DOCUMENT RESUME

ED 140 789 IR 004 830

AUTHOR Coscarelli, William C.
TITLE Inquiry in Development: Efficiency and Effectiveness of Algorithmic Representations in a Laboratory Stituation.
PUB DATE Apr 77
NOTE 34p.; Paper presented at the annual meeting of the Association for Educational Communications and Technology (Miami, Florida, April 25-29,1977)

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Algorithms; *Chemistry Instruction; Critical Thinking; *Educational Research; Flow Charts; *Instructional Design; Laboratory Training; *Teaching Methods; Time Factors (Learning)
IDENTIFIERS Watson Glaser Critical Thinking Appraisal

ABSTRACT

This study, part of an instructional development project, explores the effects of three different representations of functional algorithms in an introductory chemistry laboratory. Intact classes were randomly assigned to a flowchart, list, or standard prose representation of the procedures (algorithms). At the completion of 11 laboratory sessions, data were collected on critical thinking ability as measured by the Watson-Glaser Critical Thinking Appraisal. Laboratory instructors' estimates of completion time for each lab were obtained. Analysis indicates that mode of representation produces no significant difference between groups on critical thinking ability. However, a differential effect in laboratory completion times was found. Appended is a sample of each type of functional algorithm employed. (STS)

INQUIRY IN DEVELOPMENT:

Efficiency and effectiveness of algorithmic representations in a laboratory situation

William C. Coscarelli, Project Director
Division of Development and Special Projects
Audio-Visual Center, Indiana University
Bloomington, Indiana 47401

ABSTRACT

As developers we often find ourselves shifting from one role to another throughout the scope of a project. At first, constrained by real world limitations we seek strategies that improve precision in our work. Later, we may wonder why certain strategies are more effective and explore these questions. It is not a matter of which is better -- prediction or understanding -- for these are separate and distinct issues and should be judged accordingly. This paper primarily addresses the praxiological question, a question of alternatives (which?) rather than the theoretical or scientific question (why?). Yet, in a serendipitous way those questions of alternatives may lead to statements of understanding. We often hope they do, but we will not have failed if they do not.

This study explored the effects of three different representations of functional algorithms in an introductory chemistry laboratory. Intact classes were randomly assigned to a flowchart, list, or standard prose representation of the procedures (algorithms). At the completion of 11 laboratory sessions data were collected on critical thinking ability as measured by the Watson-Glaser Critical Thinking Appraisal. Additionally, laboratory instructors' estimates of completion time for each lab were obtained. Analysis indicates that mode of representation produces no significant difference between groups on critical thinking ability. However, a differential effect in laboratory completion times was found.

Paper presented at the Annual Meeting,
Association for Educational Communications and Technology,
Miami, Florida, April 25-29, 1977

TABLE OF CONTENTS

INQUIRY IN DEVELOPMENT:

Efficiency and effectiveness of algorithmic representations in a laboratory situation

William C. Coscarelli

BACKGROUND OF THE DEVELOPMENT PROJECT

In the fall of 1974, a single and separate two-credit chemistry laboratory course was created at Indiana University for students taking one of two possible lecture courses, Chemistry 100 or Chemistry 101. Chemistry 100 is a one-semester terminal course designed primarily for students majoring in liberal arts, business, or education. In the first third of the course, basic topics such as atomic theory, bonding, and three-dimensional molecular structure are discussed. The middle third deals with large molecules and biological chemistry. The final third examines topics of contemporary interest including drugs, food additives, pollution, etc. Little, if any mathematics is used in this course. Chemistry 101, is the first semester of a two-semester sequence designed for non-science majors and those in various allied health fields who do not need more than two semesters of chemistry. In this course, the basics of atomic theory, bonding structure, etc., are studied in more detail. Additionally, mole calculations, the gas laws, chemical equilibrium, chemical reactivity, oxidation-reduction, isomerism, and introductory organic chemistry are presented. There is no chemistry prerequisite for C100, C101, or the laboratory course. Despite the differences in the needs and backgrounds of students enrolled in C100 and C101, a laboratory course had to be designed which would serve both groups. These differences in course content and emphasis do quite clearly produce students having different backgrounds of chemical knowledge. Since no one background can be assumed, the laboratory course has to provide any information necessary for the successful completion of an experiment. During the fall semester of 1974, the course was presented in a rather traditional format and the problems with this approach became evident. In the Spring semester of 1975, a concerted effort was made to develop the course with the assistance of the Division of Development and Special Projects at Indiana University.

FINAL PRODUCT OF THE PROJECT

a. Components

From the results of a student questionnaire and a knowledge of the level of performance which the students had achieved (as assessed from the results of various exams conducted throughout the semester), a basic instructional format was designed and applied to each of the experiments and study exercises used throughout the course. Each laboratory experiment or exercise was presented in a Learning Activity Package (LAP) form. These packages contain seven components and range in length from 13 to 41, single-spaced typewritten pages. The sections are described as follows: (1) Introduction: Each experiment is introduced by describing the nature of the problem to be investigated.
(2) Objectives: A detailed list of objectives is provided and divided into three sections: (a) Entry behaviors (those tasks which the students are expected to be able to perform before they begin the experiment), (b) procedures (those tasks which pertain to procedural aspects), and (c) instruction and results (those

tasks which deal with background material, calculations, interpretation of results, etc.). (3) Instruction: A discussion of the principles, calculations, etc., which are involved with the experiment is provided. Often, more than one type of instructional approach, such as prose, programmed instruction, practice problems in the text, is used in this section. The physical length and complexity of this material varies from one experiment to another. (4) Procedures: A detailed discussion of the nature of the procedures section is provided below. (5) Data and Report Sheets: These are sections in which data are recorded, results are calculated, and interpretations and conclusions are made. (6) Advanced Study Assignments: Exercises are specially designed to prepare students for the experiment by covering background material as well as experimental methods whenever necessary. Completion of the Advanced Study Assignment ensures that the student will be familiar with the experiment. Consequently, the student will not have to spend any laboratory time getting organized. (7) Practice Post Test: This consists of a series of questions designed to allow the student to evaluate his progress in learning and applying the principles in the experiment. Answers are provided, the material in the instruction section and the questions in the advanced study assignment and practice post test are keyed by number to the objectives.

b. Measurement of Student Performance

Evaluation of student performance is made in several ways during the course of the semester. (1) A pretest over various arithmetic skills is given at the beginning of the semester.

From the results of this test, students are advised to complete various remedial exercises. (2) Advanced study assignments and reports are graded weekly. Students can follow their progress and determine their areas of weakness. (3) Practice post tests included with the lab material are used by the student himself for his own evaluation. They provide immediate feedback. (4) Four examinations are given during the course. The first is a short exam whose purpose is to acquaint students with the type of test items and to show them how exam questions cover the objectives. The other three are full-length exams which include questions at the knowledge level, questions which require application of principles, and questions which require analysis of information or synthesis of ideas. Laboratory work constitutes 70 percent of the student's grade, while exams total 30 percent.

c. Algorithmization of Procedures

The general package as described above, seemed quite capable of dealing with many of the problems which the students faced. It did not, however, address the problem of student anxiety and lack of confidence. The students are limited to two hours per laboratory session. In order to collect the quantity of information required to make observations, to perform calculations, and to reach conclusions in an experiment, the student must complete his procedure and he must believe that his information is correct and complete. Students enrolled in this course generally lack experience in a laboratory and experimental situation. They are also unfamiliar with the practice of organizing themselves so that tasks can be completed in a reasonable period of time. These factors combine to cause uncertainty, anxiety, and a certain number of errors. In order to alleviate these problems and to insure early success and self-confidence, the procedures or algorithms were presented in a flowchart form. These flowcharts served various purposes: (1) To simplify otherwise complicated procedures; (2) To make procedures more organized and efficient, especially when several steps in one section of a procedure are repeated over and over; (3) To reduce procedures to a series of short steps, so that attention is focused on one aspect at a time; (4) To ask questions, and require that decisions be made at any appropriate times during the procedure. An example of a flowchart appears in Appendix I. This algorithm was designed for a portion of a qualitative analysis experiment in which a mixture is being tested for chloride and iodide ions. Since these ions interfere with each other, a separation procedure is required, making the analysis relatively complicated.

A FRAMEWORK FOR THE PROBLEM

a. Definitions

Each laboratory procedure the student performs is a sequence of operations that leads to the solution of a problem, in short, an algorithm.[1] In addition, these operations or algorithms

---

[1]Landa defined the algorithm as a "precise, generally comprehensible prescription for carrying out a defined sequence of elementary operations in order to solve any problem belonging to a certain class." The algorithm has three characteristics:

1) Specificity--direct instructions that preclude chance components in the choice of actions.
2) Generality--any member belonging to the defined class can be substituted.
3) Resultivity--the same result is always produced in the presence of the appropriate data set.

Others (Brecke, 1975; Merrill, 1975; Gerlach, et al, 1975) have adopted similar definitions.

maintain different levels of control with respect to a given task.

Viewed from the point of intended goals there are two types of algorithms: algorithms of transformation and algorithms of identification. The algorithm of identification produces a judgment of the initial objects' belonging to a certain class, e.g., identifying the ions in a solution. The algorithm of transformation produces a change of state in the initial object, e.g., combining hydrogen and oxygen to form water.

Viewed from the point of control there are also two types of algorithms. A functional algorithm exists when no other control of the system is necessary by additional systems. A controlling algorithm exists to provide a functional algorithm with a set of procedures for coping with unspecified (by the functioning algorithm) circumstances, e.g., if a student is using a functional algorithm to identify the ions in a solution and notes a reaction occurring that is not in the procedures, he can turn to another set of procedures or his teacher to provide the procedures for coping with this unexpected circumstance. The procedure he turns to, either in another book or through the teacher, is the controlling algorithm. It should be noted that the concepts of "functional" and "controlling" algorithms are relative. A system that controls a functional algorithm may be functional itself, requiring assistance from another algorithm in the event of a circumstance occurring that it is not equipped to handle.

Table 1 illustrates the relationship between the goal of the algorithm and the level of control exercised by the algorithm.

		Level of Control	
		Functional	Controlling
Goal	Identification		
	Transformation		

Table 1

Given that we have determined that a problem a student is facing can be solved via an algorithm we can develop approaches to teaching these algorithms. Whether we wish to teach an algorithm of addition, ion identification, or sentence classification, we can choose from five basic techniques (as outlined by Landa):

(1) Teach the algorithm of solution--We can provide the student with the algorithm to solve the problem. This would entail description of steps and decision points with alternative courses of action outlined.

(2) Teach a search algorithm to identify other algorithms--All possible operations and their sequences are given to the student without explaining the algorithm of solution, e.g., try switch 'a' and 'b'; if 'x' happens then do 'y.' If not, try 'z,' etc. In carrying out these operations the algorithm of solution is discovered.

(3) Teach general methods of searching which are non-algorithmic in nature--The algorithm is neither explained or provided. The student is given instructions that could lead to the discovery of the algorithm, e.g., "try

different sequences," "identify the parts." This approach leaves open the possibility of not discovering the algorithm.

(4) Teach separate rules of action--Teach the rules that apply to the situation, without any specific order, e.g., "turn knob A," "move bishop on the diagonal."

(5) Don't explain the algorithm or rules--This implies a structured environment to allow the student a chance to carry out search trials.

These five categories identify the possible alternatives available to the instructional developer in specifying instructional strategies utilizing an algorithmic approach. One suspects that certain strategies are more effective and/or efficient under certain conditions, e.g., situations placing a premium on time to completion and low error rate for a task would most likely require the teaching of an algorithm of solution.

For the developer, acting as inquirer, these categories represent the nucleus of a concentrated research effort in identifying optimum strategies for tasks given real world constraints, e.g., "low error rate," "learn search strategies." Indeed, the focus of the present study is to examine some of the effects of presenting an algorithm of solution to the learner.

Because we were dealing with a relatively naive population (at least in chemistry knowledge) with a high anxiety level and because we did not have a large amount of time available for each lab we placed a premium on a strategy that would reduce error rates and increase efficiency. Additionally, we decided that until the students were more sophisticated we should provide them with the algorithm of solution for each problem rather than attempt to have them derive the appropriate algorithm. (In our laboratory situation we were presenting functional algorithms of identification and transformation.)

Initially we chose to use flowcharts to represent the algorithms. As Lewis et al (1), note:

> "Flowcharts have compelling advantages over their prose counterparts. From the user's point of view, they simplify the reasoning process in several ways. Instead of leaving him to find his own way through a mass of tiresome prose, they present him with a minimum sequence of simple (yes/no) questions. Moreover, each question is unambiguous and relevant...There is never any need for the user to wonder if the sentence (or question) he is reading is relevant to his own case. And there is never any need for him to wonder what he should consider next, because each answer automatically routes him to the next relevant question."

Finally, Lewis, et al (2), have demonstrated the advantage of flowcharts in decreasing task completion time and decreasing error rates.

b. Alternative Representations

Just as there are more ways than one to skin a cat, there are more ways than one to represent an algorithm. Each representation can vary in terms of readibility, structural clarity, effort required to produce copy, and space required for printing (3).

Classically, standard prose has been the method of representing an algorithm in the laboratory situation. However, written instructions are often presented in ways that are difficult to understand (3, 4, 5). Prose instructions require the reader to process all information regardless of relevance to the task. This alone could lead to confusion and an improper solution to the task; especially when the task itself is fairly complex. Furthermore, this complexity can be compounded through the grammatical structure of the prose. As a result prose should probably be restricted to situations in which procedures or instructions are short, have a minimum of interactions and qualifications, and can be presented in positive, active, and affirmative sentences (6).

Another alternative representation for an algorithm is the list form. This representation is closely related to the flowchart form. The list form replaces the graphic characteristic of the flowchart with prose. Discrete decision points with alternative tasks are identified through reference to numbered statements. So too, the reader has only to read what is relevant to his specific task rather than the sum total of information that would need to be read in a prose situation.

Other types of representations: coded graphics, decision tables, and linear listing (7) have their own unique characteristics but are not particularly appropriate for use in this laboratory situation. Coded graphs and linear lists would probably require more skill to use than other representations and could become an obstacle to the student rather than a help. Decision tables are more properly used in situations requiring identification of particular conditions--they cannot represent the appropriate sequence of tasks which must be performed over a period of time as is the case with laboratory procedures.

As a result of these considerations one could conclude that procedural algorithms in the laboratory could best be represented in prose, flowchart, or list form. Appendix I contains an example of each of these representations.

c. Possible Cosequences

Because each representation has its own unique characteristics one might suspect that use of a given representation would have specific consequences on the manner in which a problem is resolved Research to date in the use of algorithmic representations has generally been limited to an examination of the efficiency of the algorithm in completing a procedural task as well as decreasing error rates (8). Only recently has an attempt been made to assess higher order effects of these "ready-made algorithmic prescriptions."

Coscarelli, Visscher, and Schwen (9) discovered that critical thinking ability was developed by presenting an algorithm to the student in a flowchart representation. While there exists no generally accepted explanation for this phenomenon it is possible that the mode of representation (in this case, a flowchart) provides the learner with a generalized model with which to approach problem solving. Carpenter in Solomon (10) observed that media are not simply envelopes into which letters of various kinds can be slipped. The medium itself may be a message with a code and grammar of its own. Soloman has also suggested that media can affect cognition much as language can structure thought. Consequently, the manner of representation could have a serendipitous side-effect, that of increasing overall problem solving skills.

PURPOSE OF THE STUDY

The purpose of the present study will be to explore, in a chemistry laboratory situation, the effect of different representations of functional algorithms on critical thinking ability and laboratory efficiency.

a. Statement of the Problem

As we have seen earlier, each representation of an algorithm has its own particular characteristics. Furthermore, there seems to be some evidence that these representations can affect the efficiency with which a task is completed as well as modify cognitive skills. As a result we are posing two researchable questions in relation to the use of flowchart, list form, and prose representations of an algorithmic process.

b. Researchable Questions

(1) Will the type of representation affect the time necessary to complete a procedure?

(2) Will the type of representation affect critical thinking ability as measured on a standardized test of critical thinking?

c. Independent Variables

The independent variable will be the manner of representation of the algorithms. The variable will have three values. These are based on a systematic variation of three rules for representation, i.e., each statement in the algorithm provides information critical to performing each step in the procedure, statements may contain one or more than one task, decision points may be represented via flowchart symbols, referral to numbered statements, or standard prose.

As an algorithm defines each step of a procedure and accounts for any possible occurrence, e.g., "if a precipitate occurs, add 2 ml. of $NaNO_3$; if no precipitate occurs, centrifuge the solution;" the representations will vary the characteristics of the manner in which each step is presented to the student. Each step in the representations will contain only information necessary for the completion of one task, e.g., "add 1 ml. of H_2O to the testtube." For the flowchart and list form representation each statement will contain only one task. (A statement is defined as the basic unit of representation. For the flowchart this will be the area in a box, for the rule-set a numbered command, and for the standard prose representation this will be a sentence.) The standard prose representation will often have more than one task in a unit, e.g., "After you have added 1 ml. of H_2O to the testtube, stir and filter the solution."

The three values of the independent variable are :FLOWCHART REPRESENTATION (Group I)

(1) Each statement contains only one task.

(2) At decision points alternatives are indicated graphically in accordance with IOS Standard 102[8]--"Information Processing-Flowchart Symbols."

LIST FORM REPRESENTATION (Group II)

(1) Each statement contains only one task.

(2) At decision points alternatives are indicated through referral to numbered statements.

(NB: It is the difference between Groups I and II that is of major interest. These groups vary only one way--the representation of the decision points and the alternatives.)

STANDARD LABORATORY REPRESENTATION (Group III)

(1) Each statement may contain more than one task.

(2) At decision points alternatives are indicated through unnumbered statements.

Table 2 summarizes the variations between groups.

RULE \ GROUP	I	II	III
1. CRITICAL TO TASK	X	X	X
2. ONLY ONE TASK	X	X	0
3. FLOWCHART REPRESENTATION	X	0	0

TABLE 2

d. Dependent Variables

There are two dependent variables in the present study: score on the Watson-Glaser Critical Thinking Appraisal (W-G) and time spent in performing the laboratory exercise.

The degree of skill in critical thinking ability will be defined in terms of the score on the W-G. Watson and Glaser (1964) concluded that critical thinking can be viewed as a "composite of attitudes, knowledge, and skills." This composite includes:

(1) Attitudes of inquiry that involve an ability to recognize the existence of problems and an acceptance of the general need for evidence in support of what is asserted to be true.

(2) Knowledge of the nature of valid inferences, abstractions, and generalizations in which the weight or accuracy of different kinds of evidence are logically determined.

(3) Skills in employing and applying the above attitudes and knowledge. More specifically, a person with a high degree of critical thinking skills would be able to do the following:

(1) Define a problem.

(2) Select pertinent information for the solution of a problem.

(3) Recognize stated and unstated assumptions.

(4) Formulate and select relevant and promising hypotheses.

(5) Draw valid conclusions and judge the validity of inferences. (Dressel and Mayhew, 1954)

Independent studies (Houle, 1943; Morse and McCune, 1957; Hovland, 1959; Rust, 1960, 1962) have verfied the construct validity of the W-G as a measure of critical thinking. Watson and Glaser (1964) report a split-half reliability coefficient corrected by the Spearman-Brown formula of .85 for liberal arts freshmen.

The time spent in performing the laboratory exercise was measured by the two lab instructors in each lab. They were asked to estimate the average time spent by the students in completing each lab exercise.

e. Design

The present study is a pretest-posttest design. Table 3 illustrates this design.

R	0	X_1	0
R	0	X_2	0
R	0	X_3	0

TABLE 3

f. Instrumentation

1. independent variables

For each of the values of the independent variable three representation schemes were devised in accordance with the rules specified for each value. Appendix I lists an example of flow-chart, rule-set, and standard laboratory representations.

2. dependent variables

The measure for critical thinking skill was a single score on the W-G. The measure for time spent in performing the lab exercise was a primarily subjective estimate made by the laboratory instructors.

g. Sample

Approximately 190 students in an introductory laboratory chemistry course at Indiana University-Bloomington served as respondents in the experiment. Ten intact classes were randomly assigned to one of the three treatment groups. This produced a nested design with classes nested under treatment. Four classes totaling 82 students used the flowchart representation, 3 classes totaling 56 students used the list-form, and 3 classes totaling 52 students received the standard prose representation.

h. Procedures

Previous to the first laboratory session students were instructed to purchase a particular color coded lab manual. The use of this coding procedure allowed the experimenter to assure that there was no intermixing of representations in a given laboratory session.

All students were given the W-G during the first week of classes before instruction had begun. At the end of 11 lab sessions the W-G was administered. Alternate forms of the W-G were randomly assigned to treatment groups in the pretest situation and then reversed for posttesting. It was felt that this would help control for practice effects that might occur if the same forms were used for both administrations. Additionally, both forms were used on the pretest to help assess differences attributable to each form. (It was found that the scores differed in accordance with published standards and were properly equated in all analyses.) In addition, estimates of completion time were collected from the lab instructors.

RESULTS

As was noted earlier the selection and assignment of intact classes produced a nested design. Ideally one would begin the analysis using an analysis of covariance (ANCOVA) with a nested design. However, due to time limitations and the general lack of an acceptable computer program, the SPSS ANCOVA program, which does not provide for a nested design, was run to determine the effects of mode of representation on critical thinking ability. (It should be noted that a series of one-way analyses of variance were performed to determine that all treatment groups were not significantly different on the pretest.) The ANCOVA procedure was selected to provide additional precision in estimating the effect of the treatments by controlling for critical thinking ability as assessed by the pretest.[2]

---

[2]The correlation between pre and post critical thinking scores was approximately .48.

a. Effect of Representation on Critical Thinking Ability

The results of the ANCOVA procedure are reported in table 4.

SOURCE	SUM OF SQUARES	df	MEAN SQUARE	F	SIGNIFICANCE OF F
COVARIATE PRETEST	4402.674	1	4402.674	58.323	.001
MAIN EFFECTS REPRESENTATIONS	25.929	2	12.964	.172	.842
EXPLAINED	4403.982	3	1467.994	19.447	.001
RESIDUAL	14040.734	186	75.488		
TOTAL	18444.716	189	97.591		

TABLE 4

b. Effect of Representation on Completion Time

The results of the various representations on completion time are found in Figure 1.

INSERT FIGURE 1 ABOUT HERE

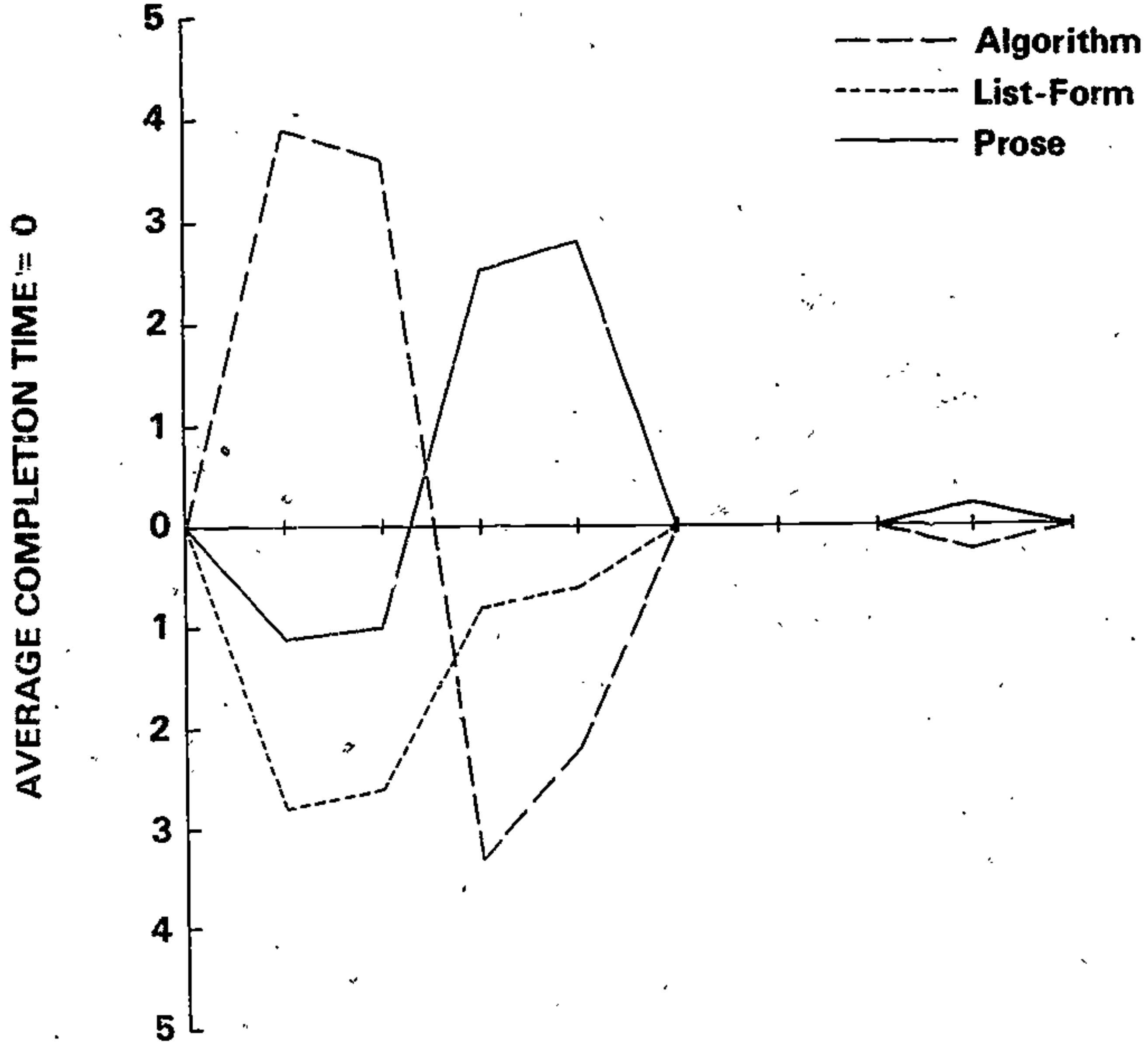
The X-axis represents the average completion time for each lab session as reported by the lab instructors. Each mark along this axis represents an individual laboratory session. The Y-axis represents deviations from the average laboratory completion time. A positive score indicates that the time of completion was greater than average; a negative score indicates completion time was less than average. The units along this axis represent minutes.

c. Effect on Grade for Qualitative Analysis Lab

Because there appears to be a highly differential effect between representations during the third and fourth labs an analysis

FIGURE 1

Average Completion Time per Treatment



of variance was added to assess the effect of mode of representation on the grade for these labs. Table 5 reports the results of this analysis. ANCOVA procedures were not deemed necessary (though could be added later) due to the low correlation between pretest score and grade on these labs (.14).

SOURCE	*df*	SUM OF SQUARES	MEAN SQUARES	F	F Prob.
BETWEEN GROUPS	2	317.4583	158.7292	1.808	.167
WITHIN GROUPS	180	15806.789	87.8165		
TOTAL	182	16124.4372			

TABLE 5

DISCUSSION

The present results suggest that there may be no connection between mode of representation and critical thinking ability. If this is the case one might question the hypothesis of Solomon that media can influence cognition much as language structures thought. However, one might also conjecture that the strength of the treatment was insufficient to cause a change in overall problem solving skills. To be sure, the effects of any of the representations could be mediated by the availability of lab instructors and fellow students who could provide additional guidance (controlling algorithms) in difficult situations. This would diminish the effect of the representation in structuring new thought processes.

In an earlier study (Coscarelli, et al), critical thinking--as defined by another measure, was enhanced by a flowchart representation.

If the transfer effect found in that situation existed; the question raised now is: Did the dependent variable in that study measure critical thinking? If not, what did it measure? These questions are worth further exploration.

For the time being, the theoretical question must remain unanswered; but the praxiological one of serendipitous side effects may be one step closer to resolution. In a real-world laboratory situation there may not be much hope of generating critical thinking via representation mode.

In the area of efficiency we found an interesting effect among representation modes. Generally speaking, the flowchart group performed poorly compared to other representations on the initial labs, moved on to demonstrate efficiency and then tapered off. For the prose group the result was the reverse before tapering. The list-form group proved the most stable across all labs.

One might hypothesize that these results can best be explained as a function of familiarity and algorithmic difficulty. For the students using the flowchart representations, an initial period of adjustment to an unfamiliar mode of representation was necessary. Those using representations more nearly parallel to standard prose found initial adjustment quite elementary. However, upon encountering the Qualitative experiments, <u>perhaps the most difficult of the labs</u>, the flowchart provided a definite advantage to the student in clarifying a complex series of instructions. Additionally, an analysis of the score for these labs indicates there exists no significant difference between groups. In this instance, one could argue that the use of flowcharting provides an efficient and effective method of representing a functional algorithm of identification.

Interestingly enough the list-form remained most constant across labs in approaching the average time of completion. Later, in a final laboratory experiment where students were required to develop their own set of procedures for a lab exercise; students would tend to list the procedures in the manner in which they had received instruction, i.e., flowcharts used in the flowchart group, etc. However, if the procedures were not detailed in the mode of instruction they were almost always presented in a list-form. This, despite a lack of interaction with the list-form representation, may indicate a generalized mode of thinking among students in approaching a complex procedure. Again, it remains a question open to further exploration.

Finally, the tapering effect found after the first four labs may be due to the students' ability to deal with the environment, not as the naive respondents they were upon entering the course, but as relatively sophisticated chemists. As they became more assured and knowledgeable it would be possible for them to move from the crutch of a specific representation mode and attend to the complexities of the individual task; transcending the representation scheme.

CONCLUSION

We have seen that the mode of representation for algorithmic situations may not provide an increase in a generalized skill such as critical thinking but that it may have an advantageous effect on more specific measures of efficiency and effectiveness (as measured by tasks closely related to the use of the procedure) in complex situations. What we may have seen is that the mode of representation can be a useful tool or hindrance depending on the complexity of the task and as with so many other things task complexity is a relative matter, i.e., lab procedures initially found difficult may be difficult to factors beyond the scope of the algorithm involved such as situation familiarity, confidence, etc. For these situations a flowchart or list-form may prove most useful. In other situations where complexity is not an issue, representations are equalized and might best be selected using an affective criteria of student preference.

REFERENCE NOTES

1. Lewis, B.N., Horabin, I.S., and Gane, C.P. (1967). Flow charts, logical trees and algorithms for rules and regulations. London: Her Majesty's Stationery Office.

2. Lewis, B.N., Horabin, I.S., and Gane, C.P. (1967). Case studies in the use of algorithms. Oxford: Pergammon Press.

3. Chapanis, A. (1965). Words, words, words. Human Factors, 7, 1-17.

4. Houghton, J. (1968). Round holes not circular orifices. London: The London and Southern Junior Gas Association.

5. Jones, S. (1964). Why can't leaflets be logical? New Society, 102, 16-17.

6. Davies, I.K. and Packer, D.G. (1969). Decision tables, algorithms, heuristics and continuous prose: models for writing complex rules, procedures and instruction. Paper presented at the Ergonomic Research Society Conference. London.

7. Gerlach, V., Reiser, R., Brecke, F. (1975). Rule learning and systematic instruction in undergraduate pilot training. Technical Report #51201, College of Education, Arizona State University, Tempe, Arizona.

8. Lewis, et al (1967): Oxford.

9. Coscarelli, W., Visscher, M., and Schwen, T. (1976). Algorithmization and transfer of learning. Paper presented at the annual meeting of the American Educational Research Association, San Francisco: April, 1976.

10. Solomon, G. (1972). Can we affect cognitive skills through visual media? An hypothesis and initial findings. Audio-Visual Communication Review, 20(4).

REFERENCES

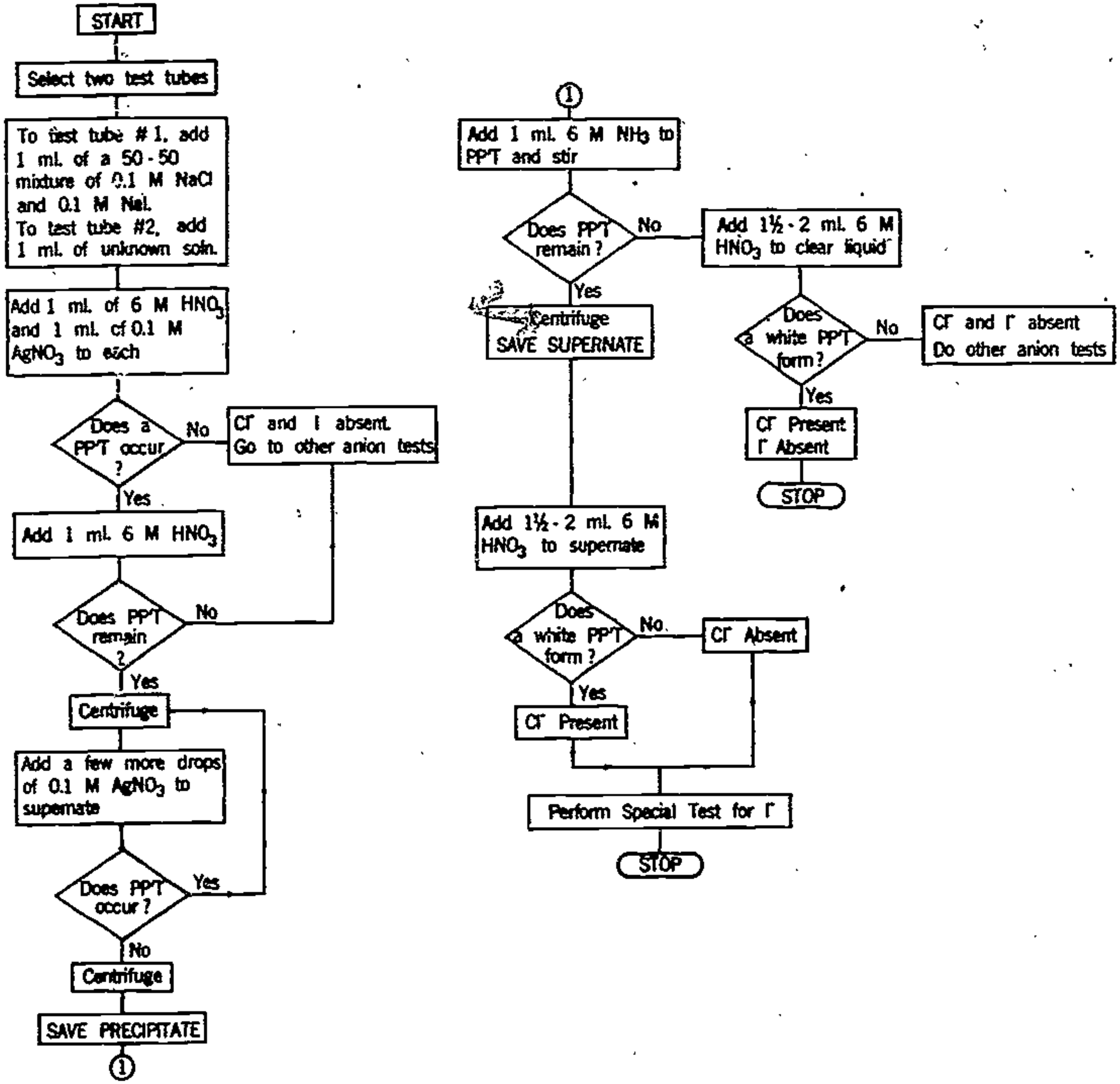
Brecke, R., Gerlach, V., and Shipley, B. (1975). Algorithms: a new tool for educational technology. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.

Landa, L. (1974). Algorithmization in learning and instruction. Englewood Cliffs, N.J.: Educational Technology Publications.

Merrill, P. (1974). Algorithmic organization in teaching and learning: the literature and research in the U.S. Paper presented at the annual meeting of the American Educational Research Association, Chicago, Illinois.

APPENDIX I

QUALITATIVE ANALYSIS: FLOWCHART REPRESENTATION



QUALITATIVE ANALYSIS: LIST-FORM REPRESENTATION

1. Select two test tubes.
2. Add 1 ml of a 50-50 misture of 0.1 M NaCl and 0.1 M NaI to test tube #1.
3. Add 1 ml of the unknown to test tube #2.
4. Add 1 ml of 6 M HNO_3 to each test tube.
5. Add 1 ml of 0.1 M $AgNO_3$ to each test tube.
6. If a precipitate occurs, go to statement #9.
7. If no precipitate occurs, go to statement #8.
8. Cl- and I are absent. Go to statement #39.
9. A 1 ml 6 M HNO_3.
10. If the precipitate remains, go to statement #12.
11. If no precipitate remains, go to statement #8.
12. Centrifuge the solution.
13. Add a few drops of 0.1 M A_gNO_3 to supernate.
14. If a precipitate occurs; go to statement #12.
15. If no precipitate occurs, go to statement #16.
16. Centrifuge the solution.
17. Save the precipitate.
18. Add 1 ml 6 M NH_3 to precipitate.
19. Stir solution.
20. If the precipitate remains, go to statement #22.
21. If no precipitate remains, go to statement #27.
22. Centrifuge the solution.
23. Save the supernate.
24. Add 1 1/2-2 ml 6 M HNO_3 to supernate.
25. If a white precipitate occurs, go to statement #30.
26. If no white precipitate occurs, go to statement #33.
27. Add 1 1/2-2 ml of 6 M HNO_3 to clear liquid.
28. If a white precipitate occurs, go to statement #35.
29. If no white precipitate occurs, go to statement #37.
30. Cl- present.
31. Perform special test of I-.
32. Go to statement #38.
33. Cl- present.
34. Go to statement #31.
35. Cl- present and I- present.
36. Go to statement #38.
37. Cl- absent and I- absent.
38. STOP
39. Proceed to other anion tests

QUALITATIVE ANALYSIS: STANDARD PROSE REPRESENTATION

Select 2 test tubes adding 1 ml of a 50-50 misture of 0.1 M NaCl and o.1 M NaI to the first test tube and 1 ml of the unknown to the second. Then add 1 ml 6 M HNO_3 and 1 ml of 0.1 M $AgNO_3$ to each test tube. If no precipitate occurs you have determined that Cl- and I are absent and you should proceed to the other anion tests. If a precipitate occurs add 1 ml of 6 M HNO_3. If the precipitate disappears; Cl- and I are absent and you should proceed to the other anion tests. If the precipitate remains, centrifuge the solution and add a few drops of 0.1 M $AgNO_3$ to the supernate. If a precipitate occurs, centrifuge the solution again and add a few more drops of the o.1 M $AgNO_3$. Continue to do this until no precipitate occurs. At this point,centrifuge the solution and save the precipitate.

Add 1 ml of 6 M NH_3 to the precipitate and stir. If no precipitate remains add 1 1/2-2 ml 6 M HNO_3 to the clear liquid. If a white precipitate occurs Cl- is present and I is absent. If a white precipitate does not occur, Cl- and I are absent. If, after adding the 6 M NH_3 a precipitate does remain, centrifuge the solution and save the supernate. Add 1 1/2-2 ml of 6 M HNO_3 to the supernate. If no white precipitate forms Cl- is absent. If a white precipitate forms, Cl- is present. In either case, it is necessary to perform the special test for I.

A FINAL NOTE

Because of the nature of this study I must also acknowledge the contributions of Marty Visscher who was my client in the development of this course and Tom Schwen who served as consultant and teacher throughout the project. The chemistry (excuse the pun) of the team led to a synergistic whole that will not be duplicated for sometime to come.