involve process skills such as formulating hypothesis, controlling variables, interpreting data, and experimenting (Pizzini, Shepardson, and Abell, 1989). But there are other researchers such as Presseisen (1985) and Sternberg (1985) who have used different models of thinking skills to describe problem-solving skills.

Presseisen's (1985) thinking skills for problem solving include:

- assembling of facts,
- determining if additional information is necessary,
- inferring or suggesting alternative solutions and testing them,
- reducing the problem to simpler levels of explanation,
- eliminating discrepancies, and
- checking solutions for generalization.

Sternberg (1985) classified thinking skills for problem solving into three groups:

(a) Metacomponents
- recognizing the problem,
- defining the problem,
- deciding on a problem-solving procedure,
- allocating time and resources,
- monitoring the solution to the problem,
- utilizing feedback regarding the solved problem, and
- forming a mental representation

(b) Performance components
- inductive reasoning,
- deductive reasoning,
- spatial visualization, and
- reading

(c) Knowledge - acquisition components
- selective encoding - screening information,
- selective combination - assembling and organizing relevant information, and
- selective comparison - relating existing knowledge to new information.

Studies of problem solving (Bruner, 1966, Newell and Simon, 1976 and Gagné, 1977) have identified strategies that generalize across many types of tasks and also sets of distinct steps and strategies for separate subject-matter disciplines and for problem types within them. Quellmalz (1985) summarizes the problem-solving paradigm as follows:

Students engage in purposeful, extended lines of thought during which they:

- identify the task or problem type,
- define and clarify essential elements and terms,
- judge and connect relevant information,
- evaluate the adequacy of information and procedures for drawing conclusions and/on solving problems.

To many researchers and educators, higher-order thinking skills are equivalent to problem-solving skills. However, based on the work of such psychologists as Bruner (1966), Newell and Simon (1976), and Gagné (1977), Quellmalz (1985) considers that higher-order thinking skills are more than just the goal-directed problem-solving strategies; when faced with novel tasks metacognitive thought processes are also involved. Students become self-conscious about their thinking and develop self-monitoring problem-solving strategies. A summary of higher-order reasoning processes in terms of cognitive and metacognitive components are shown below:

Higher-order reasoning processes are:

1. <u>Cognitive</u>
   Analyze
   Compare
   Infer/Interpret
   Evaluate
   (Quellmaiz, 1985, pg 30)

2. <u>Metacognitive</u>
   Plan
   Monitor
   Review/Revise

What is critical thinking? Critical thinking is sometimes equated as an umbrella term to include all thinking operations, or sometimes equated as "problem solving" or Bloom's taxonomy when all such terms are in fact quite distinct. Many researchers think that critical thought involves the evaluation of the worth, accuracy or authenticity of various propositions (McPeck, 1981; Toulmin, Rieke and Janik, 1984; Beyer, 1988; Ennis, 1989). Dewey (1933) defined critical thinking or reflective thought as the careful, persistent examination of an action, proposal, or belief and the analysis or use of knowledge in light of grounds that justify it and its probable consequence. The critical thinker is . skeptic, that is, one who is unwilling to accept any assertion or ideas until and unless sufficient evidence can be demonstrated to warrant its acceptance. Smith (1953) defined critical thinking as "what a statement means and whether to accept or reject it". Ennis (1962) elaborated on Smith's definition of critical thinking by delineating skills that called for the application of formal and informal logic. About twenty years later, he (Ennis, 1985) expanded his critical thinking skills as clusters that include:

- clarifying issues and terms,
- identifying components or arguments,
- judging the credibility of evidence,
- using inductive and deductive reasoning,
- handling argument fallacies, and
- making value judgements.

Beyer (1988) offers a clearer conceptualization of critical thinking and treats it as one kind of cognitive process. Beyer agrees that critical thinking requires a certain mind-set that is essentially evaluative in nature but distinguishes critical thinking from "micro thinking skills" such as Bloom's taxonomy and those typically taught in logic and philosophy (inductive, deductive, and analogical reasoning). Micro thinking skills handle simple reasoning tasks which requiring the thinkers to follow only a limited number of rules, steps and procedures. Beyer also differentiates critical thinking from "thinking strategies" such as problem solving and decision making, which are more complex cognitive processes. According to Beyer, critical thinking is a repertoire of specific operations, somewhere between major thinking strategies and micro thinking skills in their complexity and function. Based on the literature of science, language and social studies instruction, Beyer (1988) suggested the following ten operations of critical thinking which are quite similar to but more specific than Ennis' (1985) critical thinking skills (see above).

- distinguishing between verifiable facts and value claims;
- distinguishing relevant from irrelevant information, claims, or reasons;
- determining the factual accuracy of a statement;
- determining the credibility of a source;
- identifying ambiguous claims or arguments;
- identifying unstated assumptions;
- detecting bias; identifying logical fallacies;
- recognizing logical inconsistencies in a line of reasoning;
- determining the strength of an argument or claim.
  (Zeidler, Lederman, Taylor, 1992, page 439)

According to Beyer (1988), there exists a hierarchy of micro thinking skills, critical thinking operations, and macro thinking strategies (i.e. problem solving, decision making). Critical thinking necessarily includes micro thinking skills and is understood to be a necessary condition for the adequate execution of problem-solving strategies. Critical thinking pertains to the judgement aspect of thinking.

Another important set of thinking skill is creative thinking. Despite the fact that there is the need to foster creative talent in science (Guilford, 1959; Hainsworth, 1964; Cockroft, 1966), creativity is seldom discussed in the science education literature (Washington, 1971; Moravcsik, 1981; Garrett, 1987). Creativity and the so-called 'creative subjects' are separate areas of the curriculum commonly isolated from science and usually not thought of as a proper domain of the school science laboratory (Garrett, 1987). One area in science mentioned in the literature concerning creativity is the project work (Swain, 1977). Both teachers and pupils who took part in Nuffield physical science curriculum agreed that project work allowed creative work to be carried out in science and a two-thirds of the teachers felt that creativity should also be assessed.

Teaching Thinking Skills in Science

Goal of teaching for thinking is to create meaningful learning (Mayer, 1992). The literature has tried to answer two important questions: (1) How to teach thinking skills? and (2) Where thinking should be taught. Should the teaching of thinking skills focus on product or process, that is, on getting the right answers in problem solving or on the methods and strategies for problem solving? For enhancing the development of thinking skills, is it better to teach thinking skills in domain-independent (general problem-solving course) or to integrate thinking skills instruction with existing subject-matter domains?

Domain-specific (content related) versus domain-general strategies (content free)

Niaz (1995) based on a critical appraisal of the philosophy of science suggests to science educators to choose between domain-specific and domain-general strategies for enhancing the thinking skills of their students. Basing their conclusions on the nature of scientific practice, that is, gathering evidence by making observation and conducting experiment in order to test hypotheses, many science researchers suggest that the teaching of thinking skills should lay greater emphasis on content-process (Cook, 1982; Kuhn, Amsel and O'Loughlin, 1988; Cook and Mayer, 1988; Mayer, 1992; Niaz, 1995). Mayer (1992) suggests three conditions for the successful teaching of thinking skills: (1) a focus on teaching component skills, (2) use of modeling techniques that emphasize problem-solving process, and (3) embedding instruction within existing subject matter domains. Kuhn et al. (1988) have similarly endorsed the importance of both of prior knowledge and the process of scientific reasoning for enhancing the learning of thinking skills.

Methods of Teaching Thinking Skills

One important teaching strategy or approach that can improve thinking skills is problem-solving approach which includes the processes of acquiring information and recalling knowledge learnt previously, solving novel problems, and evaluating the answers (Halpern, 1992). Halpern (1992) believes that the most important rule in thinking skills instruction is to teach for transfer, because the ultimate goal of this problem-solving approach is to develop students who can solve a large variety of novel problems, not just those previously presented in assignments. The use of problem-solving instructional models to teach science influences the problem-solving ability of students. In addition, Gagné (1977) noted the effectiveness of a problem-solving instructional approach at developing science concepts. Gagné (1977) stated that if learned through problem solving, science concepts were meaningfully learned. A good deal of research evidence supports the fact that students showed greater cognitive growth through the explicit teaching of problem solving in science (Mayer, 1975; Frundlich, 1978; Greeno, 1978; Simon and Simon, 1978; Blum, 1979; Chiappetta and Russell, 1982; Sternberg, 1985). Other researchers also indicate that students are able to think more critically when instruction provides opportunities to analyze and solve problems (Rickert, 1967). There are many problem-solving models proposed by researchers, e.g. Osborn's (1963) Creative Problem Solving (CPS) process; Bransford and Stein's (1984) Identify, Define, Explore, Act and Look (IDEAL) model; and the Search, Solve, Create and Share (SSCS) model created by Pizzini and his co-workers (Pizzini, Abell and Shepardson, 1988; Pizzini, Shepardson and Abell, 1989). The SSCS model has identified 45 underlying specific process skills such as brainstorming, predicting, questioning, creating, defining, reporting, verifying, evaluating, etc., to the different stages of the problem-solving model. The teacher designs investigative tasks that present a novel nature which is open-ended with no one definite answer. The teacher functions as a facilitator in a problem-solving model of instruction, assisting students in developing strategies to effectively obtain and process information. Selection of a problem-solving model of instruction is one of the critical choices a teacher must make. Linkage skills and problem translation skills (Gunstone, 1980; Chi, Faltovitch and Glasers, 1981; Novak, 1984; Lee, 1985; Lee, Goh, Chia and Chin, 1996) and thinking-aloud problem-solving strategy (Whimbey and Lochhead, 1986; Lee, 1993; Pestel, 1993) are some of the other strategies or techniques that can improve the higher-order thinking skills.

Other than using problem-solving approach to develop thinking skills, a computer-based programme or communication device can be used to individualize learning and thinking, provide a more active mode of responding, and detect errors and gaps in knowledge. A technology-based programme will present a unique opportunity to study the process of knowledge acquisition in depth (Halpern, 1992). In addition, concept mapping (Novak, 1984), the enquiry and guided discovery approach (Gangoli and Gurumurthy, 1995) and constructivist approach (Fensham, Gunstone and White, 1994) are also very powerful in developing thinking skills. Concept mapping stresses fundamental principles and relationships rather than rote recitations of lists and definitions. The method of enquiry and guided discovery probes students' thinking through students' investigation tasks or teachers' practical demonstrations. Constructivism motivates students to construct their scientific knowledge and to actively think about and take responsibility for their own learning.

Effects of Explicit Teaching of Thinking Skills

Research focusing on explicit teaching of problem-solving strategy and process skills in the context of science education/teaching has also taken note of some positive effects of this teaching (Huffman, 1997; Preece and Brotherton, 1997). The explicit teaching of thinking skills can improve students' problem-solving skills, students' cognitive development and science achievement. Huffman (1997) investigated the effect of explicit problem-solving instruction on high school students' problem-solving performance and conceptual understanding of physics. Eight physics classes, with a total of 145 students were randomly assigned to either a treatment or a comparison group. The four treatment classes were taught how to use an explicit problem-solving strategy, while the four comparison classes were taught how to use a textbook problem-solving strategy. The results indicated that the explicit problem-solving strategy improved the quality and completeness of students' physics problem representations more than the textbook strategy. In terms of conceptual understanding, there was no overall difference between the two groups.

The Cognitive Acceleration through Science Education (CASE) project has provided evidence that including in science lessons activities based on Piagetian formal reasoning patterns, which broadly overlap with secondary science process skills (Brotherton and Preece, 1995, 1996), gives a short-term boost to cognitive development and leads to subsequent gains in science achievement that are sustained over several years (Adey and Shayer, 1993). The above results were confirmed by the follow-up replicated study (Preece and Brotherton, 1997). A positive effect of the intervention on Year 8 males was found on examining subsequent GCSE science results.

Difficulties in Teaching/Learning Thinking Skills

Recent research also includes some studies of teachers' use of teaching techniques and teachers' assessment of higher-order thinking skills in science instruction (Stiggins, Griswold and Wikelund, 1989; Lawrenz, 1990; Chin, Goh, Chia, Lee, and Soh, 1994). Three studies are reviewed in details here to provide some insights into the difficulties that occur while teaching/learning thinking skills in schools.

Lawrenz (1990) studied the frequency of use of particular techniques and the underlying structure of and the interrelationships between these techniques. A stratified random sample of seventh and eighth-grade science teachers in Minnesota was asked to respond to a questionnaire about teaching techniques relating to higher-order thinking skills. One hundred and thirty-nine teachers (86%) responded. The results of the study show that the teachers' most emphasized objective was to learn basic science concepts followed by becoming aware of the importance of science in daily life and by developing curiosity about natural phenomena. The least emphasized objectives were learning how to design and carry out experiments; and learning what evidence is necessary to constitute proof. The most common assessment category was classroom tests followed by homework. The type of question used most frequently was one that required the knowledge of definitions of concepts. This was followed by items that required the recall of specific information, items that required the students to explain concepts in their own words, and problems with one specific answer. The science teachers were also inclined to use multiple-choice items. For the general utilization of time in teaching science, in a typical 50-minute class session, 26% of the time (about 13 minutes) would be spent in lecture, 18% of the time (9 minutes) in discussion, and 16% of the time (8 minutes) working with hands-on materials. The remaining 40% of the time (20 minutes) would be spent completing worksheets of homework, watching demonstration, in daily routine and in other science activities like reading, movie, etc. None of the teachers reported spending time working with computers in a typical lesson. About 59% of the teachers reported using cooperative groups once or twice a month or more.

Chin et al. (1994) also conducted a study similar to Lawrenz's (1990), but it involved only pre-service science teachers. It investigated the extent to which pre-service primary teachers used the problem-solving approach in science instruction during their teaching practice in schools. The study also sought to identify factors which hindered their effort in teaching science through this approach. One hundred pre-service science teachers were involved in this study. A questionnaire was used to elicit the pre-service teachers' views on the two abovementioned aspects. It was found that the following factors affected the teaching of higher-order thinking skills in schools:

- Factors pertaining to the teachers - Inadequate science content knowledge and pedagogical knowledge about how to use a problem-solving approach in teaching science.

- Factors pertaining to the students - Students' unfamiliarity with a problem-solving approach and lack of ability can discourage some teachers from using the approach. The teachers felt that their students had been conditioned to learning in the 'traditional' way in being 'spoon-fed' by their teachers and would need a long time to adapt to a new approach. The pupils' weaknesses in language and the lack of ability to co-operate in groups, identify a problem, design an experiment, hypothesize and interpret results were also cited as problems. A lack of motivation to learning and hence to thinking, made it difficult to teach higher-order thinking skills to such students.

- Factors pertaining to classroom management - The extent to which the teachers were able to cope with the disruptive behaviour of their class affected the efficacy of their teaching. The teachers felt that with problem-solving activities in group work, students would tend to become over-excited and rowdy, and feared that things would get out of hand.

- Factor pertaining to the school system - Time constraint, limited space to conduct science activities in, difficulties in getting access to the science room and other facilities, lack of appropriate and relevant activities and materials, and the inconvenience of having to search for such material beyond the prescribed textbook and workbook.

(extracted from Chin, et al. 1994; pages 44-48)

Stiggins, Griswold and Wikelund (1989) investigated in depth the extent to which the school teachers measured their students' higher-order thinking skills in mathematics, science, social studies, and language. Thirty six teachers from three schools of pacific Northwest in USA, at three different school levels (grades 2-12): high school, middle school and elementary, were involved in the study. A wide variety of assessment documents were analyzed, teachers were observed asking oral questions in their classrooms, and each teacher was interviewed. The results indicated that paper-and-pencil assessment documents were dominated by recall questions across all grade levels. However, inference was assessed too, especially in mathematics. Oral questions tended to tap recall too, with analysis and inference reflected to some extent. Across grades, subjects, and forms of assessments, comparison and evaluation questions were rare. Although these teachers had been trained to teach thinking skills to some extent, they were less often trained to assess such skills. Those who were trained in this study on the teaching and assessment of thinking skills tended to ask a higher proportion of thinking skills questions than those who were not. In this study, it was recommended that Quellmalz's (1985) cognitive processes of analysis, comparison, inference and evaluation are the fundamental skills that should figure in any assessment framework that merges psychological and philosophical views of essential reasoning strategies.

In summary, the teachers encountered difficulties in teaching thinking skills with the emphasis on higher-order ones. The difficulties include:

- The teachers place least emphasis on the use of problem-solving approach as part of their science instruction at the secondary level; they do not allocate much time for conducting cooperative or group learning in the laboratories.

- Three important factors that discourage the teachers to adopt problem-solving approach to teach science are that (a) the teachers fear losing control of their students' behaviour during problem-solving activities, (b) the teachers are concerned about time constraint and often prefer completing the syllabus in time to teaching problem solving, and (c) the inadequate science facilities and resources, and lack of supporting laboratory staff.

- For the assessment of students' science performance, the teachers tend to use a lot of recall questions in both the written tests and oral questions in the classrooms.

Implications for Teaching Thinking Skills

In views of the literature reviewed above, there are two implications for teaching thinking skills:

(1) Training for teachers:
Teachers will need training and support in the teaching and assessing of higher-order thinking skills. The work of Stiggins et al. (1989) has implied that those teachers who were trained in teaching and assessing thinking skills tended to ask a lot more of thinking questions in the written tests as well as their oral questions.

(2) Improved science facilities and resources for both primary and secondary schools and supporting laboratory staff for primary schools:

For encouraging teachers to teach higher-order and critical thinking skills in science, an increase in the numbers of science laboratories or science rooms and additional resources such as teaching materials for conducting hands-on activities are necessary. Frequent use of science laboratories or science rooms can be time-tabled. At present, supporting laboratory staff at the primary level is lacking. If problem-solving approach is to be seriously employed by teachers as part of science instruction, they need assistance and support from laboratory staff to cut down the time required in preparing hands-on activities.

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