Teaching Problem Solving: An Instructional Design Strategy

John A. Ross and Florence J. Maynes
ontario institute for studies in education, trent valley centre

This article provides an outline of an instructional design strategy for improving problem-solving performance in a variety of domains. The strategy emerges from a series of instructional improvement projects undertaken collaboratively by a small team of academics and groups of practicing teachers in eastern Ontario. These projects were stimulated by recent developments in cognitive psychology. The strategy entails the selection of an appropriate domain of problem-solving tasks, the construction of learning hierarchies, the design of teaching methods, the assembly of learning materials, the design of teacher training and the evaluation of instructional interventions. Obstacles to be overcome and directions for future research are identified.

Cet article donne un aperçu d'une stratégie de planification pédagogique visant l'amélioration de la capacité de solution de problèmes dans des domaines variés. Cette stratégie a été mise au point dans le cadre d'une série de projets d'amélioration pédagogique entrepris en collaboration par une petite équipe d'universitaires et des groupes d'enseignants en exercice de l'est de l'Ontario. Les découvertes récentes de la psychologie cognitive ont stimulé l'élaboration de ces projets. La stratégie comporte le choix d'un ensemble approprié de tâches de solution de problèmes, l'élaboration d'hiérarchies d'apprentissages, la création de méthodes d'enseignement, le recueil du matériel d'apprentissage, la planification de l'entraînement des enseignants et l'évaluation des interventions pédagogiques. Les obstacles à surmonter sont identifiés et des orientations pour des recherches futures sont suggérées.

Progress toward the creation of an effective instructional technology has historically been stimulated by developments in the social sciences, particularly psychology. This article provides an overview of a series of instructional improvement projects undertaken collaboratively by a small team of academics and groups of practicing teachers in eastern Ontario which were stimulated by recent developments in cognitive psychology. We describe a set of curriculum design strategies which emerged from an attempt to apply principles and hypotheses of information processing theory to classroom practice.

Our concern throughout is with the achievement of complex curriculum objectives, especially problem-solving objectives, that have come to occupy a prominent status among Canadian educational goals. We define a problem as "a situation in which an individual is called upon to perform a task not previously encountered and for which externally provided instructions do not specify completely the mode of solution" (Resnick and Glaser, 1976, p. 209). The problem solver must assemble a solution from processes or knowledge that exist outside the problem situation.

A summary of the scope of the projects is contained in Table 1. Figure 1

TABLE 1

Field Trials of Problem-Solving Programs

Problem Type	*Grade/Subject Context*	*Field Trial Design*	*Number of Students in Treatment Group*
Correlational	Grade 8: Agriculture in South America	1	423
	Grade 10: Mining in Ontario	1	128
Comparative	Grade 7: North American Regions	1	108
	Grade 4–8: Language Arts	2	179
Experimental	Grade 8: Heat and Temperature	2	150
	Grade 6: Bicycles (Science)	3	336
Decision-Making	Grade 7: Population Patterns	3	205
	Grade 10: Canadian Resources	3	157
	Grade 7–8: Guidance	2, 4	568

Design Code

[1]Non-experimental: pretest and posttest of treatment group
[2]Quasi-experimental: pretest and posttest of treatment and equivalent nontreatment group
[3]Experimental (delayed treatment design): pretest and posttest of treatment and control group
[4]Experimental: Solomon four-way design

FIGURE 1
Outline of an instructional design strategy

1. Select an appropriate domain of problem-solving tasks.
2. Construct learning hierarchies.
3. Devise instructional strategies.
4. Assemble learning materials.
5. Design teacher training.
6. Evaluate instructional interventions.

outlines the steps in the curriculum design strategy. Throughout our exposition correlational problem solving serves as a sustained example, with references to other projects where appropriate.

INSTRUCTIONAL DESIGN STRATEGY

Select an appropriate domain of problem-solving tasks

Consideration of the underlying cognitive structures and processes of students is a difficult and costly instructional enterprise requiring elaborate analysis and planning. The demands placed on teachers by this approach are very substantial and there are many problem-solving domains that simply do not warrant such exhaustive efforts. For example, there seems to be little point in making such special efforts to teach basic skills, such as counting, which almost all children learn anyway. So too, there is little point in selecting perplexing toy puzzles successfully completed by few adults that have little relevance to school learning regardless of how useful such activities may be in developing and testing conceptions of how learning occurs.

Thus, several criteria come to mind for selecting appropriate tasks. The problem-solving tasks should have prominence in several grades and subjects. They should have direct application to the real-life problems confronting students during and after their school experience. The problems should be part of the explicit goals of education. The problems should be tasks that children have difficulty mastering and/or tasks that constitute a domain that is receiving insufficient attention in the existing curriculum.

Four problem types have been identified that meet all these criteria: (1) decision-making problems in which the student must select the best course of action in a complex situation; (2) correlational problems in which the student tries to find an association between two or more variables in circumstances in which the values of the variables cannot be physically manipulated; (3) experimental problems in which the student seeks to establish a causal relationship between two or more variables by physically manipulating the variables; and (4) comparative problems in which the student establishes similarities and differences between two or more entities. A fifth domain, which is yet to be addressed, is that of transformational problems in which the student is required to transform known elements of the problem to meet the conditions of the unknown. Student mastery of these five problem-solving domains would contribute substantially to the achievement of the overarching goals of schools in Ontario and other provinces to develop a "self-directed problem solver ... a methodical thinker who is capable of inquiry, analysis, synthesis and evaluation" (Ontario Ministry of Education, 1980, pp. 2–3).

Although these general types of problems occur across grades and subjects, instructional activities, on the other hand, take place within specific contexts. First-order responsibility for improving problem-solving performance is being assigned to particular divisions and subjects. In the case of correlational problem solving, Intermediate Geography (Grades 7 to 10) became the specific context. This assignment was based partly on the importance of correlational problem solving to geographic investigation and partly on the interests of participating teachers and the instructional priorities of their boards of education.

Construct learning hierarchies

This step in the instructional strategy defines a developmental process for the behaviour to be learned. A learning hierarchy consists of a series of descriptions of cognitive behaviours that break down the discrepancies between expert and novice problem solvers. Cognitive psychologists who have contrasted expert with novice problem solving (for an excellent review see Chi, Glaser, and Rees, 1981) have drawn the following inferences germane to improving student performance. Novices can be distinguished from experts by some abilities that are exclusively related to maturation, e.g., size of information-processing capacity (more precisely the relative amount of total processing space that can be devoted to operations as opposed to storage) or degree of field independence. Both capacities are undeveloped in young children; each is directly linked to problem-solving competence, and neither is modifiable through instruction (Case, 1975; Case, Kurland, and Goldberg, 1982). By contrast, there are also problem-solving abilities which can be learned, the most noteworthy being the development of more sophisticated executive schemata.

Schema (schemata, in the plural) is a highly ambiguous concept of increasing importance to information processing theory. Schemata (also called frames, scripts or maps) are postulated internal knowledge structures that organize what an individual knows around main concepts. Each schema is a flexible representation of encyclopaedic knowledge; that is, it consists of the label and the attributes of a particular concept together with whatever facts and propositions are associated with that concept by the individual (Rummelhart and Ortony, 1977). A schema is a network in the sense that pieces of knowledge are linked together in an ordered rather than haphazard way. Each schema is itself connected to other schemata in a treelike hierarchy or weblike arrangements. In this larger ordering sub-schemata are represented by concept labels alone, not by their constituent elements. These constituent elements can be retrieved by processing through the larger ordering to the label of the appropriate schema and through this sub-schema to the elements of interest.

It is helpful to categorize schemata in terms of the functions they perform (Case, 1978(a); Gagné, 1977; Norman, et al., 1976). (a) *Figurative* schemata are organizations of facts, states, and meanings arranged in networks that facilitate accurate reproduction. (b) *Operative* schemata consist of sets of rules or procedures that can be used to rearrange or transform pieces of information. Operative schemata can be used to change one figurative schema into another or to create new information. (c) *Executive* schemata are superordinate sets of operative schemata that control, sequence and monitor a complex series of mental activities. Executive schemata can be understood as governing or meta-cognitive strategies that control the flow of information.

Experts differ from novices in all three categories of schemata formation. For example, with respect to figurative schemata, successful problem solvers develop a balance between highly specialized schemata corresponding to frequently encountered problem situations on the one hand, with highly generalized schemata adaptable to a broad range of less frequently encountered problems on the other (Rummelhart and Ortony, 1977). The most efficient balance is likely to comprise a tightly organized hierarchy of figurative schemata in which information about the world is stored at the highest level of generality (Chase, 1978; Collins and Quillian, 1969).

The most important dimensions of growth involve the development and refinement of executive schemata. Novices employ oversimplified strategies with relatively few steps; experts employ more complex procedures in which simpler processes are combined in a series of steps. The executive schemata of experts are typically lengthier yet they may take less time for processing (Case, 1978b; Klahr, 1976; Van Parreren, 1977) because their constituent elements are so well learned. Growth in executive schemata may also involve a remodelling of operations in which steps are eliminated or clusters of operative schemata may be collapsed into a more efficient executive process (Bransford, et al., 1977; Gregg, 1976; Norman, 1977). In this sense, the executive schemata of the mature problem solvers are qualitatively as well as quantitatively different from the corresponding executive schemata employed by novices.

An integral part of growth in the use of executive schemata is the extent to which the problem solver is conscious of his or her own mental processes (Bransford, et al., 1977; Brown, 1978; Flavell, 1976). Novices suffer from chronic deficiencies: they do not know what they don't know;

they are unable to estimate the difficulty of the task; they are unable to monitor their own performance and they are unable to detect inconsistencies in their procedures. Novices are blind rule followers who are unreflective about their executive processes. In contrast, experts are reflective investigators who consciously monitor the effectiveness of their progress toward a solution.

A variety of procedures have been developed to construct succinct descriptions of expert-novice differences in particular problem-solving tasks. The primary method involves a logical analysis of the requirements of a given task when performed at an expert level. Knowledge of how experts and novices solve problems can also be gained through think-aloud protocol analysis (Newell and Simon, 1972) in which subjects describe their thinking while completing a task or retrospectively in a diary. Structured interviews and observations of subjects manipulating experimental apparatus have also been helpful.

The descriptions of novice and expert strategies comprise the respective entry and exit points of an instructional hierarchy. Such a hierarchy may also contain intermediary levels to reduce the gap between the two end points. The rationale for intermediary levels is based on the limited capacity of the information processing system. The number of unrelated items that can be learned at any one moment is severely limited (Broadbent, 1975; Case, 1975; Miller, 1956). To attempt to teach expert strategies to novices is unlikely to succeed. Intermediary levels, however, provide mediating instructional goals such that problem-solving competence can be gradually developed.

The limited capacity of the information processing system is a pervasive problem constraining pedagogical decisions. The problem is addressed at several points in the instructional design strategy described in this paper. At this step in the strategy, two actions are taken. First, each complex problem-solving type has been decomposed into a general set of simple inquiry skills (Robinson, 1979). Second, each of these skills are being analyzed to construct a series of learning hierarchies for each skill in each problem type.

An example of a learning hierarchy (or growth scheme) is given in Table 2. This example concerns the skill of establishing a framework for a correlational inquiry. This hierarchy was constructed through a logical analysis of the demands of correlational problems using procedures developed by Robinson (1979). Observations of student performance and responses to open-ended test items were used to refine the descriptions of student behaviour.

Several explanatory comments about Table 2 are in order. The levels (1 through 6) are cumulative; each of the higher levels contains all the operations of lower levels. In this sense each level is an executive schema containing a series of simple operative schemata. No level contains more than four new operations because of the limited capacity of the information

TABLE 2

Growth Scheme For The Skill Of Establishing A Framework For Solving A Correlational Problem

Performance Level	*Operations in Strategy*	*Spatial Representation*
1	1 Make a list of factors relevant to the problem.	List of things important: weather; how far north it is; prevailing winds; kind of thermometer used; whether there is water nearby
2	2 Select two factors from the list. 3 Select a few cases for which information is available on each factor. 4 Make a chart with 3 columns: one column for identifying the cases; one column for the first factor; and one column for the second factor.	Place | How far north it is | How cold it is First place | ? | ? Second place | ? | ? Third place | ? | ?
3	5 Define the two variables and their measurement scale more precisely. 6 Increase the number of cases from a few to a dozen or more, including a broad range of values on one of the variables. 7 Order the cases on one of the variables (i.e., list the cases from lowest to highest).	Cities | Latitude (in °*N*) | Temperature (in °*C*) 1st city | ?(lowest) | ? . | . | . . | . | . . | . | . 12th city | ?(highest) | ?

TABLE 2 (*continued*)

Performance Level	*Operations in Strategy*	*Spatial Representation*
4	8 Expand the chart by adding a new column for every variable listed in step one for which there is data for the dozen or more cases.	see chart below
5	9 Select one control variable that might affect the relationship between the main variable in the 2nd and 3rd columns. 10 Group the cases into 2–3 categories in terms of their values on the control variable. 11 Select one of the value ranges. 12 Make a new chart with 3 columns; the 1st column identifying all the cases within the designated range of the control variable and one column for each of the main variables.	see chart below

Spatial Representation, level 4:

Cities	Temperature (in °*C*)	Latitude (in °*N*)	Elevation (in *m*)	Nearness to Water (in *km*)	Longitude (in mer *E*)
1st city	?(lowest)	?	?	?	?
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
12th city	?(highest)	?	?	?	?

Spatial Representation, level 5:

Cities with elevation below 2,000 metres	Latitude (in °*N*)	Temperature (in °*C*)
1st city	?(lowest)	?
.	.	.
.	.	.
.	.	.
12th city	?(highest)	?

Table 2 (*concluded*)

Performance Level	*Operations in Strategy*	*Spatial Representation*			
		Elevation	Cities	Latitude (in °*N*)	Temperature (in °*C*)
6	13 Expand the chart by adding groups of cases that fall into the other value ranges of the control variable (using the same structure as in step 12).	below 2,000 m	1st city	?(lowest)	?
	14 Increase the number of cases in each group to at least six.		.	.	.
			.	.	.
			.	.	.
			8th city	?(highest)	?
		2,001–4,000 m	9th city	?(lowest)	?
			.	.	.
			.	.	.
			.	.	.
			14th city	?(highest)	?
		over 4,000 m	15th city	?(lowest)	?
			.	.	.
			.	.	.
			.	.	.
			23rd city	?(highest)	?

processing system. Each cluster of operations has a coherent, self-supporting structure (Calfee, 1981). The table's spatial representations (to be discussed in the next section) refer to a specific problem instance based on the general question: "Why is it colder in some places than in others?"

The top level of performance corresponds to the highest performance that could reasonably be expected of the best students in the Intermediate Division. It does not describe the performance of an expert social scientist with computer facilities. The lowest level corresponds to the behaviour of the least competent students likely to be encountered in the Intermediate Division. Each of the operations contained in the schema could be broken down still further, but they are atomic for this instructional context; that is, it is assumed that each operation can be learned directly with modest amounts of instruction (for example, one 30-minute classroom period) without prior teaching of prerequisites.

Although these levels are intended to approximate the most frequently occurring cognitive behaviours of students in the intermediate grades, they should not be viewed as analogous to Piagetian stages. There is no assumption that students pass through these levels in a universal invariant sequence. Some students may skip lower levels entirely or master lower levels in the process of acquiring upper level behaviours (Resnick, 1976). The relationship between the behaviours at the upper and lower levels of the hierarchy is complex and varies with the problem type (Glaser, 1976), but it is important to recognize that the lower levels are not so much incorrect as inadequate; they are oversimplified strategies that are incomplete.

The resulting learning hierarchies provide a blueprint for development, describing the specific changes required to improve student problem-solving performance. Each level in the hierarchy can be treated as a learning objective to be achieved through specific instruction.

Devise instructional strategies

The simplest instructional strategy is to provide students with practice in the component operations, ideally using less difficult instances of the type of problem to be solved. A less difficult instance is one in which the number of items the child has to deal with at one time is severely limited, the data and problem context are familiar (for example, drawn from real-life experience) and the essential problem elements are easily detected (Case, 1978(c)). With practice, the simple executive routines required for the solution of these simple problems will become automatic, demands on processing capacity will be reduced, and execution time will decline. This in turn will provide processing space for acquiring new operative schemata to be incorporated into ever larger executive routines (Case, 1975, 1978(b)).

In the case of the example in Table 2, correlational problems were generated from topic outlines provided by provincial curriculum guidelines for Intermediate Geography. These problems were refined to ensure that there was sufficient information in available data banks to solve the problems.

Practice is effective in reinforcing an executive schema already attained in whole or in part by a student and it can gradually increase the number of operations mastered by students. But practice alone is unlikely to lead to qualitative remodelling of an executive schema because there is no incentive for the student to change if simple strategies are working. A second category of instructional strategies involves confronting the student with a problem that cannot be handled by a simple executive schema so that the student recognizes the need for change (Anderson, 1977; Case, 1978(c); Norman, 1977). Growth is likely to be maximized when the student invents a solution to the more difficult problem; with practice this solution strategy replaces the less sophisticated routine that was unable to solve the more challenging problem.

For instance, in the transition from level 2 to level 3 in Table 2, the need for expanding the number of cases (operation 6) was demonstrated with a real-life example. Students were presented with data on three students (a short stocky person, an average person and a tall thin person) that showed that body weight *decreases* with height. Students immediately recognized that the finding was valid for the data, that the data were credible but that the finding contradicted the common sense observation that tall people tend to be heavier than short people. Most students were able to invent a solution, i.e., expand the number of cases (operation 6), and could transfer this solution from the real-life situation to school problems.

Similarly the need for ordering the cases on one variable (operation 7) was demonstrated with another real-life example. A data table containing the heights and weights of students organized alphabetically by students' names was presented. Very few students were able to discover the expected relationship between the two variables until the data were reordered. When reordered the relationship was obvious to all; it conformed to reality, and the advantage of operation 7 was clearly evident.

If students are unable to invent a novel solution, a third set of instructional strategies involving teacher modelling is suggested. Providing students with simplified routines that mimic mature executive processes (Bereiter and Scardamalia, 1982) is a useful intermediary step. Such simplified routines are analogous to the problem-solving strategies that students actually invent as their thinking matures (Resnick, 1976). A good teaching routine is one that is easily demonstrated and is capable of being easily adapted by students to solve problems that cannot be handled by less complex schemata. In modelling it is essential that the teacher think aloud so that the advantages of the new solution and disadvantages of the old are evident to the learner. In the correlational problem-solving example, teacher modelling was used whenever the target operation could not be easily invented by most students, for instance, when the target operation involved a standardized format for a data table or a decision on the number of cases required to solve a correlational problem.

A fourth category of instructional strategies is helping students become more conscious of their own thought processes. Bereiter and Scardamalia (1982) suggest that efficient executive routines are more likely to develop if teachers make what are normally covert processes manifest to students, for example, by focussing their attention on particular mental operations. This is likely to be particularly important for lower level operations that disappear in expert processes or which are so compacted in higher order routines as to be invisible. Similarly requiring students to articulate their goals and verbalize plans for solving a problem also improves performance as demonstrated in an experiment by Pellegrino and Schadler (Resnick and Glaser, 1976).

Attempts to make executive schemata visible can be complemented with instructional acts to improve figurative schemata that represent the problem. Providing students with labels for problem elements (Gregg, 1978) is likely to facilitate processing of these elements. Greeno (1978) proposes that teaching students how to produce a spatial representation (or diagram) of problem elements is also likely to help them understand the relationships between the elements; it also has the advantage of making the internal representation of the problem visible.

These strategies can contribute to growth in problem-solving competence directly and they can also have an indirect effect by improving student-teacher communication. One of the greatest practical difficulties in providing problem-solving instruction that addresses the underlying cognitive structures and processes of students is that these mental activities are entirely internal. Making these structures and processes visible and providing labels for them enables teachers to diagnose more effectively what students are thinking. It also makes it much easier to describe to students what it is they are supposed to do.

A final teaching strategy in this category involves reality testing. Expert problem solving is characterized by effective checking and monitoring of partial solutions. In contrast, novices, particularly young children, are unaware of internal inconsistencies in their solutions and are unable to determine if a solution is contrary to common sense (Brown, 1978). Existing school practices tend to impede reality testing. Most schools attach a greater importance to replicative learning (reproduction of knowledge) than to applicative learning (problem solving) (Broudy, 1977). Spiro (1977) even suggests that it is sensible for students to keep personal and school schemata as separate as possible because attempts to integrate the two sets may lead to interference and might reduce student performance on tasks that call for the accurate reproduction of knowledge. Even though reality testing disrupts the mental segregation functional to school success in most curriculum contexts, it is an important step in the growth of problem-solving ability and requires a special effort on the part of teachers to overcome student resistance. Consequently, it is desirable to introduce real-life examples and tasks in school problem solving as a means of fostering the tendency to check solutions against common sense and the belief that problem solving is a meaningful activity. The use of instances taken from life also has the effect of reducing demands on processing capacity because the situations are familiar; this reduction frees processing space for the acquisition of new operations.

Throughout the instructional sequence in the correlational problem-solving projects explicit attention was given to students' awareness of their own thought processes. Students were shown how to represent problems spatially (see the last column in Table 2); reality testing was encouraged through examples from life; overt attention was given to cognitive processes and there was constant feedback on individual performance from worksheets.

Design student learning materials

Discussion of this complex matter will be very brief. Sequenced student exercises are required to provide students with appropriate practice. In the correlational problem-solving projects, student worksheets were prepared for each of the levels beyond entry performance. Each worksheet required students to perform only the operations (separately or *in toto*) at a single level – there were no other processing demands. The worksheets were intended to promote automatic processing and to consolidate new operations into the student's executive schemata. When students' mastery of the operations contained in a particular level reached the point at which the tasks could be performed quickly and successfully with little demand on students' capacities, they were deemed to be ready to take on more advanced operations. Examples of learning materials are given in Ross and Maynes (1982).

Design teacher training

The initial training for teachers participating in these projects focussed on the benefits to students of learning problem-solving strategies and on the instructional principles outlined above. The emphasis on procedural rather than theoretical knowledge was based on the conviction that it is not necessary to understand the constructs of a technology in order to use it. In these in-service sessions teachers were taught problem solving in a manner analogous to the methods used for students; that is, the lowest levels were generated by teachers and gradually revised collectively through the guidance of the workshop leader. Teachers were provided with highly detailed lesson plans and packages of student materials as examples of how to teach problem solving within specific subject/topic contexts. Slavish fidelity to these lesson plans was not required; it was assumed that teachers would make adaptations to meet the perceived demands of their classroom situations. Minimal implementation was defined as meeting the following criteria: instruction is sequenced according to the learning hierarchy defined in the program, specific instructional acts of the type defined in subsection 3 are used to improve student performance, and ample practice of the designated operations is provided before proceeding from one level to another.

More recently, in-service activities have been extended to provide training for other agents in the school system, focussing particularly on the role of the principal as an instructional leader (Ross, 1980) and addressing more general implementation concerns following Fullan and Park (1981). Attention is also being given to adapting the instructional materials and strategies for the small but important minority of teachers who do not often teach in a large group arrangement (i.e., those teachers who organize students into small homogeneous and heterogeneous groups for instructional purposes).

Evaluate instructional interventions

Table 1 above outlines the field tests that have taken place. In each field trial student performance was measured by previously developed subject-specific problem-solving instruments of a multiple-choice format. This testing was supplemented with teacher interviews and student responses to open-ended items. For examples of the assessment instruments being used see Ross, 1981(a); Ross and Maynes, 1979, 1981, 1982, 1983. After each field trial the instructional materials were revised.

The evaluation of the correlational problem-solving program involved a simple single group pretest-posttest design. In the initial pilot test (N = 217 Grades 7 and 8 students) in which the goal for the intervention was set at mastery of level 3 in the growth scheme presented in Table 2, the proportion of students reaching this criterion increased from 24% to 54% over the course of the treatment ($X^2 = 77.99$, $df = 1$, $p < .01$).[1] In a subsequent replication study involving a broad range of correlational problem-solving competence the mean performance of students also increased significantly after instruction (see Table 3).[2]

Evaluations of instruction in problem solving in other domains have produced comparable results. Investigations using more powerful evaluation designs have shown significant improvements in student problem-solving performance in the context of Grades 7 and 8 guidance (Ross, 1981, Grade 6 science (Ross and Maynes, in press (b)) and Grade 8 science (Ross and Maynes, 1983). The effects of the treatments in these studies were calculated using the formula of Glass (1978). The effect sizes are displayed in a stem-and-leaf diagram in Table 4. Stems (on the

TABLE 3
Effects of Instruction on Correlational Problem-Solving Performance

	A-B Replication (N = 171)		*B-A Replication* (N = 163)	
	Pre	*Post*	*Pre*	*Post*
Mean	13.94	16.31	15.06	16.46
Standard deviation	2.51	2.89	2.45	3.12
T-value	−9.09		−4.84	
Significance*	$p < .01$		$p < .01$	

*two-tailed test of probability

TABLE 4
Stem-and-Leaf Diagram of Effect Sizes

≥1.1	1.10, 1.33, 1.45, 1.89
1.0	2 5
.9	1 6 7
.8	1 8
.7	6 6
.6	1 6 6 7
.5	1 5 6 7
.4	0 1 1 3 6 8
.3	0 8
.2	1 4 7 8
.1	7
.0	3 5
<.0	−.10, −.38, −.52

left of the vertical line) are broken down into intervals of .1; leaves (to the right of the vertical line) represent the second decimal place (hundredths) of the effect size. In the table, 36 of the 39 data points are positive; the mean effect is .56 with a standard deviation of .42. These findings suggest that the instructional design outlined in this paper is feasible and that it is possible for teachers to incorporate some of the implications of recent developments in cognitive psychology into classroom practice.

OBSTACLES TO OVERCOME

In some pilot sites, there is evidence that not all students are benefitting from the instruction. The constraints of large group instruction are severe; the pace of instruction is clearly too rapid for some students who are unable to consolidate each level into a schema before it is disturbed by the introduction of new operations. Several teaching strategies are under scrutiny to alleviate this problem – provision of remedial assistance consisting of additional practice at lower levels and individual tutoring, grouping of students by performance level, and the development of self-instructional materials for more advanced students (thereby freeing teacher time for the less advanced). Each of these proposed strategies is extremely difficult to implement.

Almost all the teachers provided students with labels for the group of operations within each level; for example, they referred to a level 2 strategy, etc. This is a sensible procedure for helping students discriminate at higher levels of performance between desired and undesired processes. However, it is likely to become problematic as students are introduced to other problem types. A level 2 strategy in the correlational hierarchy is similar to level 2 in the experimental hierarchy but it is very unlike the level 2 of the comparative and decision-making hierarchies. A possible solution is to provide an organized set of labels for all levels in all problem types; i.e., to help students develop a figurative schema that would direct them to the appropriate executive schema once they had diagnosed the problem type.

A final concern expressed by insightful teachers is the prospect that direct problem-solving training may retard student invention of novel solutions or inhibit the development of general problem-solving skills. The argument is that students who make discoveries on their own through undirected practice will be more adept at transferring these discoveries to other contexts. This is a perfectly reasonable assumption, but we would argue that relatively few students are now spontaneously generating sophisticated executive schemata. If schools are to realize the goal of developing self-directed problem solvers, more aggressive instruction is required.

DIRECTIONS FOR FURTHER RESEARCH

Three directions are emerging from this work as a research agenda. The first direction concerns the identification of the correlates of problem-solving performance. Of particular interest is the overlap of general ability and of knowledge development on problem-solving growth. Although anecdotal evidence accumulated to date is confusing and counter-intuitive, it is hypothesized that there will be a positive correlation between problem-solving performance and other measures of cognitive ability. So too, it is hypothesized that students will perform at higher levels on problems nested in domains for which they have a superior knowledge base than for problems of the same generic type for which they have an inferior base.

The second direction concerns the effect of problem-solving instruction on various affective measures, especially locus of control and intrinsic motivation (Harter and Connell, 1981). It is hypothesized that increased competence in broad classes of problems provided by mastery of problem-solving skills will increase awareness of the source of control and modify the current deterioration across the junior division in the intrinsic willingness to approach and be involved with such problems.

The third direction concerns the retention of problem-solving competence. Existing evidence suggests that problem-solving performance is retained for at least one month after instruction (Ross and Maynes, in press, and anecdotal evidence in less controlled settings suggests there may be no measurable performance declines in some instances over longer periods. It is hypothesized that the effect of problem-solving instruction will be retained for extended periods, particularly if modest reinforcement is provided.

Successful completion of this research agenda will provide information to be used in the refinement of the instructional design strategy outlined above. It will also provide data to be used in the refinement of an implementation strategy that focusses on the benefits that can accrue to students if teachers develop programs based on this instructional design.

NOTES

[1] Two equivalent instruments, each containing three multiple-choice items were used; the items are reported in Ross and Maynes (1981). Half the students had Form A as the pretest and Form B as the posttest; the other half took the tests in the reverse order. Results were averaged to produce group scores. Criterion performance was defined as three out of three correct.

[2] Two equivalent instruments, each containing nine multiple-choice items were used; the items are reported in Ross and Maynes (1981). In the A-B replication Form A served as the pretest with Form B as the posttest; in the B-A replication the order was reversed. The maximum score possible on each test was 24.

REFERENCES

Anderson, R. C. The notion of schemata and the educational enterprise: General discussion of the conference. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 415–431.

Bereiter, C., & Scardamalia, M. From conversation to composition: The role of instruction in a developmental process. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2). Hillsdale, N.J.: Erlbaum, 1982, 1–64.

Bransford, J. D., Nitsch, K. E., & Franks, J. J. Schooling and the facilitation of knowing. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 31–55.

Broadbent, D. E. The magic number seven after fifteen years. In A. Kennedy, & A. Wilkes (Eds.), *Studies in long term memory.* New York: Wiley, 1975, 3–18.

Broudy, H. S. Types of knowledge and purposes of education. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 1–17.

Brown, A. L. Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 1). New York: Wiley, 1978, 77–165.

Calfee, R. Cognitive psychology and educational practice. In D. C. Berliner (Ed.), *Review of research in education* (Vol. 9). Washington, D.C.: American Educational Research Association, 1981, 3–73.

Case, R. Gearing the demands of instruction to the developmental capacities of the learner. *Review of Educational Research*, 1975, *45*, 59–87.

Case, R. Piaget and beyond: Toward a developmentally based theory and technology of instruction. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 1). New York: Wiley, 1978(a), 167–228.

Case, R. Intellectual development from birth to adulthood: A neo-Piagetian interpretation. In R. S. Siegler (Ed.), *Children's thinking: What develops?* Hillsdale, N.J.: Erlbaum, 1978(b), 37–71.

Case, R. A developmentally based theory and technology of instruction. *Review of Educational Research*, 1978(c), *48*, 439–463.

Case, R., Kurland, D. N., & Goldberg, J. Operational efficiency and the growth of short term memory space. *Journal of Experimental Child Psychology*, 1982, *33*, 386–404.

Chase, W. G. Elementary information processes. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes* (Vol. 5). Hillsdale, N.J.: Erlbaum, 1978, 19–90.

Chi, M. T. H., Glaser, R., & Rees, E. *Expertise in problem solving.* Pittsburgh: Learning Research and Development Center, University of Pittsburgh, 1981.

Collins, A. M., & Quillian, M. R. Retrieval time from semantic memory. *Journal of Verbal Learning and Verbal Behavior*, 1969, *8*, 240–248.

Flavell, J. H. Metacognitive aspects of problem-solving. In L. B. Resnick (Ed.), *The nature of intelligence.* Hillsdale, N.J.: Erlbaum, 1976, 231–236.

Fullan, M., & Park, P. *Curriculum implementation: A resource booklet.* Toronto: Ontario Ministry of Education, 1981.

Gagné, R. M. Schooling and the relevance of research: General discussion of the conference. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 405–413.

Glaser, R. Components of psychology of instruction: Toward a science of design. *Review of Educational Research*, 1976, *46*, 1–24.

Glass, G. V. Integrating findings: The meta-analysis of research. In L. S. Shulman (Ed.), *Review of research in education* (Vol. 5). Itasca, Ill.: Peacock, 1978, 351–379.

Gregg, L. W. Methods and models for task analysis in instructional design. In D. Klahr (Ed.), *Cognition and instruction.* Hillsdale, N.J.: Erlbaum, 1976, 109–116.

Gregg, L. W. Spatial concepts, spatial names, and the development of exocentric representations. In R. S. Siegler (Ed.), *Children's thinking: What develops?* Hillsdale, N.J.: Erlbaum, 1978, 275–290.

Greeno, J. G. A study of problem-solving. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 1). New York: Wiley, 1978, 13–75.

Harter, S., & Connell, J. P. A structural model of the relationships among children's academic achievement and their self-perceptions of competence, control and motivational orientation in the cognitive domain. In J. Nicholls (Ed.), *The development of achievement motivation.* Greenwich, Connecticut: JAI Press, 1981.

Klahr, D. Steps toward the simulation of intellectual development. In L. B. Resnick (Ed.), *The nature of intelligence.* Hillsdale, N.J.: Erlbaum, 1976, 99–133.

Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 1956, *63*, 81–97.

Newell, A., & Simon, H. A. *Human problem-solving.* Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Norman, D. A. Notes toward a theory of complex learning. In A. M. Lesgold, J. W. Pellegrino, S. D. Fokkema, & R. Glaser (Eds.), *Cognitive psychology and instruction.* New York: Plenum Press, 1977, 39–48.

Norman, D. A., Gentner, D. R., & Stevens, A. L. Comments on learning schemata and memory representation. In D. Klahr (Ed.), *Cognition and instruction.* Hillsdale, N.J.: Erlbaum, 1976, 177–196.

Ontario Ministry of Education. The goals of education. *Issues and Directions.* Toronto: Ontario Ministry of Education, 1980, 1–7.

Resnick, L. B. Task analysis in instructional design: Some cases from mathematics. In D. Klahr (Ed.), *Cognition and instruction.* Hillsdale, N.J.: Erlbaum, 1976, 51–80.

Resnick, L. B. & Glaser, R. Problem-solving and intelligence. In L. B. Resnick (Ed.), *The nature of intelligence.* Hillsdale, N.J.: Erlbaum, 1976, 205–230.

Robinson, F. R. ICPOGMU: A framework for the preparation of curriculum guidelines and related instructional materials. Unpublished manual. Toronto: O.I.S.E. Curriculum Department, 1979.

Ross, J. A. The influence of the principal on the curriculum decisions of teachers. *Journal of Curriculum Studies,* 1980, *12*(3), 219–230.

Ross, J. A., & Maynes, F. J. Measuring the skills of scientific inquiry. Unpublished item pool. O.I.S.E. Trent Valley Centre, Peterborough, Ontario, 1979 (ERIC Document Reproduction Service No. ED 211 568).

Ross, J. A. The measurement of student achievement in a decision-making approach to values education. *Alberta Journal of Educational Research,* 1981(a), *27*(1), 1–15.

Ross, J. A. Improving adolescent decision-making skills. *Curriculum Inquiry,* 1981(b), *11*(3), 279–295.

Ross, J. A., & Maynes, F. J. *Geographic thinking skills.* Toronto: O.I.S.E. Press, 1981.

Ross, J. A., & Maynes, F. J. *Teaching problem-solving.* Toronto: O.I.S.E. Press, 1982.

Ross, J. A., & Maynes, F. J. The development of a test of experimental problem-solving. *Journal of Research in Science Teaching,* 1983, *20*(1), 63–75.

Ross, J. A., & Maynes, F. J. Experimental problem-solving: An instructional improvement field experiment. *Journal of Research in Science Teaching,* in press.

Rummelhart, D. E., & Ortony, A. The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 99–135.

Spiro, R. J. Remembering information from text: The "state of schema" approach. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, N.J.: Erlbaum, 1977, 137–165.

Van Parreren, C. A building block model of cognitive learning. In A. M. Lesgold, J. W. Pellegrino, S. D. Fokkema, & R. Glaser (Eds.), *Cognitive psychology and instruction.* New York: Plenum Press, 1977, 3–12.

John A. Ross is an Associate Professor and Head and Florence J. Maynes is a Research Associate at the Trent Valley Centre of The Ontario Institute for Studies in Education, P.O. Box 719, 150 O'Carroll Avenue, Peterborough, Ontario, K9J 7A1.