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ABSTRACT

Ninety students in an introductory chemistry class were divided into three groups to test the power of algorithms to increase logical thinking abilities. The experimental group received approximately 10 hours of laboratory instruction based on the use of procedural algorithms. Experiment and control groups were tested for logical thinking abilities. Preliminary analysis supported the contention that the experimental group performed significantly better than either control group on the posttest measure of logical ability. The use of algorithms explained a substantial portion of the variance in posttest scores. Theoretical as well as educational implications are discussed. (Author)

ALGORITHMIZATION

AND

TRANSFER OF LEARNING

Presented at
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BACKGROUND

In the spring of 1975 the Indiana University Chemistry Department approached the Division of Development and Special Projects (DDSP) for assistance in developing the introductory chemistry laboratory course at Indiana University. The authors comprised the interdisciplinary team that was formed to develop the course. As a result of our preliminary analysis we were able to identify several salient learner characteristics:

(1) The typical student in the course (C121) had little or no background in chemistry or the sciences.

(2) Most students were freshmen or sophomores.

(3) The course was designed as a terminal level course in that students taking this course would not usually be taking any other chemistry laboratory courses.

(4) Generally speaking, the students were nursing, business, liberal arts, or education majors.

(5) Students were extremely anxious and apprehensive about the laboratory environment and their ability to perform in the chemistry laboratory.

In synthesizing all of these characteristics, and paying particular attention to the anxiety expressed by the students, we chose to use algorithms as an integral part of our instructional strategy. As Lewis (1967) notes, an algorithm "reduces a problem solving task to series of comparatively simple operations, and indicates (for a variety of contingencies) the order in which these operations should be carried out." We decided that all lab procedures would be expressed in algorithmic form. As many have observed algorithms have been shown to be very successful for dealing with procedures and routines. It was felt that the completeness of the algorithm would allay much of the anxiety of the student.

During initial course development and revision, in the summer of 1975, it occurred to the team that students who used the algorithms might be transferring the inherent logic expressed in the algorithms to a problem solving strategy, i.e., by using the algorithms the students would begin to structure their problem solving strategies in the same logical manner as an algorithm. We shall refer to this manner of thinking as "logical thinking." (An operational definition of this construct is provided in the discussion of the dependent variables, p. 7). Preliminary analysis supported this speculation and as a result the developers began an attempt to verify the transfer effect found in the use of algorithms in chemistry laboratory instruction.

SOME THOUGHTS ON THEORY

The transfer literature indicates that the use of algorithms by students on one task could influence performance on another task. Landa (1974) felt that

> "Although each particular algorithm serves only to solve problems of a specific class, in devising the algorithms, the students penetrate into the structure of objects and phenomena of the external world and of the intellectual processes themselves. They get to know the significance of general methods of reasoning, they learn how to discover, analyze, synthesize and apply the methods..." (Landa, 165)...(and) ...there also emerges the ability to apply

> operations at will to new conditions, i.e., the ability to make broader transfer onto these circumstances emerges. Applying the operations to new objects or conditions now depends less on how much these conditions externally resemble those under which operations were formed...such a transfer facilitates a broader and quicker generalization of operations (the logic of the algorithms) which is extremely important for the intellectual development of students. The wider the range of transfer, the greater the possibility for new 'moves' of thought, for new conclusions and discoveries."

Klausmeier and Davis (1969) noted that "...it is the ability, such as syllogistic reasoning, rather than knowledge of the specific content, or syllogisms, that facilitates subsequent performance of a broad number of tasks..." And again, to paraphrase Landa:

> "We taught them logical operations in the form of (laboratory) operations, the logical structure of (chemistry) operations...In brief, we taught them the logic of (chemistry). But since the logical structures of chemistry have common elements with the logical structures of any other knowledge, when we taught general methods of (chemistry procedures) we taught the students some general methods of thinking." (p. 601)

It was felt that one could encourage the development and transfer of "logical thinking," though one must face the problem of measurement of transfer.

Instructional developers have been sensitive to the concerns of content specialists that our measurement systems be able to tap higher level abilities. Coupled with an interest in assessing "logical thinking," the team chose the transfer model as a tool that would enable us to measure "logical thinking." The authors adopted the basic experimental paradigm outlined by Klausmeier and

Davis (1969) where the transfer group was to perform a task (use of algorithms) and then perform a second task, which in this case would be the dependent variable. In addition, two control groups performed, respectively, parallel chemistry tasks and no tasks at all. It was felt that such a separation of treatments isolated the independent variable of algorithmization from a possibly confounding variable of familiarization with laboratory procedures and equipment, as well as indicate that learning has taken place.

Rising from our concern of measuring "logical thinking" and the studies which have indicated that the similarity between stimulus and response is critical in assessing transfer effects, we chose to use two tests to measure "logical thinking." We selected a similar (the student would be given a unique chemistry problem and told to describe a procedure to solve the problem) and a dissimilar (an objective test that would require minimal knowledge of chemistry and chemistry procedures) transfer task. Table 1 summarizes this design.

TRANSFER	Chemistry and Algorithms	Chemistry	No Treatment
Dissimilar			
Similar			

GROUP

<u>Table 1</u>

PURPOSE OF THE STUDY

The purpose of this study is to determine if using algorithms in a chemistry laboratory situation will increase a student's skill in "logical thinking." The algorithms were used only as procedural guides and were thus an instructional strategy, not instructional content.

HYPOTHESES

The developers suspected that the use of algorithms as a procedural strategy in an introductory chemistry course would encourage "logical thinking." The following directional hypotheses were used to guide the study:

H_1: Students who have had chemistry instruction regardless of procedure will perform better on a similar transfer task than on a dissimilar task.

H_2: Students using the algorithms as a procedural guide will think in a more logical manner than students who have not used the algorithm.

H_3: Students who have had chemistry instruction regardless of procedural method will think in a more logical manner than students who have not had chemistry instruction.

INDEPENDENT VARIABLES

The independent variable will be instructional strategy. The variable will have three values:

Group T---The main treatment group in which students will receive all procedures are expressed through the use of algorithms.

Group C_1--A control group in which students will receive chemistry instruction and in which all procedures are expressed in standard prose format.

Group C_2--A control group in which students have received no instruction in chemistry nor use of algorithms.

DEPENDENT VARIABLES

The dependent variable will consist of a score received on two tasks, analyzed separately.

S---A transfer task in which students are given a novel chemistry laboratory problem and required to solve the problem. A score is assigned as a mean score based on 4 judges' estimates of a logical approach to solving the problem.

D---A transfer task in which students are given a test that is designed to measure "logical thinking" in a non-laboratory situation. A score is assigned based on the number of questions answered correctly.

DESIGN

Table 1 summarizes the design of the study. We conducted two studies to test our hypotheses. The design is the same for both studies with two exceptions: 1) length of treatment and 2) characteristics of C_1. In our first study we used students who had taken a similar course, covering the same techniques as our main treatment group. For the second, an even tighter control was exercised by insuring that exactly the same content was taught, the only difference being that the procedures were in standard algorithmic form or prose.

INSTRUMENTATION:

INDEPENDENT VARIABLE

For the independent variable of "algorithms" procedural algorithms were constructed for the laboratory course. Students were given a lecture of approximately 15 minutes in the use of the algorithm. Appendix I illustrates the demonstration algorithm. This algorithm contains all the attributes found in any given algorithm in the treatment group.

DEPENDENT VARIABLE

For the dependent variables we constructed two tests. For the similar task the students were given a choice of two problems. They would select one problem and propose a technique or method to solve the problem. We selected 4 chemistry associate instructors for C121 to serve as judges. In a 60 minute training session with the judges we indicated that selection of the correct technique, e.g., titration, chromatography, was not to be the basis for assigning a score. We emphasized that scoring should be based on the ability to demonstrate a logical approach to the solution of the problem. We outlined guidelines for the judges and arbitrarily established a possible range of scores (0-20). The judges then graded all tests. The tests were coded and shuffled so that the judges would not know which test belonged to which condition. In addition, copies were made of each test so that each judge could proceed at his own pace and could assign a score without possible cues from another judge.

The mean score for each subject was calculated and used for the Analysis of Variance procedures. An intra-class correlation was calculated for inter-rater reliability and yielded an alpha of .882.

The use of a similar transfer task would enable one to measure transfer of learning related to the logic of chemistry procedural operations alone. The use of a dissimilar transfer task would measure the application of "logical thinking" to more general situations. A dissimilar transfer task is thus a test for general ability rather than specific content.

For the dissimilar task we developed a test to measure "logical thinking." We operationally defined this as requiring the following skills:

1. The student will separate unnecessary information from useful information.
2. The student will determine the next step in a procedure to solve a problem.
3. The student will organize material into a logical order by establishing a mathematical relationship.
4. The student will make a correct decision after a procedure has been followed and observations made.

The test originally consisted of 35 items. We administered the test to a sample of 121 intermediate level chemistry students to obtain an estimate of reliability. Using the K-R 20 and the Spearman-Brown correction formula we obtained a reliability of .68 with a standard error of measurement of 2.12. Eliminating non-discriminating items the test was reduced to 24 items. Current use indicates that the revised test has a corrected estimate of reliability of approximately .80 with a standard error of measurement of 1.51.

At present we can provide no validity estimate on this this test. We believe that we have at least achieve a fair degree of face validity but will be unable to provide an estimate of construct validity until the summer of 1976. However, the fact that the mean scores seem to vary as a function of length of instruction lends support to the test's validity.

It is interesting to note that we found no commercially available test of this nature. An examination of several test subscales that were similar to our operational definition of "logical thinking" showed that basic algebraic problems could be used satisfactorily as a measure of "logical thinking." We also believe that knowledge of chemistry is not necessary for the test; though it would be helpful. After the content validation has been completed we will make a final item analysis and revision of the test. We must emphasize that the test has yet to meet an exhaustive validation, but for the moment we think it will serve as an adequate measure of "logical thinking."

POPULATION

For Study I, 600 students enrolled in an introductory chemistry laboratory course at Indiana University-Bloomington and 200 students enrolled in an introductory laboratory course at Indiana University-Purdue University at Indianapolis (IUPUI). The IU-Bloomington students served as the Algorithm and Chemistry (T) and No Treatment (C_2)

groups. The IUPUI students served as the Chemistry-only group (C_1). For Study II, 215 students at IU-Bloomington served as the population of groups T and C_1. Students were randomly selected for all groups except C_1. In Study I the C_1 group was comprised of volunteers, in Study II a class section was randomly chosen.

Table 2 summarizes the population and sample. The differences between the number of students selected and the number taking the test were due to the students' dropping the course, illness, or otherwise unknown causes.

PROCEDURES

We cannot lay claim to a standardized testing procedure for all groups. Again, as with any real world situation we had to adjust to meet the demands of the environment (oh, for a white rat!). In Study I, students in group T took the tests in leiu of their normal final exam. Students were not informed of the tests in advance but were assured that their score would not penalize their final grade. The C_1 group was paid $3.00/student to take the test in addition to their regular final exam. All students in a group took the test at the same time. The C_2 group was allowed to take the tests at any one of 5 sessions before instruction began.

In Study II, T and C_1 students could take the test at any one of 5 sessions. In both Study I and Study II all students were proctored during testing. All tests and answer sheets were collected after testing. Table 3 summarizes the testing procedures for each group.

Table 2

<table>
<tr><th>STUDY I</th><th>STUDY II</th></tr>
<tr><td>POPULATION:

600 students enrolled in an introductory chemistry laboratory class at Indiana University-Bloomington and 200 students enrolled in an introductory laboratory class at Indiana University-Purdue University at Indianapolis (IUPUI).

SAMPLES:

T---36 students were selected at random. 28 students took the test.

C_1--11 students were volunteers from from the IUPUI course.</td><td>POPULATION:

215 students enrolled in an introductory chemistry laboratory class at Indiana University-Bloomington.

SAMPLES:

T---30 students were selected at random. 27 students took the test.

C_1--24 students making up one class. The class was randomly chosen, not the students. 20 students took the test.</td></tr>
<tr><td colspan="2">C_2--36 students selected at random from the pre-registration list for C121, Spring semester, 1976, at Indiana University-Bloomington. 33 students took the tests before instruction in the course began. Data from this group was used as the C_2 data for both studies.</td></tr>
</table>

Table 3

STUDY I	STUDY II
PROCEDURES: T---After 30 hrs. of laboratory instruction (Fall, 1975) students took the tests in lieu of their regular final exams. Assurances were made (and accepted) that performance on the tests would not adversely affect their final grade. All students were tested at the same time.* C_1--After 30 hrs. of laboratory instruction (Fall, 1975) students were advised that we would pay volunteers $3.00 to take the tests. All students were tested at the same time.	PROCEDURES: T---After 10 hrs. of laboratory instruction (February, 1976) students were required to take the tests. Students were informed that failure to do so may jeopardize their grade but that the score on the tests would not have an adverse effect on their final grade. Students could take the test at any one of 5 sessions. C_1--After 10 hrs. of laboratory instruction (February, 1976) students were tested as per the treatment group.

C_2--Students were allowed to take the tests at any one of 5 sessions. Testing took place in January, 1976, before any instruction had taken place, as per the conditions of the replication group.

*The tests usually require less than 1½ hours to complete.

RESULTS

Appendix II lists the ANOVA source tables for both studies. In addition, we performed two other analyses. The first test we performed was a Newman-Keul multiple range test to determine homogenous groups. We chose the Newman-Keul and the level of .10 as this would be a less conservative test of the differences. We believe that the exploratory nature of this study is such that the risk of accepting a false treatment effect is less than the possible rejection of a true effect.

Table 4 lists the means for each treatment group in the pilot study (30 hours of instruction) as well as associated p values. An "=" indicates homogenous subsets.

TRANSFER	Algorithm + Chemistry	Chemistry	No Treatment	
Similar	17.8	8.2	.5	$(p < .001)$
Dissimilar	13.3	10.6 =	10.9	$(p < .01)$

GROUP

Table 4

SIMILAR TRANSFER TASK

At the end of 30 hours of instruction we found that each group in the similar transfer task was significantly different. This seems to indicate a transfer of logic above and beyond chemistry knowledge; as well as the fundamental concern that learning is taking place.

DISSIMILAR TRANSFER TASK

At the end of 30 hours of instruction we found that the two control groups were not significantly different. Ignoring for the moment the no treatment control we found that students did as predicted. The mean score on the dissimilar test for the no treatment control group leads us to believe that we may have some validity problems or that the task may be so dissimilar that the student's general knowledge could be more influential in determining the score.

Table 5 lists the means, p values, and homogenous subsets for Study II. (Note the change of order of the cells for the dissimilar task.)

	Algorithms + Chemistry		Chemistry	No Treatment	
SIMILAR TASK	3.85	=	3.37	.5	$(p < .002)$

	Group	Mean		No Treatment	
DISSIMILAR TASK	Algorithm + Chemistry	11.7	=	10.9	$(p < .138)$
	Chemistry	9.8	=		

GROUP

Table 5*

*While both Algorithms and Chemistry groups are homogenous with the no treatment group, they are significantly different from each other.

SIMILAR TASK

At the end of 10 hours of instruction we found that both treatment groups did significantly better than the control, though there was no significant difference between these two groups. There is a tendency toward transfer of "logical thinking" for the main treatment group. We suspect that this difference would become more pronounced as the length of treatment increased.

DISSIMILAR TASK

At the end of 10 hours of instruction we found that the differences were again in the predicted direction. With the same caveat we made in Study I concerning the no treatment group, we find the differences consistent with theory, however modest.

The second test we performed was a measure of transfer made between the Algorithm and Chemistry groups. Following the formula in Murdock (1957) where percentage of transfer is the difference between the means of the transfer group (T) and the control group (C) to the sum of the means we can obtain a rough estimate of the percentage of transfer found through the use of algorithms controlling for chemistry knowledge. The formula is:

$$\text{percentage of transfer} = \frac{T-C}{T+C} \times 100.$$

Table 6 lists the percentage of transfer attributable to the algorithms for both transfer conditions in both studies.

		10 hr.	30 hr.
TRANSFER	Similar	6.6%	36.9%
	Dissimilar	8.8%	11.3%

TIME

Table 6

HYPOTHESES

In relation to our initial hypotheses we would make the following observations:

H_1: Students in the 30 hour group transferred 36.9% to the similar task compared to 11.3% on the 10 hour group, though neither figure was as large as those of the first group.

H_2: In all but the 10 hour similar transfer task students using the algorithms scored significantly higher than the non-algorithmic chemistry group. The direction of the scores with the 10 hour similar transfer group was in the expected direction, however.

H_3: In the similar transfer task we found that students with chemistry instruction scored higher than the no instruction group. The results were mixed on the dissimilar task.

CONCLUSIONS

Murdock's formula seems to indicate the two major conclusions of this study:

1. Algorithms appear to make a difference in logical thinking abilities. Students appear to transfer the logic of a procedural algorithm when solving a problem. The true strength of the transfer effect still remains undetermined but, as seen in Table 6, we may have found an effect.

Interestingly enough, there was less transfer involved with the similar task in the 10 hour group than with the dissimilar task. This may be due to the effect of the students' general knowledge over and above the main treatment effect. The results of the 30 hour group were congruent with theoretical expectations. The relatively large effect found in the similar transfer task (36.9%) may, in retrospect, be due to a similarity of the test and recent class exercises. This could be a confounding variable in our analysis. However, the general pattern between the two studies leads one to suspect that:

2. There seems to be a relationship between time in treatment and transfer.

Because of the possibility of a confounding variable the nature of the relationship--linear or curvilinear--must remain indeterminate.

(NOTE: We have resisted comparing the two studies in a rigorous statistical manner with time entered in as a treatment level because of the differences in the two chemistry control samples as well as a lack of rigorous sampling procedures.

DISCUSSION

We think it is perfectly appropriate that this paper is being presented in a session entitled "Promoting More Effective Learning in Real World Settings," indeed the authors would be uncomfortable in a session with a more formal title. Algorithms were chosen for use in an introductory chemistry course as a procedural crutch to help anxious students. Self report forms and personal interviews showed that this strategy was effective. As another possible outcome the authors considered the value of algorithms in nurturing some logical approach to solving a problem. We suspect that students who use algorithms as a procedural guide may transfer the logic of the procedure to new tasks, that as a result they engage in "logical thinking."

The study has its fair share of sampling problems and worked with a dependent variable (dissimilar transfer task) that is not above reproach. What the study indicates is that algorithms may be a powerful tool for the educator, that their use as a procedural guide may have a serendipitous effect on higher order thinking processes, and that further research in this field is both warranted and possibly fruitful.

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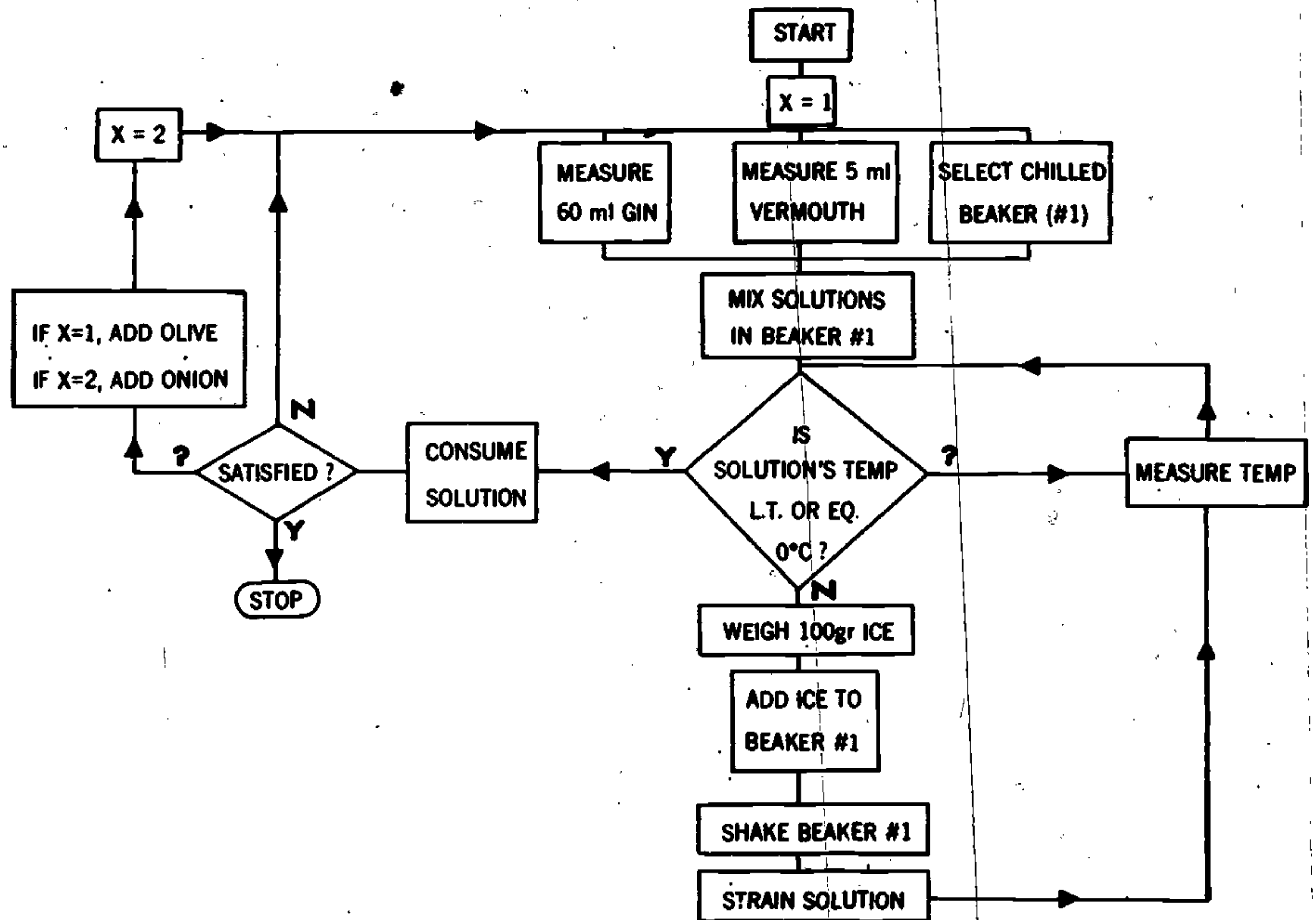
APPENDIX I


START
X = 1
X = 2
MEASURE 60 ml GIN
MEASURE 5 ml VERMOUTH
SELECT CHILLED BEAKER (#1)
MIX SOLUTIONS IN BEAKER #1
IF X=1, ADD OLIVE
IF X=2, ADD ONION
N
?
SATISFIED ?
Y
STOP
CONSUME SOLUTION
Y
IS SOLUTION'S TEMP L.T. OR EQ. 0°C ?
?
MEASURE TEMP
N
WEIGH 100gr ICE
ADD ICE TO BEAKER #1
SHAKE BEAKER #1
STRAIN SOLUTION

APPENDIX II

SOURCE TABLES FOR STUDY I

SIMILAR TRANSFER TASK

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	2	4554.1362	2277.0681	213.370	<.001
WITHIN GROUPS	69	736.3625	10.6719		
TOTAL	71	5290.4988			

DISSIMILAR TRANSFER TASK

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	2	118.8244	59.4122	4.866	<.010
WITHIN GROUPS	77	940.0631	12.2086		
TOTAL	79	1058.8875			

SOURCE TABLES FOR STUDY II

SIMILAR TRANSFER TASK

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	2	183.5814	91.7907	6.670	<.002
WITHIN GROUPS	74	1018.3858	13.7620		
TOTAL	76	1201.9672			

DISSIMILAR TRANSFER TASK

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	2	44.9420	22.4710	2.031	<.138
WITHIN GROUPS	77	851.7455	11.0616		
TOTAL	79	896.6875			