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Principles for Developing

Algorithmic Instruction

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EDUCATIONAL TECHNOLOGY

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An algorithmic procedure was examined under several instructional approaches to yield design principles pertinent to military training. Learning factors were selected from information-processing theories to test their applicability with instruction directed by learning algorithms. A version of a logical, or familiar, and a computational algorithm was generated, further divided into verbal and symbolic (mathematical) forms, and presented to sixty undergraduates. Multivariate analyses were employed on two dependent   (over)

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measures, instructional effectiveness and efficiency. Posttests were administered both immediately following instruction and one week later. Attention was also given to the criterion-referenced effectiveness of the various algorithmic forms. Learners achieved high scores following very brief instruction, with verbal and logical groups outperforming their comparison treatments. Retention losses after the time delay were found to closely match the typical needs of a training environment. Tentative principles for using algorithms in instructional design include emphasis on concrete, familiar content, short, compact structures, and complete mastery of each preceding operator or discriminator. The efficiency of the algorithmic approach is highlighted as having unusual utility in meeting the future demands of schooling and training.

Rule Learning and Systematic Instruction in
Undergraduate Pilot Training

Vernon S. Gerlach, Principal Investigator

PRINCIPLES FOR DEVELOPING
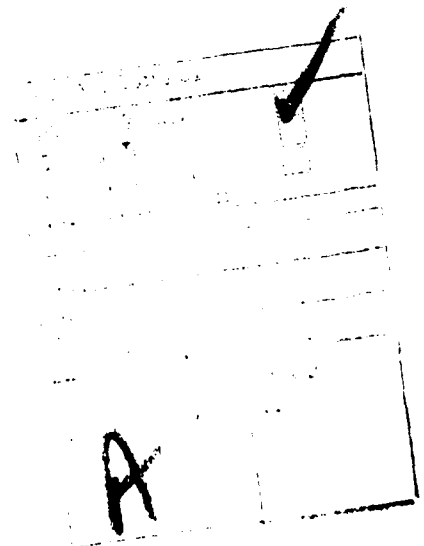ALGORITHMIC INSTRUCTION

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Technical Report #81201

College of Education
Arizona State University
Tempe, Arizona

December, 1978

PRINCIPLES FOR DEVELOPING
ALGORITHMIC INSTRUCTION

Principles for Developing Algorithmic Instruction

Algorithmic instruction has grown rapidly in popularity as a tool for education and training. Unfortunately, the efficacy of algorithms for both teaching and learning is based more on its association with its conceptual predecessors than on empirical demonstration. For example, because algorithms are similar to computer programs in format and problem solving effectiveness, it is inferred that they can be developed, "taught", and implemented in the same fashion. From a' instructional standpoint, it may be of use to draw parallels between programmed instruction and algorithmic instruction. However, basic structural differences suggest that such efforts be carefully analyzed and thoroughly tested. While Landa (1974, 1975) has provided an initial theoretical foundation and conceptual introduction to algorithmic instruction, instructional designers, educators, and trainers would be ill-advised to incorporate algorithms into an instructional system without the benefit of intermediate research and specific design principles.

Typically, either a well-tested theoretical base or a set of logically derived principles must precede the adoption of any instructional method. Historically, algorithms do not belong to any nomothetic net, and little, if any, benefit accrues from constructing a post hoc foundation for this technology. Rather, we have examined the learning effects of algorithms in controlled classroom settings in search of general principles, a procedure often found in the development of "theories" of instruction (Hilgard & Bower, 1975). Because instructional principles are readily operationalized, this approach lends itself well both to immediate implementation and field testing in actual schooling and training

environments, as well as to experimentation to refine and extend the
initial findings. Recent studies by Schmid and Gerlach (1977), Ehrenpreis
and Scandura (1974), and others have begun work in this direction by
adding empirical evidence that an algorithmic approach to instruction can
in fact effectively assist learners in attaining mastery of highly
structured information. Futhermore, it is the contention of Landa that
most instruction is highly structured if adequately analyzed; if this is
true, algorithmic instruction is amenable to a wide variety of learning
tasks. Notwithstanding, before we apply this approach to any curriculum,
we must consider factors other than the above conceptual precedent and
data.

The intent of our research was to borrow from information-processing
theory factors which are known to affect learning in a predictable manner
and to apply them to algorithmic instruction. This approach effectively
tests learning principles generated primarily from basic research and
converts these principles into usable "advice" to instructional designers,
depending upon the outcome. These results, as do any experimentally
contrived data, have restricted generalizability. However, it is
important to recognize that any instructional method is dependent upon
the control of certain environmental factors. The precision of our advice
will be dependent upon the identification of and compensation for these
environmental factors. Precision is also necessary to effectively respond
to questions and difficulties regarding transfer, resource limitations,
and adverse attitudinal effects. Instructionally, we are less concerned
with the underlying mechanisms of learning than we are with the medium

and its product. To gain the necessary level of precision, it is essential
that instructional designers have a set of operational principles with
which to work.

Another more basic problem related to the use of experimentation in
instructional research has been voiced by J. M. Stevens (1967). He
provided compelling logic accompanied by solid empirical data which
suggested that any attempt to revolutionize or even to substantially
improve schooling or training is likely to fail. Therefore, if a
researcher or developer intends to justify the efforts expended in the
creation of a unique instructional system, some response must be given to
his thesis. To evaluate algorithmic instruction within this context, we
first present for consideration selected excerpts from Stevens' The
Process of Schooling in an attempt to represent his case. Instructional
innovations are analyzed for their contribution to education. Algorithmic
instruction is then scrutinized in light of Stevens' comments. This
analysis leads to a comparison between present day research methods and
a new, alternative approach. Evidence is presented that this new set of
criteria might supply researchers with more realistic and effective goals
for advancing the instructional effort.

Instructional Innovation: Egotistical Enrichment or Educational Improvement?

Stevens argues that throughout history efforts to alter the course of
education in the school have made small gains indeed. His views are best
presented in selected quotations.

> ...we try to improve the educational process by elaborate and
> refined changes in the program of instruction. But...this
> program of instruction may turn out to be a mere incidental
> feature in the educational process. The essential features of
> education may reside not in the program itself but in a few

primitive forces which always accompany the program. These
processes, like those involved in the germination of seeds,
are so humble and so automatic that they demand little attention.
Yet, they provide the basic mechanisms on which all educational
activities depend. (pp. 4-5)

If learning processes are in fact naturally adaptive and flexible,

then the question remains why researchers pursue answers to hypothetical,

if not imaginary, problems. Stevens responds:

It is true, of course, that we do have thousands of investigations
regarding the effectiveness of this or that specific device.
Regarding the essential underlying mechanisms of schooling,
however, we even lack serious detailed speculation, to say nothing
of convincing evidence. (p. 4)

The constancy of the school's accomplishment is one of those
things that everybody knows. It is part of the folklore that,
in educational investigations, one method turns out to be as
good as another and that promising innovations produce about as
much growth as the procedures they supplant, but no more. Nachman
and Opochinsky (1958), to take one example, feel safe in stating,
as a matter of common knowledge, that "Reviews of teaching research
have consistently concluded that different teaching procedures
produce little or no difference in the amount of knowledge gained
by students." In truth this has been a refrain ever since Rice
(1897) discovered the surprising constancy of spelling attainment
in the face of marked variations in the time devoted to study
and since Merriam (1915) reported regular growth in school
subjects in the absence of formal instruction in those subjects.
(p. 10)

Stevens' point carries a painful truth for those of us who, by untold

hours of tedious research and painful thought, endeavor to improve learning

in the schools. Yet the discouraging fact remains that little has been

done to alter the natural process of learning as we understand it.

Stevens does offer some hope, but his proposals may require researchers

to adopt an entirely new set of assumptions and methods.

In this general notion of the origin of the schools, survival is
the key. To have a good chance of survival, members of a group
must attain reasonable proficiency in many different kinds of
behavior. Typically, these ways of behaving, or tendencies, call

for nurture or cultivation. It follows, then, that a group
is more likely to survive if it has mechanisms for the necessary
cultivation of these useful tendencies. ...there are scores
of frivolous, playful, or decorative tendencies which for years
contribute nothing immediately to survival but which, on rare
occasions, have made tremendous contributions to the survival
of the group. ...It follows, therefore, that the society which
evolved some means of nurturing these luxury traits (as well as
those necessary for survival) would, in the long run, have an
advantage over any society which limited its nurture to those
traits having an immediate and obvious payoff. It is held that
in most surviving societies something similar to a school or
near-school has evolved. Such schools, or the near-schools of
the extended family, have given the same immediate, daily, and
urgent concern to reading, learning history, or dancing as the
more immediate home typically provides for talking or for the
proper handling of sharp instruments. (pp. 6-7)

In summary, Stevens contends that how we teach makes little difference.

What is important is that we teach, and secondly, what is taught. We

are somewhat assured that the former condition will remain. However,

the answer to the question regarding "what" is taught appears to be

process of trial-and-error. A major contention of this paper is that from

a schooling standpoint algorithmic instruction may aid in this game of

chance.

Educational research method. To proceed in accordance with Stevens'

observations, several major alterations in instructional research are

warranted. Most often, instructional research tests the relative

effectiveness and efficiency of two or more training methods, holding "all"

other factors constant. The results usually indicate no significant

differences. If we are to assume that schools will remain with us, then

Stevens' comments imply that schools should teach a wider variety of

behaviours than a society's or the learners' immediate needs. To improve

schools, we must teach more diverse skills and attempt to better anticipate

future needs. By way of comparison, industry has contended for years that

adequate preparation for a specific occupation is impossible until one
finally begins performing the actual tasks. Since schools cannot address
the needs of every job, general preparation followed by a certain degree
of specialization is recommended. If the demands of the environment and
the impending future have changed, then educators, too, must change if
they are to provide learners with those tools which may at some point,
if not immediately, prove useful. Analyzing the interdependencies and
relevancies of a wide array of subject matters would not be an easy task,
but survival never is. In addition, instructional researchers can
discontinue their search for the holy grail of education, significantly
improved learning, and begin improving schooling.

Schooling and training. An important distinction should be made at
this point between schooling and training. Schools provide the student
with the means to confront future demands and needs as they arise.
Training, on the other hand, deals primarily with satisfying immediate
requirements of an ongoing or existing system. Most of the instructional
activities in the Air Force are training oriented. Less emphasis is
placed on forming flexible, adaptive students than is normally found in
a classroom. Any other approach within the context of the military would
result in management and performance chaos. However, the training of
fighter pilots is unique because it must also concern itself with providing
the student special creative capabilities necessary for survival. The
principles cited earlier apply more patently to general schooling, but
the instruction of pilots in particular involves far more than usual
training, and consists of mastery of a group of simple and complex

psychomotor tasks. The skills of anticipation, quick judgment, and concentration are the mainstay of a fighter pilot's effectiveness, and these areas are dependent at least as much on intangible concepts as they are on trainable procedures. The military cannot apply the same instructional approach to certain aspects of fighter pilot training that they do to training a mechanic or gunner.

Algorithmic Instruction in Schooling and Training

In light of the foregoing discussion, the question remains: what value might algorithmic instruction have in training and schooling? It is apparent that standard research techniques on instructional effectiveness will yield little information. Past studies have demonstrated that algorithms can be excellent instructional tools which provide the user with a quick and easy means for solving a variety of problems (Schmid & Gerlach, 1977; Landa, 1974; Scandura, Durnin, Ehrenpreis, and Luger, 1971). However, there is no data showing that the use and retention of an algorithmic approach is superior to other strategies. Existing studies on algorithms have indicated that algorithms may be used as external storage devices and/or as processing techniques. Schmid and Gerlach (1977) have shown the effectiveness of algorithms as external storage devices. The lack of substantive data regarding their effect on learning per se suggests, however, that processing induced by algorithms differs little from other procedures. While there is no evidence that algorithmic instruction induces more effective learning, it does appear to differ from other teaching techniques in regard to efficiency. This advantage possibly stems from the algorithm's ability to enable the learner to organize and

transfer information in an explicit physical format (Schmid & Gerlach, 1977).
If in fact the organizational structure of algorithms increases the
efficiency of instruction, an effective byproduct may be that a greater
variety of learning experiences can be encountered by the student in the
same amount of time.

Even if algorithms fail to produce more efficient learning, they do
possess two additional structural characteristics which may affect the
instructional process external to cognitive acquisition. It has been noted
by Schmid and Gerlach (1977) that when designing an algorithm, the instructor
must consider every aspect of the learning sequence in order to insure
that the process yields a correct answer. The authors know of no other
instructional approach which provides this sort of guarantee. Most
learners' confusion can be traced either to inadequate learner preparation
or to incomplete or misorganized instruction (Landa, 1976). In the case
of algorithmic instruction, if the student fails to find a correct answer
or solution, a weakness in the algorithm is indicated and must be rectified.
Either the instruction was incorrectly formulated or the steps involved
were not sufficiently elementary for the student. This test of effectiveness
cannot be readily imposed on traditional methods of instruction, even
post hoc. Thus, given an accurate specification of the range, domain, and
user entry skills, algorithms must, by definition, provide the learner with
an adequate solution strategy.

To empirically demonstrate this characteristic resurfaces a point
made earlier regarding methodological considerations of instructional
research. Any test of an instructional innovation must be made against
a complete, well-constructed alternative format if the results are to

carry any logical weight. That is, instructional research cannot tolerate the type of comparison found in many verbal learning studies where processing theories are tested by minute performance or latency differences. It is not surprising that differences are seldom found when both methods of instruction are reliably "good". Algorithmic instruction therefore sets itself apart from other methods because to generate any self-respecting algorithm requires the kind of care which almost necessarily produces good instruction.

A second external organizational characteristic of algorithms is related to Landa's assertion that algorithmic instruction can be applied to a diverse range of problems. The definition of algorithms assumes that each operator or discriminator is unambiguous. However, algorithmic instruction is not limited to areas of study where unambiguous responses are always available. Landa (1976) discussed quasi-algorithms and the heuristic value of the algorithmic approach which deal with the organization of the information provided. In the case of heuristics, the decision space is adjusted to include the correct solution path; unlike a strict algorithm, a correct solution is not guaranteed. Within the domain of heuristics, Landa distinguished between problems which require the problem solver to choose from among prespecified alternatives or to search a field in which a solution might exist. In either case, heuristics, from a cybernetic approach, is best understood as process of incomplete algorithms. The user does not yet possess the information necessary to cast the problem into an algorithmic form. Often such information is simply not available. However, because training and schooling strive to lead the

student to some sort of solution, the relative accuracy of a solution, or its probability of correctness, can usually be assessed realistically when an algorithmic approach is employed.

Regarding the notion of heuristics, a clear difference also exists between schooling and training. Fortunately, training is usually algorithmic if the answer is guaranteed, or quasi-algorithmic if the range of alternative paths is finite and known. In quasi-algorithmic situations, known probabilities of each alternative usually lead the user to the correct solution, or when feasible, the solution is arrived at through a finite number of attempts. As the number of alternatives increases, the user may either attempt each path until the solution is found, or first narrow the choices by some decision-making strategy. The latter approach decreases the chance of finding the solution, but increases efficiency. Schooling differs from training because it contains a wider range of problems, often requiring the learner to generate an entire field of paths just to begin choosing from among them. Selecting from this ill-defined field constitutes the most difficult stage in the cognitive process of problem solving. In a sense, the learner does not even know where to begin. Clearly, a goal of education and training is to either eliminate this stage by supplying learners with many viable alternatives within a problem class, or to reduce the difficulty of this stage by providing them with selection strategies which effectively narrow or expand the field of choices for arriving at the correct solution. Logically, algorithms can assist in meeting this goal, and can therefore be applied to instruction of any level of complexity and abstractness.

The Study

As stated earlier, the primary aim of this study was to delineate some guiding principles for the design and implementation of algorithms in instruction. The three areas of concern we elected to address were those of (1) learners' prior knowledge or familiarity with the specific problem area, (2) transfer effects as manipulated by instructional format, and (3) the degree of retention over time.

The issue of learners' prior knowledge as a variable in learning has been studied by many researchers along a diverse range of learning tasks and theoretical notions. Ausubel (1968), Anderson and Bower (1973), Bransford and Johnson (1972), Paivio (1971), and Schmid (Note 1) have all examined prior knowledge in one form or other, and all agree that the degree of initial familiarity with the content of instruction has a strong positive relationship to amount learned. The first factor in the study therefore consisted of two algorithmic forms of the problem solution, identical in structure, but differing in the degree to which the learners would be familiar with the content questions. In order to accomplish this, the sequence of logic varied between the forms, one of which was assessed to be more familiar to the target population.

Because of the mathematical nature of the learning task (calculation of taxes), it was discovered that the content of the algorithm could be cast into an abstract form of equations, such as "Is $A > B$?" Indeed, protocols from earlier studies using the same materials (Schmid & Gerlach, 1977) contained unsolicited learner-generated strategies using this method. It was felt that this format would provide the learners with a condensed representation of the solution, and would be easier to remember than a

prose version. In addition, such abstractions are typically found in the instruction of mathematical problem-solving because of their power to enable the learner to generalize. The two familiarity levels were therefore duplicated in both prose and abstract forms, each form remaining mathematically equivalent.

The third factor under study was that of the amount of retention learners displayed over time. Both training and school environments are concerned with the degree to which students can retain and reproduce a given task after a period of time without intermittent rehearsal. Any instructor must also be concerned that a sufficient amount of time and effort be dedicated to the mastery of a task so that a high degree of proficiency can be maintained until the skill is no longer needed. The present study therefore employed both the normal immediate posttest and a one-week delayed test to assess both overall retention and the interactive effects of the various learning strategies over time. In line with the above comments on the use of comparative methods in studying instructional techniques, all three factors were viewed in the context of an absolute rather than a mere relative level of performance.

Method

Design and Subjects

Two factors, Algorithmic Sequence and Instructional Form were combined factorially to form four treatment groups. Test Interval was varied as a within-subject factor. The design was thus a two Sequence (*computational vs. logical*) x two Form (verbal vs. symbolic) x two Test

(immediate vs. delay) mixed model. A repeated measures multivariate analysis and a multivariate analysis on a practice section were employed.

The subjects consisted of 60 undergraduate volunteers from Arizona State University. Eight subjects were dropped from the experiment for failure to follow procedural instructions. Thirteen subjects failed to complete all parts of the study. The number of subjects per cell is included in Table 1, page 18.

Materials

The instructional task was adopted from the workbook Algorithms (Horabin & Lewis, 1974), and cast into four versions (Appendix A). All four versions contained the same number of discriminators and operators, with either two or three discriminations preceeding the single solution operator. The prose, or verbal, forms confronted the learner with the task of generating the solution to tax problems involving profit and loss on the sale of securities, given the purchase price, the selling price, the market value on April 15th, and expenses. The first version was identical to that used in Schmid & Gerlach (1977), which presented all information in a verbal flowchart. The aim of this version was purely computational, and followed the format of the corresponding tax law from which it was generated. The second version reassigned the questions of the discriminators to more closely match the logical questioning of the layman. For example, the first question in the computational version was, "Is the selling price greater than the April 15 value?" The logical version asked, "... did you make or lose money?" While both versions led to the same operators using the same discriminator format, the logical

format differed in its line of questioning. The logical version also allowed for a minimum of verbal explanation behind the questioning, but provided no additional benefits regarding mathematical computations. Six practice and six posttest problems were used (Schmid & Gerlach, 1977).

In order to test both the mathematical equivalence of the two forms and the instructional value of a symbolic representation in teaching computational problems of this sort, two additional versions were created. Each matched exactly the format of the corresponding verbal versions described above. The verbal discriminators and operators were replaced by alphabetic symbols and presented in identical flowchart graphics (Appendix A). No description of the tax problems was provided. Rather, subjects were given the practice problems with the same computational numbers used in the verbal treatments. For example, "C = $145" corresponded to "The Cost price of the stocks was...$145," or "E = $90" represented "Your Expenses on the Transaction were...$90."

The practice booklets consisted of a 400-word introduction informing the subjects as to the nature of the task and the procedure (Appendix B). The instructions specific to each treatment followed, containing the appropriate flowchart and an explanation of the type of problems to be solved. In all cases the instructions stressed that the learners must memorize the flowchart or computational procedure for solving the posttest problems. The verbal versions added a small amount of information specifically relevant to the tax problem. The symbolic groups were told only that the problems dealt with the buying and selling of unspecified items and that the symbols were to be used to arrive at numerical solutions.

All subjects received corrective feedback following each practice problem. Answers were supplied in separate answer booklets, consisting of a cover sheet of instructions, answers to each problem, and blank sheets interspaced between answers to prevent peeking or accidental exposure to the answer before the problem solution had been reached.

The posttest booklets included a cover sheet instructing the learners about the task, six additional randomly ordered problems of the same class as those in the verbal practice, and a questionnaire regarding the subject's previous experience with such tax problems and the strategies employed in solving them. The verbal instructions indicated that the problems would be conceptually identical to the practice problems. The symbolic group was introduced to the tax problem format with the same instructions given earlier for the corresponding tax problem items; subjects were told to utilize the mathematical format they had learned in exactly the same way. The symbols were matched with the appropriate application problem terms to avoid any confusion.

Each problem page for both the practice and posttest sections contained spaces in which subjects were instructed to write the starting and finishing times for work on the problem. The one-week-delay posttest utilized the same posttest which had been administered following the practice, again with the problems randomly ordered. Instructions on the cover sheet reminded subjects of the response format and asked them to again include the starting and finishing times in the spaces provided. The questionnaire following the delayed posttest asked whether the subject had expected a delayed test, again asked about response strategies, and

finally asked whether a sincere effort had been made to master the procedure needed to solve the problems. The workbook, including the instructions, procedure, and six practice problems, were presented on 8 1/2" x 11" paper, the answer forms in 8 1/2" x 3 2/3" booklets, and the posttest on 8 1/2" x 5 1/2" sheets.

Procedure. The initial experimental sequence consisted of (a) a practice session, (b) an immediate posttest, and (c) a questionnaire. Subjects were run in groups ranging from 11 to 36 students in their normal classroom. The materials for all treatments were enclosed in envelopes, shuffled, and distributed randomly to subjects after they were seated. The subjects were asked to follow silently, while the task orientation and procedural instructions printed on the first two pages of the workbook were read aloud. All questions were answered, and the subjects' attention was directed to the front board, where a proctor would be writing the elapsed time at 10 second intervals. They were told that the elapsed time was to be recorded at the start and finish of each problem of both the practice and test sections as stated in the instructions. The answer booklet instructions were next read aloud. If there were no further questions, the students were told to begin by acquainting themselves with the computational procedure specific to their condition, and then to continue working through the practice problems, all at their own pace. Although the materials were designed to be self-explanatory, subjects were also encouraged to ask questions during the study if they were confused. Instructions on the last page of the answer booklet directed the subjects to raise their hand. A proctor guided them to the posttest, and insured

that the subjects did not have the procedure available. The availability

of the flowchart was withdrawn for two reasons. This procedure eliminated

the possible confounding effect of one or the other formats being "easier"

to use in continued problem solving, i.e., the abstract format constituted

an abbreviated nomenclature, and thus could be employed without understanding

the transfer from an abstract sequence to applied problems. Second, the

design required a test of the learning effect of the abstract and prose

forms, which changed at the point of the immediate test to prose-type

problems only. Posttest completion and response to the questionnaire on

the last page of the posttest were self-paced. Subjects returned all

materials to the envelope and were excused.

The delayed posttest was given one week following the initial session,

and was administered in exactly the same manner as the immediate test.

The instructions were read aloud, and subjects worked through the six

posttest problems at their own pace, again recording elapsed times. Finally,

the second questionnaire appearing on the final page of the posttest was

completed. All groups were then informed about the purpose of the study.

Results

Achievement

All protocols were scored for number correct, with one point for the

dollar amount and one for the tax status (plus, minus, or zero). Omissions

were counted as errors. Means and standard deviations appear in Table 1.

A two Sequence x two Form multiple analysis of variance was first

performed on the practice data, producing no effects. A two Sequence x

Table 1

Means and Standard Deviations for Achievement Scores

			Sequence	
			Computational	Logical
Form				
Verbal	n = 8	Practice	$\overline{X}$ = 9.63 SD = 2.56	$\overline{X}$ = 9.56 SD = 2.19
		Immediate	$\overline{X}$ = 4.75 SD = 1.83	$\overline{X}$ = 5.44 SD = 2.07
	n = 9	Delay	$\overline{X}$ = 4.25 SD = 2.12	$\overline{X}$ = 4.22 SD = 1.99
Symbolic	n = 10	Practice	$\overline{X}$ = 8.70 SD = 3.68	$\overline{X}$ = 9.92 SD = 2.19
		Immediate	$\overline{X}$ = 3.50 SD = 2.64	$\overline{X}$ = 5.42 SD = 2.31
	n = 12	Delay	$\overline{X}$ = 2.40 SD = 1.43	$\overline{X}$ = 3.17 SD = 1.70

two Form x two Test repeated measures multiple analysis of variance was then performed on the immediate and delayed posttest data. The Form and Test main effects both reached significance, F (1,35) = 4.12, p <.05, and F (1,35) = 9.98, p < .003, respectively. The Sequence main effect reached marginal significance, F (1,35) = 3.20, p < .08. Analyses of interactions produced *no significant differences.*

Subjects who received the verbal instruction performed significantly better than the symbolic groups. Scores on the immediate posttest were higher than those on the posttest following a week's delay. Of particular interest was the marginally significant difference between Sequence treatments, where the logical group out-achieved the computational group. To *confirm the validity of the sequence effect,* a separate analysis of variance was completed on the immediate test only, as treatment differences tend to diminish over time and high subject attrition occurred over the delay. This procedure allowed the analysis of the scores of those subjects who failed to participate in the delayed test, thereby adding reliability to the test with a larger sample. In this analysis, the Sequence main *effect reached* the conventional level of significance, F (1,51) = 5.58, p < .02. Means and standard deviations for this analysis appear in Table 2.

Time

Time data were generated by computing the mean number of seconds taken per problem solution. Omitted problems were not included in the estimates. Means and standard deviations are listed in Table 3.

A two Sequence x two Form multiple analysis of variance was conducted on the practice session. As with the scores, no differences were found.

Table 2

Means and Standard Deviations for Practice and Immediate Achievement

Scores Only

Sequence

Form			Computational	Logical
Verbal	n = 13	Practice	$\overline{X}$ = 10.31 SD = 2.21	$\overline{X}$ = 10.08 SD = 2.11
		Immediate	$\overline{X}$ = 4.62 SD = 1.89	$\overline{X}$ = 6.00 SD = 2.22
			n = 12	
Symbolic	n = 14	Practice	$\overline{X}$ = 9.21 SD = 3.31	$\overline{X}$ = 10.14 SD = 2.11
		Immediate	$\overline{X}$ = 3.71 SD = 2.43	$\overline{X}$ = 5.71 SD = 2.33
			n = 14	

Table 3

Means and Standard Deviations for Time Measures
in Seconds

			Sequence		
			Computational		Logical
Form		Practice	$\overline{X} = 152.00$		$\overline{X} = 146.56$
			$SD = 43.02$		$SD = 36.20$
Verbal	$n = 8$	Immediate	$\overline{X} = 72.75$	$n = 9$	$\overline{X} = 60.89$
			$SD = 11.08$		$SD = 13.61$
		Delay	$\overline{X} = 54.00$		$\overline{X} = 38.00$
			$SD = 13.48$		$SD = 11.30$
		Practice	$\overline{X} = 123.60$		$\overline{X} = 132.83$
			$SD = 35.38$		$SD = 56.17$
Symbolic	$n = 10$	Immediate	$\overline{X} = 88.60$	$n = 12$	$\overline{X} = 76.58$
			$SD = 28.02$		$SD = 25.52$
		Delay	$\overline{X} = 54.44$		$\overline{X} = 49.42$
			$SD = 19.64$		$SD = 23.89$

A repeated measures two Sequence x two Form x two Test multivariate analysis was then performed on the immediate and delayed posttest data. All three main effects reached significance, Sequence, F (1,35) = 4.18, p < .05, Form, F (1,35) = 4.17, p < .04, and Test, F (1,35) = 47.19, p < .001. No interactive comparisons were statistically different.

Learners using the Logical Sequence and the groups using the Verbal Form completed the problems more efficiently. The amount of time spent on the delayed posttest problems was far less than completion times on the immediate test.

The correlation between the amount of time spent on the test items and achievement was low, r = .126.

Discussion

The learning curve demonstrated by subjects during the practice and acquisition session of the present study was similar to that found by Schmid and Gerlach (1977). That is, while the learners' initial ability to accurately solve problems using an algorithmic flowchart began at only about 20%, after six trials nearly 100% effectiveness was obtained in all groups. The significant decrease in performance when the flowchart was withheld for subsequent testing was also replicated. Despite the decrease, the flowchart was withheld to enable us to attribute performance differences to the instructional treatments rather than to the potential differential usefulness of the physical presence of the flowchart.

The overall familiarity of content sequence was found to be a significant factor in the acquisition of the solution procedure. Although

there were no group differences between the computational and logical
versions during the practice session, performance on the immediate posttest
was higher for the logical format. While the effect appeard to
lose potency over the delay period, marginal significance was attained
even with the subject attrition. Learners were apparently able to retain
more of the algorithm when its line of questioning could be better
associated with their own prior knowledge. Somewhat unexpectedly, this
effect held up even when the entire procedure was initially learned in
the abstract. It is conjectured that subjects were better able to
accomodate the separate computational and application tasks: that is, when
the acquired procedure was cast into the context of the tax problem, a
more logical approach evolved from the familiar sequence, and was thus
more readily retained and effectively employed. The solutions were also
arrived at more efficiently when the familiar form was used. Thus, as
has been the case in cognitive research, content familiarity was found to
be an important variable in the learning of an algorithmic solution
procedure.

A general principle for the use of algorithms would therefore be to
select or create a procedure which matches the potential learners on the
basis of both process (logic) and terminology. While learners may be
able to effectively use an algorithm somewhat unrelated to their previous
experience (thus technically meet the necessity of prerequisite entry skills),
more efficient and effective learning will occur when the procedure is
as familiar as possible. This finding is of particular practical significance
because of the little known fact that most algorithmically definable tasks
can be ordered or sequenced in a variety of ways and still retain resultivity.

For example, Gerlach, Reiser, and Brecke (1975) developed three very different algorithmic versions of a single Euclidean problem-solving method. Given the choice, instructors should use the version which they feel would be best understood by their students. If the instructor must design an original algorithm, the learners' perspective should be kept foremost in mind. If the resultant procedure is not judged to be clear for the intended users, it is critical that designers realize that there is likely a more effective alternative version. They can then continue to work on making a "better" algorithm, while possibly retaining the other version(s) for future situations.

Algorithms can be designed to meet the needs of many learning and teaching situations and can be used on almost any learner population for a given unit of instruction. It is up to the teacher to use the most appropriate version. A side benefit of this characteristic is that by testing and validating algorithms within schools, industry, or the military, the results can be widely generalized and applied. Minor knowledge deficiencies of the learners can be addressed by the instructor, while the bulk of teaching will have been "automated". Instructors will then have more time to spend working on new areas of information or improving present methods with changes and more variety. In addition, they will have the opportunity to do more remedial work with slow learners. The resulting remedial work can itself be algorithmized and applied to future cases rather than starting from scratch each time. The algorithmic approach stresses the emphasis in education for more front-end work which anticipates and mediates, analogous to prevention rather than cure.

While the cure is more spectacular, prevention is more practical.

As a final note on the first principle, instructional designers will find the production of familiar algorithms most useful when applied to fairly stable fields of knowledge. Mathematics, language, history, elementary science, and specific psycho-motor skills are highly amenable to this approach because the level of familiarity is unlikely to change significantly over time, and can thus be used repeatedly. Algorithms are also invaluable, as mentioned above, for short-lived tasks which require extremely high resultivity, as in pilot training or industrial production. The a priori analysis virtually eliminates the possibility of providing "bad" instruction, a critical feature in circumstances where learners have no prior knowledge of the skill.

The second treatment factor, the use of the abstract format as a means of introducing an algorithmic procedure, was both less effective and less efficient in all posttest conditions. While subjects receiving the symbolic flowchart performed as well in the practice session as those receiving the verbal flowchart, they were either less able to retain the procedure or they found it difficult to translate the abstraction into an applicable context. Although the intervening instructions could be construed to have acted as an interpolated task, thus having a depressing effect on subsequent performance, two factors argue otherwise. First, the abstraction procedure accurately simulated a popular method of mathematics instruction, which is assumed to facilitate generalization of underlying operations. This method may be effective for the instruction of basic skills as adding or deriving square roots, but it appears from the results to be less functional when specific problem-solving tasks are to be learned, as is usually the

case with algorithmic skills or operations. Secondly, classical interpolated tasks act to divert the learners' attention to an unrelated topic so as to eliminate memory traces from short-term recall. The application of instructions would hardly fit into this mold. The learners were, rather, adding concrete modifiers to ambiguous terms and operations. Based on these data, algorithmic instruction should utilize the concrete referents applicable to the specific skill. Cognitive research in the domain of material meaningfulness and schema generation would support this inference (Johnson, 1973; Haviland & Clark, 1974). While this study gives only initial data regarding the effect of instructional form, learners seemed to have learned better from concrete examples to which they could attach operational procedures. The supposed benefit derived from an abbreviated aid may develop once the skill has been firmly rooted in a practical, familiar context. The instructional problems faced in military and industrial training seldom involve the use of such abstractions. However, instructional designers in schooling would be well advised to generate algorithms which work from the specific to the general. In cases where a concrete foundation is already established, such abstract algorithms may in fact be ideal instructional vehicles for further training development and transfer. Other studies are required to answer this question.

The third factor in the experiment, procedural retention, followed the same pattern found in earlier research (Schmid & Gerlach, 1977). While a statistically significant loss was observed over the time delay, absolute retention levels were somewhat stable. The counter effect to the loss in retention was the highly significant increase in problem-solving efficiency. Subjects solved the problems in the delayed posttest on the average 53%

faster than they did those in the immediate test. This increase in
efficiency was attributed to a possible combination of two factors. First,
learners may have lost some of the incentive to perform well and simply
spent less time on the delayed problems. If this were the case, they
still responded correctly at almost 75% of their immediate posttest
level. Second, subjects may have been able to respond quickly to the
problems they were able to solve, and could also quickly recognize those
that they couldn't solve, suggesting a high awareness of their own relevant
strengths and limitations. As a followup to these results, it was found
that 86% of the problems correctly answered were more "typical"; i.e., the
stock holder made money and had to pay taxes. Problems using operators
which involved the "market" value, a less familiar concept, were least
likely to be correct. Although the familiarity factors appears again to
have influenced the results, any effect of prior knowledge had to be based
on the process of learning during instruction: pilot data demonstrated
that subjects were unable to solve any problems without the flowchart.
Lastly, the algorithm's relative efficiency resurfaces the value of this
procedure as an instructional tool when confronted with the arguments of
Stevens as stated above.

In summary, the design of algorithms is enhanced when a familiar,
concrete format is employed. Learners also obviously perform better when
they are allowed to retain the physical flowchart. Under circumstances where
algorithm availability is limited, instruction should require the learner
to demonstrate mastery of the procedure in an environment realistic to
actual content use. When memorization is necessary, it is adviseable to
keep the algorithm short (or teach the algorithm in sections), and insure

that all parts (branches) are equally well learned. Given these conditions,
the procedure is likely to be well retained, especially in training situa-
tions where accuracy is imperative and tasks frequently performed.

Reference Note

1. Schmid, R.F. <u>Prior knowledge, content familiarity and the comprehension of natural prose.</u> Unpublished doctoral dissertation, Arizona State University, 1979.

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Appendix A

Instruction for Individual Treatments:

Verbal Computational   - A

Verbal Logical   - B

Symbolic Computational - C

Symbolic Logical   - D

In order to gain a better conceptual grasp of the following task, we have cast the procedure into the context of tax problems. Each problem assumes that you at one time bought, and have now sold shares of stock. Naturally, you will have to pay tax on the transaction, and the procedure below will enable you to calculate the tax. For each problem, we will give you the following information:

(a) the original cost of the shares
(b) the amount you received when you sold the shares
(c) your expenses in the transaction, and
(d) the stock's value on the most recent April 15th (tax deadline)

Keeping these figures in mind, carefully study the flowcharted law below.

```
                        ┌─────────────────┐
                        │ Is selling price│
                        │  greater than   │
                        │ April 15 value? │
                        └─────────────────┘
             YES                              NO
    ┌─────────────────┐              ┌─────────────────┐
    │ Is April 15     │              │ Is April 15     │
    │ value greater   │              │ value greater   │
    │ than cost price?│              │ than cost price?│
    └─────────────────┘              └─────────────────┘
  YES            NO                  YES              NO
          ┌─────────────────┐   ┌─────────────────┐
          │ Is selling price│   │ Is selling price│
          │  greater than   │   │  greater than   │
          │  cost price?    │   │  cost price?    │
          └─────────────────┘   └─────────────────┘
              YES    NO       YES         NO
```

Your taxable income increases (+) by the selling price less the April 15 value less expenses	Your taxable income increases (+) by the selling price less the cost price less expenses.	No change in taxable income.	Your taxable income decreases (-) by the cost price less the selling price plus expenses.	Your taxable income decreases (-) by the April 15 value less the selling price plus expenses

Please make special note of the fact that for each problem you solve, you must give two (2) answers: (1) the amount in dollars, and (2) whether this amount represents an increase (+) in taxable income or a decrease (-) in taxable income. If there is any change, a plus or minus sign must accompany each answer.

The order of tasks is as follows: (a) enter the starting time, (b) read any information provided, (c) solve the problem using the procedure, (d) enter the finishing time, (e) tear off the top sheets of the answer booklet and determine whether your answer is correct, and (f) turn to the next problem.

Now, tear this page from the booklet so that you can use the procedure in solving each problem. Then begin work on problem 1!
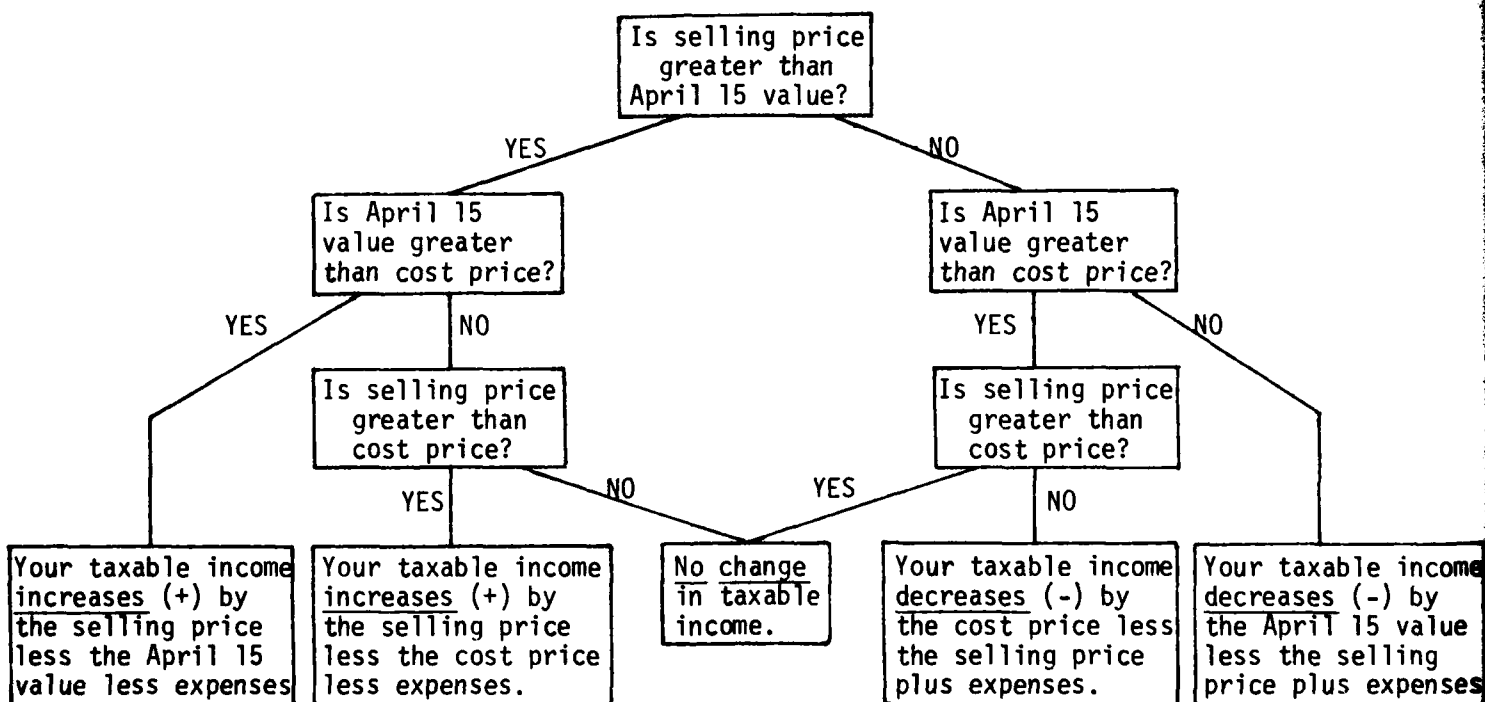
In order to gain a better conceptual grasp of the following task, we have cast the procedure into the context of tax problems. Each problem assumes that you at one time bought, and have now sold shares of stock. Naturally, you will have to pay tax on the transaction, and the procedure below will enable you to calculate the tax. For each problem, we will give you the following information:

(a) the original <u>cost</u> of the shares
(b) the amount you received when you <u>sold</u> the stock
(c) your <u>expenses</u> in the transaction, and
(d) the stock's value on the most recent <u>April 15</u>th (tax deadline)

Keeping these figures in mind, carefully study the flowcharted law below.

```
                    ┌──────────────────────────────┐
                    │ Considering only the cost and│
                    │ selling price of your stock, │
                    │  did you make or lose money? │
                    └──────────────────────────────┘
              MAKE  /                          \  LOSE
        ┌──────────────────────┐        ┌──────────────────────┐
        │ Would you have made  │        │ Would your losses    │
        │ even more had you    │        │ have been less had   │
        │ sold them at the     │        │ you sold them at the │
        │ April 15 value?      │        │ April 15 value?      │
        └──────────────────────┘        └──────────────────────┘
     YES /            NO \            YES |              NO \
```

Your profits were as high as the market allowed, so you want to minimize your taxes. Fortunately, the government allows you to subtract from the selling price either the cost price or the April 15 value, whichever is <u>larger</u>. Comparing one at a time, is the April 15 value <u>larger</u>?

YES   NO

Your losses were as high as possible, so you want to get the greatest deduction you can. Unfortunately, the government requires you to subtract the <u>selling price</u> from either the cost price or the April 15 value, whichever is <u>smaller</u>. Comparing one at a time, is the April 15 value <u>larger</u>?

YES   NO

| No change in taxable income. | Subtract <u>it</u> and your expenses from the selling price to get the <u>increase</u> (+) in taxable income from your profit. | Subtract the <u>cost price</u> and your expenses from the selling price to get the <u>increase</u> (+) in taxable income from your profit. | Subtract the selling price from the cost price and <u>add</u> your expenses to get the <u>decrease</u> (-) in taxable income from your loss. | Subtract the selling price from the April 15 value and <u>add</u> your expenses to get the <u>decrease</u> (-) in taxable income from your loss. | No change in taxable income. |

Please make special note of the fact that for each problem you solve, you must give two (2) answers: (1) the amount in dollars, and (2) whether this amount represents an <u>increase (+)</u> in taxable income or a <u>decrease (-)</u> in taxable income. If there is any change, a plus or minus sign must accompany each answer.

The order of tasks is as follows: (a) enter the starting time, (b) read any information provided, (c) solve the problem using this procedure, (d) enter the finishing time, (e) tear off the top sheets of the answer booklet and determine whether your answer is correct, and (f) turn to the next problem.
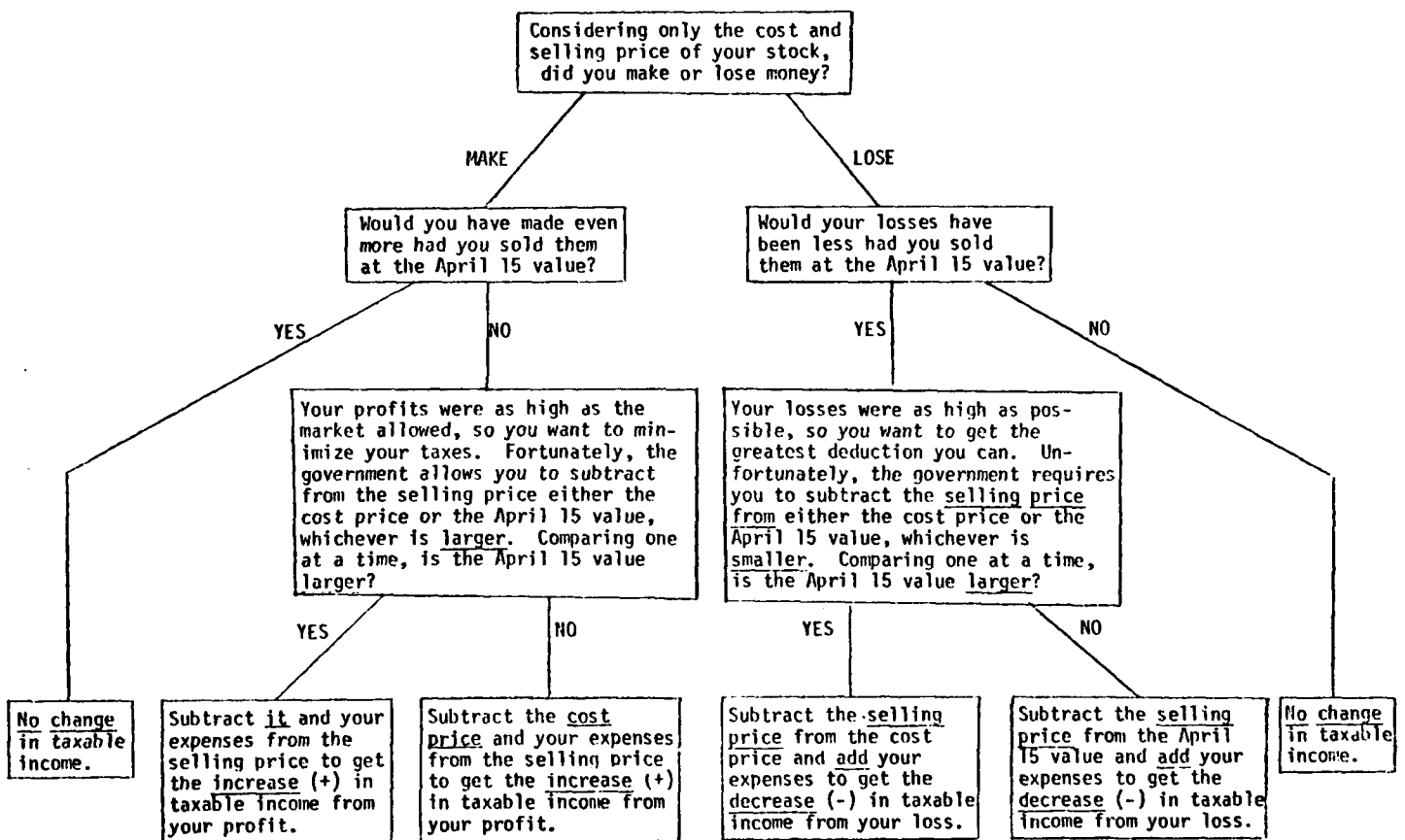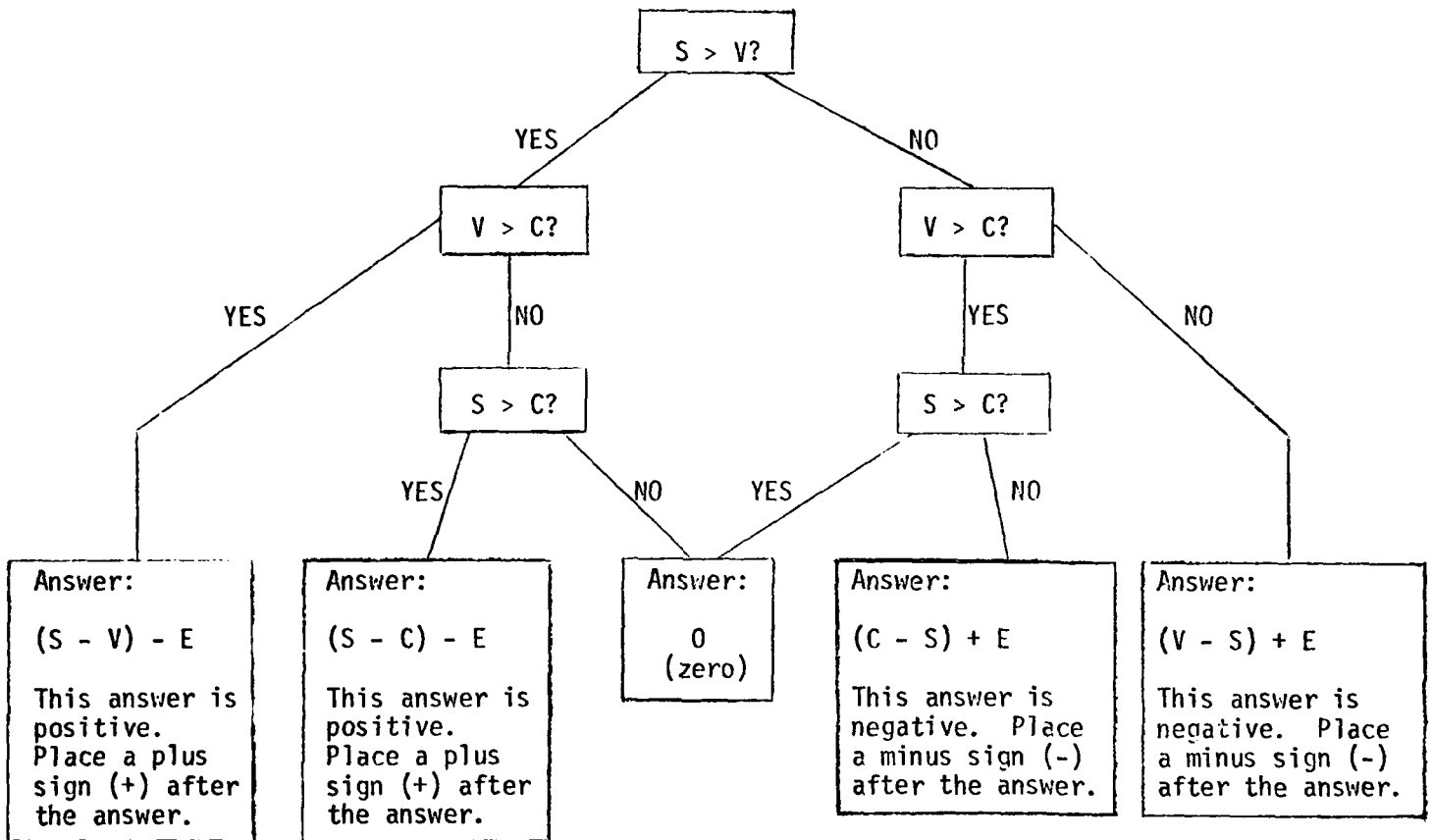
Now, <u>tear this page</u> from the booklet so that you can use the procedure in solving each problem. Then begin work on problem 1!

The chart below is a representation of the procedure you are to use in determining the outcome of the sale of each item. We want you to learn a _procedure_, rather than a specific method for solving one type of problem. Therefore, the values have been placed in the abstract using only symbols. To solve each problem, simply substitute the value for the symbol and follow the flowchart for computing the answer. For each problem, we will give you the following information:

    (a) the original cost of the item (C)
    (b) the amount you received when you sold the item (S)
    (c) your expenses in the transaction (E), and
    (d) the item's value on an earlier date when you _could_ have
          sold it (V).

Keeping these figures in mind, carefully study the flowcharted procedure.

```
                              S > V?
                    YES                    NO
              V > C?                          V > C?
        YES          NO                  YES          NO
                  S > C?                  S > C?
               YES     NO              YES     NO

  Answer:      Answer:    Answer:    Answer:      Answer:
  (S - V) - E  (S - C) - E    0      (C - S) + E  (V - S) + E
                             (zero)
  This answer  This answer          This answer  This answer
  is positive. is positive.         is negative. is negative.
  Place a plus Place a plus         Place        Place
  sign (+)after sign (+) after      a minus sign a minus sign
  the answer.  the answer.          (-) after    (-) after
                                    the answer.  the answer.
```

Please note that according to the procedure, each problem will have one of three possible outcomes: (a) the answer will be positive (+), (b) the answer will be negative (-), or (c) the answer is zero. Be sure your answer to each problem includes either the plus or minus sign if the result isn't zero.
    The order of tasks is as follows: (a) enter the starting time, (b) read any information provided, (c) solve the problem using the procedure, (d) enter the finishing time, (e) tear off the top sheets of the answer booklet and determine whether your answer was correct, and (f) turn to the next problem.

    Now, _tear_ _this_ _page_ from the booklet so that you can use the procedure in solving each problem. Then begin work on problem 1.
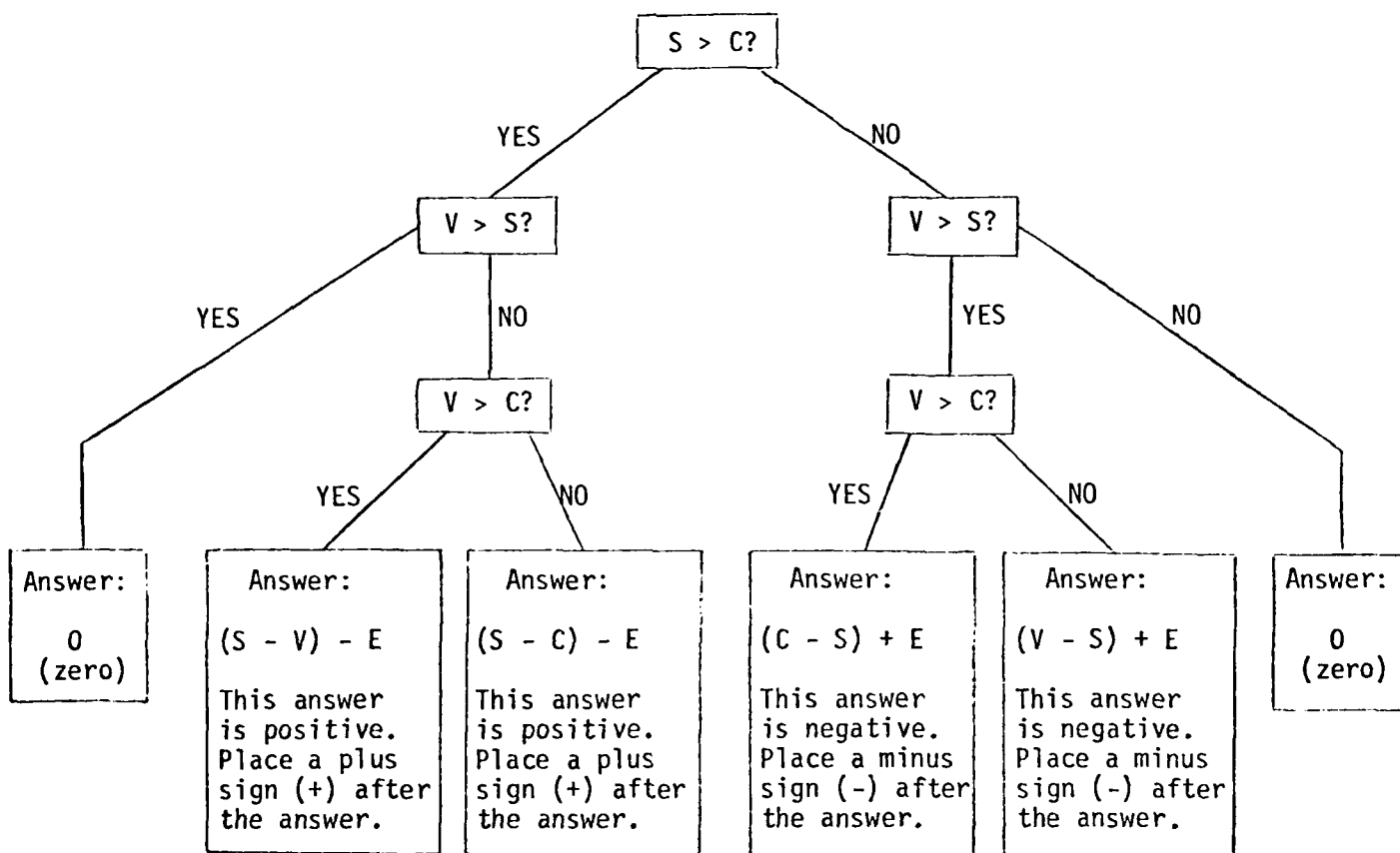
Tear here

The chart below is a representation of the procedure you are to use in determining the outcome of the sale of each item. We want you to learn a procedure, rather than a specific method for solving one type of problem. Therefore, the values have been placed in the abstract using only symbols. To solve each problem, simply substitute the value for the symbol and follow the flowchart for computing the answer. For each problem, we will give you the following information:

(a) the original cost of the item (C)
(b) the amount you received when you sold the item (S)
(c) your expenses in the transaction (E), and
(d) the item's value on an earlier date when you could have sold it (V).

Keeping these figures in mind, carefully study the flowcharted procedure.

Please note that according to the procedure, each problem will have one of three possible outcomes: (a) the answer will be positive (+), (b) the answer will be negative (-), or (c) the answer is zero. Be sure your answer to each problem includes either the plus or minus sign if the result isn't zero.

The order of tasks is as follows: (a) enter the starting time, (b) read any information provided, (c) solve the problem using the procedure, (d) enter the finishing time, (e) tear off the top sheets of the answer booklet and determine whether your answer was correct, and (f) turn to the next problem.

Now, tear this page from the booklet so that you can use the procedure in solving each problem. Then begin work on problem 1.

Appendix

B

Instructions

Posttest Instructions for the Verbal
Flowchart Treatments

A & B

POSTTEST (delay)   FO SO FL SL

NAME _____ # _____

The following test contains the same type of tax problem you solved during
the testing session last week. Please use the same format for responding:
that is -

The dollar amount <u>and</u> the plus (+) or minus (-)
sign, or <u>no</u> change (zero).

Be sure to include the starting and finishing times for every problem.
Although the amount of time is of interest to us, the accuracy of your answer
is most important. Again, no corrective feedback will be given.

<u>Please do your very best</u> to solve the problems. We realize that you may have
forgotten some, but as before, you will be surprised to see how much you
actually remember once you solve the problem. If you aren't sure of a response,
<u>guess</u>, even if it is only the dollar amount and/or the plus or minus sign.

THANK YOU AGAIN FOR YOUR EFFORT. NOW, TURN TO THE NEXT PAGE AND BEGIN.

Posttest Instructions for the Symbolic
Flowchart Treatments

C & D

FO SO FL SL

NAME _____ # _____   W WO

Now that you have learned the procedure in the abstract, we would like
to see how well you can apply it in a real-life problem situation. We have
cast the procedure into the context of tax problems. Each problem assumes
that you bought, and have now sold shares of stock. The unspecified item
in the practice problems can now be thought of as stocks. Naturally, when
such a transaction occurs, you will have to pay tax. By using the procedure
which you have already learned, you can solve this type of problem. For
each problem, we will give you the same information as before:

     (a) the original cost of the shares (C)
     (b) the amount you received when you sold the shares (S)
     (c) your expenses in the transaction (E), and
     (d) the stock's value on the most recent April 15th (tax deadline)
        (V)

TURN TO THE NEXT PAGE

Using the logic employed in solving the practice problems, work out the
test problems as tax computations. Please keep in mind that according to the
procedure, each problem has one of three possible outcomes: (a) the amount
is positive, which indicates an increase (+) in taxable income, (b) the amount
is negative, which indicates a decrease (-) in taxable income, or (c) the
amount is zero (0), which indicates no change in taxable income. Continue
to use the plus and minus sign as before.

Be sure to include the starting and finishing times for every problem.
Although the amount of time is of interest to us, the accuracy of your answer
is most important. No corrective feedback will be given in this section of
the study. Even though you will not be using the procedure, you will find
that you are able to solve the problems with great proficiency. If you are
not sure of an answer, please feel free to make an educated guess at either
the dollar amount, the plus or minus sign, or both. Please do your best!

When you have completed all the problems, follow the directions given
on the last page of the test booklet. (Double check to make sure you didn't
miss any problems. If you do, just write in the times and solve it, and we'll
figure the rest out.

Thank you for your effort!

TURN TO THE NEXT PAGE