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The Effects of Two Modes of Representation on Field-Dependent and Field-Independent Students' Learning in an Introductory Chemistry Course.

Mary Elizabeth Gardiner

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ABSTRACT

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This investigation examined how high, medium and low field-independent students' learning was affected by two algorithmic modes of representation in an introductory chemistry course and whether speed and accuracy with which they tackled the problem sets differed depending on the treatment.

Seventy-two students were evaluated as field-dependent to independent and, randomly assigned to one of two treatments: a highly-structured flowchart mode of representation and 2) a low-structure standard prose mode of representation. The content of the algorithm consisted of a chemistry concept known as the 'mole'.

Participants were given a pretest, a posttest and a delayed posttest on their ability to solve a number of chemistry problems. A repeated measures ANOVA was performed on both achievement and time data. Results showed that participants in the highly-structured flowchart mode of representation performed significantly better immediately following instruction than those students who received the standard prose mode of representation. However, there was a significant decrease in performance for those utilizing the flowchart on the delayed test. No such decrease was apparent for the standard prose group. Mode of representation had little effect on the time taken to complete the tests. In terms of field-dependency, the low group performed significantly lower than the medium category group but not significantly lower than the high group on achievement.

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Dedicated to

my father, Kevin Gardiner and

Dr. Edith G. Stewart

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Rationale

As noted by Schmid and Gerlach (1986), there is much evidence to support the finding that the application of algorithms to learning and instruction is an effective approach to teaching in many areas of instruction. However, despite the success of the procedures, the approach has had little influence on the technology of instructional design. Much of the literature on algorithmic teaching suggests that educators are most often concerned with offering the student knowledge about the content of what is being studied and considerably less concerned with giving him/her the means with which to operate on the content - to discover the steps involved in carrying out the solution to a problem.

Research conducted by Landa (1974) on material related to students' solutions of certain grammatical problems, revealed the following: "They [students] cannot give a complete answer to the question of what must be done and in what sequence when solving certain grammatical problems, because they do not know the general method for the solution of these problems" (p.555).

Studies have produced data which indicate that the use of algorithms in teaching and learning enhances achievement. In a pilot study conducted by Coscarelli, Vischer and Schwen (1976), improved performance on higher order outcomes in an algorithm treatment was attained. Also, an experiment conducted by Lewis, Horabin and Gane (1967) to assess the performance of participants using two different versions of solutions for solving tax computation problems revealed that the algorithmic method was the more efficient version. It was found that, "...using the official prose version, performance on this test turned out to be slow and inaccurate"(p.16) "In contrast, performance using the algorithm turned out be fast and correct" (p.16). Thus, not only does the algorithmic method enhance achievement, it also enhances speed and accuracy.

In a similar, but more comprehensive experiment, they (Lewis, et al., 1967) again found enhanced achievement, as well as enhanced speed and accuracy. In this experiment, participants in treatment 1 were given a prose version of the Capital Gains Tax and a set of six hypothetical problems to solve. Participants in treatment 2 were asked to solve the same set of six problems using a more simplified prose version and participants in treatment 3 were requested to solve the same six problems using an algorithm. A statistical analysis conducted on the individual results showed that the official prose version took significantly longer ($p < .001$) to handle than both the simplified prose and the algorithm and that the prose versions were significantly worse ($p < .001$) with respect to accuracy (Lewis, et al., 1967). Also, in terms of enhanced achievement, the results with the algorithm were better than those with the simplified prose.

In an experiment conducted by Schmid and Gerlach (1977), the effectiveness of algorithms is further demonstrated. Results from this experiment yielded very promising results. "First, the effectiveness of the algorithm was demonstrated by the high performance not only immediately following instruction, but also one week later...this effect is compounded by the high efficiency of instruction (mean learning time approximately 5 minutes, 55 seconds)" (Schmid and Gerlach, 1977, p.22).

Despite the success of algorithms in the preceding studies, much controversy still remains as to whether algorithms really do enhance achievement. Coscarelli and Schwen (1979) found no significant differences in the effects on achievement when three different representation modes (flowcharts, lists, and standard prose) were used. Also, in a pilot study conducted by Schmid and Gerlach (1977), no significant differences were found among three algorithmic representations. Both time required per item and total scores were approximately equivalent.

When, where and for how long the use of algorithmic instruction will be optimal is something that research in the area must address. Algorithmic instruction is intended to facilitate learning but when this technique, as any, is misapplied, the consequences can be detrimental to the learning process. More research is needed in order to validate the relevant task types, the relevant subject matter and the relevant learner populations that will benefit from such an approach.

This study attempts to shed some light on the use of algorithms in chemistry - a subject matter relatively untouched by previous research and to further explore whether or not the approach retains its effectiveness over time. As well, the effect of field-dependence/field-independence is explored, as it is an aptitude which may influence students' ability to use structured algorithms.

Field-dependence and field-independence is described by Witkin, Moore,Goodenough and Cox,(1977) as a global versus articulated cognitive style. This suggests that people have different cognitive functionings and that they impose different degrees of organization on a 'field'. According to Witkin et al.,(1977), if unstructured subject matter is presented, there is a distinct difference in performance between field-dependent and field-independent students. If the subject matter is highly-structured or well organized so that students do not have to impose structuring, no influence of field-dependence/field-independence will be found. This study attempts to shed some light on these types of learners as well.

Literature Review

A survey of the literature on algorithms reveals that their use in the educational arena has been varied. The most obvious impact of the use of algorithms has been in the highly quantitative area of mathematics. Up until the end of World War 11, algorithms, or algorithmic processes, were viewed as specific mathematical phenomena, devised mainly for cognitive operations of which people were often unaware (Landa, 1974). An example of such an algorithm is the procedure for performing long division, commonly taught in the elementary school.

With the advent of computer technology, algorithms became equally important in the field of computer science. The computer program utilized to compute the gross and net pay for salaried employees or the program developed to compute statistical information on data gathered are examples of computerized algorithms. Other processes which are algorithmic in nature have been known for centuries, although they have not been labelled algorithmic in the past. Tasks such as operating machinery involved observable motor operations and therefore prescriptions were devised, because without them, it was difficult to effectively perform many of these tasks.

Landa (1974) has defined an 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" (p.11). Others, such as Brecke, Gerlach and Shipley (1975) and Merrill (1974) have adopted similar definitions. Lewis, et al.,(1967) have defined an algorithm as follows:

> Briefly, an algorithm is an orderly sequence of instructions for solving a problem. Its special merit is that it reduces a problem-solving task to a series of comparatively simple operations, and indicates (for a variety of contingencies), the order in which these operations should be carried out (p.3).

If the process consists of series of relatively elementary operations which are to be executed in some uniform way to solve all problems of a certain class, the process is algorithmic in nature.

According to Knuth (1968) an algorithm has five important features or characteristics:

1) The operations or steps of the algorithm must be unambiguously defined.
2) An algorithm should produce the correct result in a reasonably finite number of steps.
3) An algorithm should have zero or more inputs from a specified set of objects or domain.
4) An algorithm should have one or more outputs having a specified relationship to the inputs.
5) The operations or steps of an algorithm should be sufficiently basic so that they can be done precisely

in a finite length of time.

In many situations, however, the steps involved in carrying out a solution can only be described as general strategies as opposed to precise rules. The solution cannot be stated in a regular or uniformed fashion, under the same conditions each time. These types of problems are considered heuristic in nature as the operations are often non-elementary and directions are ambiguous. Landa (1983) gives an example of choosing geometrical attributes as a heuristic procedure: "...normally it is not known which of all the attributes is to be used in each particular case and no unambiguous directions that guarantee the solution to the problem can be given..." (p.175).

This distinction is an important one. However, some researchers utilize the term 'algorithm' in a general sense to include both algorithmic and heuristic processes. From an instructional standpoint, it may be of use to categorize the two processes together as many instructional applications involve the use of heuristic procedures, either because the subject matter does not allow for the rigidity of an algorithm or simply because time and expense does not allow one to achieve a guaranteed correct solution. For the purposes of this study however, heuristic processes and algorithmic processes will remain distinct and the features of an algorithm will be adhered to strictly.

The Algorithm and Instruction

According to Landa (1974), there are three ways of increasing the efficiency of instruction using algorithms. He distinguishes between three types of prescriptions:

1) Performer algorithms - which indicate to performers what they should do in order to be able to perform on mastery level. These represent the content for instruction.
2) Learning algorithms - which indicate to learners what they should do in order to learn how to perform on a mastery level.
3) Teaching algorithms - which indicate to teachers what they should do in order to develop in performers and/or learners algorithmic processes. These are methods of instruction.

There are three ways then, that the instructional designer utilizes algorithmic processes: 1) content, 2) strategy, and 3) production. The content application is described as instructing students to solve problems using algorithms. "This approach results not only in the solution of the immediate problem but also trains students to approach other problems in an algorithmic fashion"(Terrell,1983,p.33). Strategy application of algorithms involves using algorithmic processes in order to come up with procedures which aid the student in learning clearly defined and highly specific tasks. The production application of algorithms allows the instructional designer to use algorithms for instructional design.

The principal difference between these methods and the more conventional methods of, say, learning by trial and error, discovery through example, etc., is that the methods described by Landa (1974) are:

> ...based on a more or less complete knowledge of the unobservable cognitive processes underlying performances, skills and abilities - the mediating connection between inputs and outputs- is that here a teacher handles not just inputs and outputs but also understands, and purposefully, in a more direct way, influences the internal processes taking place in between. (p.179)

Because the teacher is clearly better aware of the internal processes using algorithmic prescriptions than when using conventional methods, the former allows for greater potential in terms of reliability, efficiency and effectiveness of instruction.

Thus, algorithms have been used to aid in task analysis, to describe cognitive processes in learning and problem solving, to develop and describe complex instructional strategies and in the design and development of instructional materials (Merrill, 1977). Evidence of the potential benefits of using algorithmic prescriptions is demonstrated in a study conducted by Schmid and Gerlach (1977), in which three forms of instructional presentation were used (prose, flowchart and faded flowchart). The task consisted of solving tax problems involving profit or loss on the sales of securities.

> The effectiveness of the algorithm was demonstrated by the high performance not only immediately following instruction, but also one week later. The classic forgetting curve appears to have been defied, even without the presence of a ceiling effect. Thus, the absolute value of the algorithm was demonstrated. (p.22)

The use of algorithms in instruction has been supported here - but this represents one level of using algorithms in instruction.

This present study was mainly interested in the actual method used to present the algorithm to the student; that is, the mode of representation as it affects efficiency and effectiveness of instruction. "Naturally, an adequate test of the algorithmic approach can be made only when an effective method of teaching algorithms has been developed" (Schmid & Gerlach, 1977, p.7).

The Algorithm as Instructional Technique

In most instructional environments, educators are faced with the need to present the learner with a series of operations that will guide them in attaining acceptable solutions to a given problem. The way these operations are presented to the learners will either help or hinder them master the procedures. In designing instructional materials, one attempts to design material that is not only effective, but efficient as well. As such, the instructional material is evaluated by the amount of time and effort it requires to enable the learner to achieve the goal. Algorithms, by definition, are effective because they guarantee the correct solution; however, the design of the algorithm and differences in presentation are what influence its efficiency.

There are several ways to represent an algorithm. These representations vary in terms of readability and structural clarity (Chapanis, 1965). Standard prose is the most traditional form for presenting an algorithm in many instructional situations. However, written instructions are usually difficult to understand and often require the learner to process more information than is necessary. As Coscarelli and Schwen (1979) note:

> Prose instructions require the reader to process all information regardless of relevance to the task. This alone could increase the probability of confusion and lead to an improper solution to a task, especially when the task is fairly complex. Furthermore, this complexity can be compounded through the grammatical structure of the prose. (p.59)

Flowcharts, on the other hand, have compelling advantages over their prose counterparts:

> Instead of leaving [the user] 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 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. (Lewis, et al, 1967, p.7)

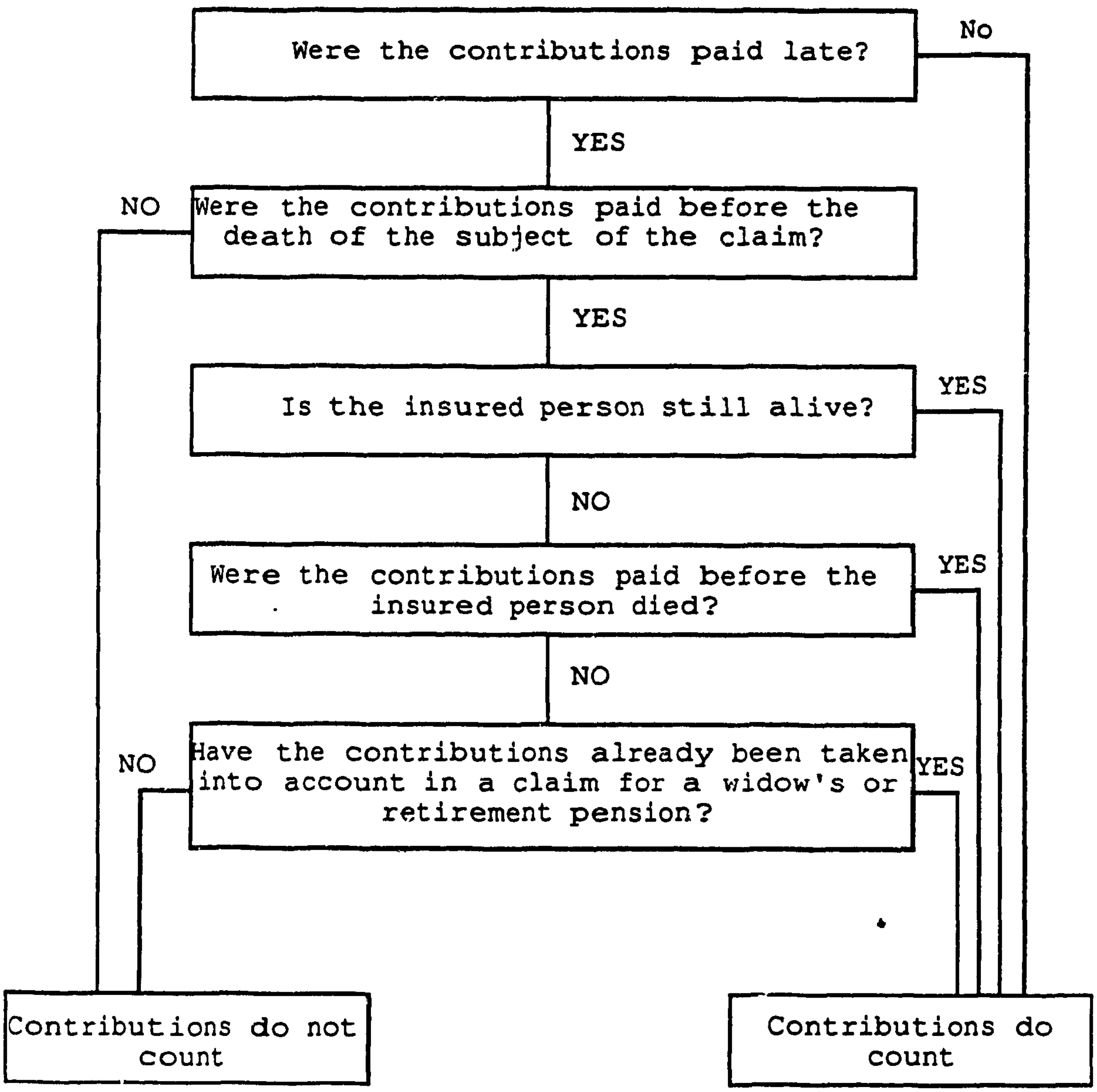
In studying the use of flowcharts as an alternative form of presenting official rules and regulations, Lewis, et al.,(1967), uncovered many examples of poorly written prose instructions which appeared to ignore the needs of the target audience. The following passage illustrates one such case. This public leaflet was issued to the public in England regarding qualifications for Death Grant:

> Contributions paid late cannot normally count for death grant (other than towards yearly average) unless they were paid before the death on which the grant is claimed and before the death of the insured person if that was earlier. But if the insured person died before the person on whose death grant is claimed, contributions which, although paid late, have already been taken into account for the purpose of a claim for widow's benefit or retired pension, will count towards death grant. (Lewis, et al., 1967, p.7)

Lewis, Horabin and Gane thus devised an algorithm, represented in flowchart form, in order to make the information more intelligible to the public of England. The flowchart is as follows: (Figure. 1)

Thus, the form the algorithm takes can help or hinder the target audience in their understanding of the information. In this case, the flowchart was successful in unravelling specific instructions that may well have been overlooked when they were wrapped up in the unduly dense prose version. Other forms of algorithms could have been chosen, such as a checklist, a chart and/or a decision table. It may be left to the instructional designer or developer to choose the appropriate format, keeping in mind the degree of complexity involved in a particular algorithm.

Figure 1. Death Grants Benefit Algorithm



Note. From Case Studies in the use of Algorithms (p.11) by Lewis,B.n., Horabin, I.S., and Gane, C.P., 1967, Permagon Press Ltd.

Algorithms may differ tremendously in terms of complexity. "Some algorithms may be linear in nature where the same sequence of ope ·· ·ons is followed each time the algorithm is executed. In contrast, other algorithms may have decision points where the results or outputs from previous operations are tested or evaluated to determine if certain specific conditions have been satisfied" (Merrill, 1977, p.94). Thus, branches are formed and distinct paths are created for each decision point.

Evidence of the fact that complexity of the algorithm must be considered as a relevant factor in determining their use is demonstrated in a pilot study conducted by Schmid and Gerlach (1977). In the hopes of establishing the conditions within which algorithmic instruction can best occur and the optimal length of instruction, the pilot study was devised in order to push each parameter to its logical extreme. In terms of complexity and length, the algorithmic representations contained 21 discriminators and 12 operators. Results showed that,"...the task requirement appeared to be unwieldy, requiring an inordinately large number of decisions for a single learning session" (Schmid and Gerlach, 1977, p.9).

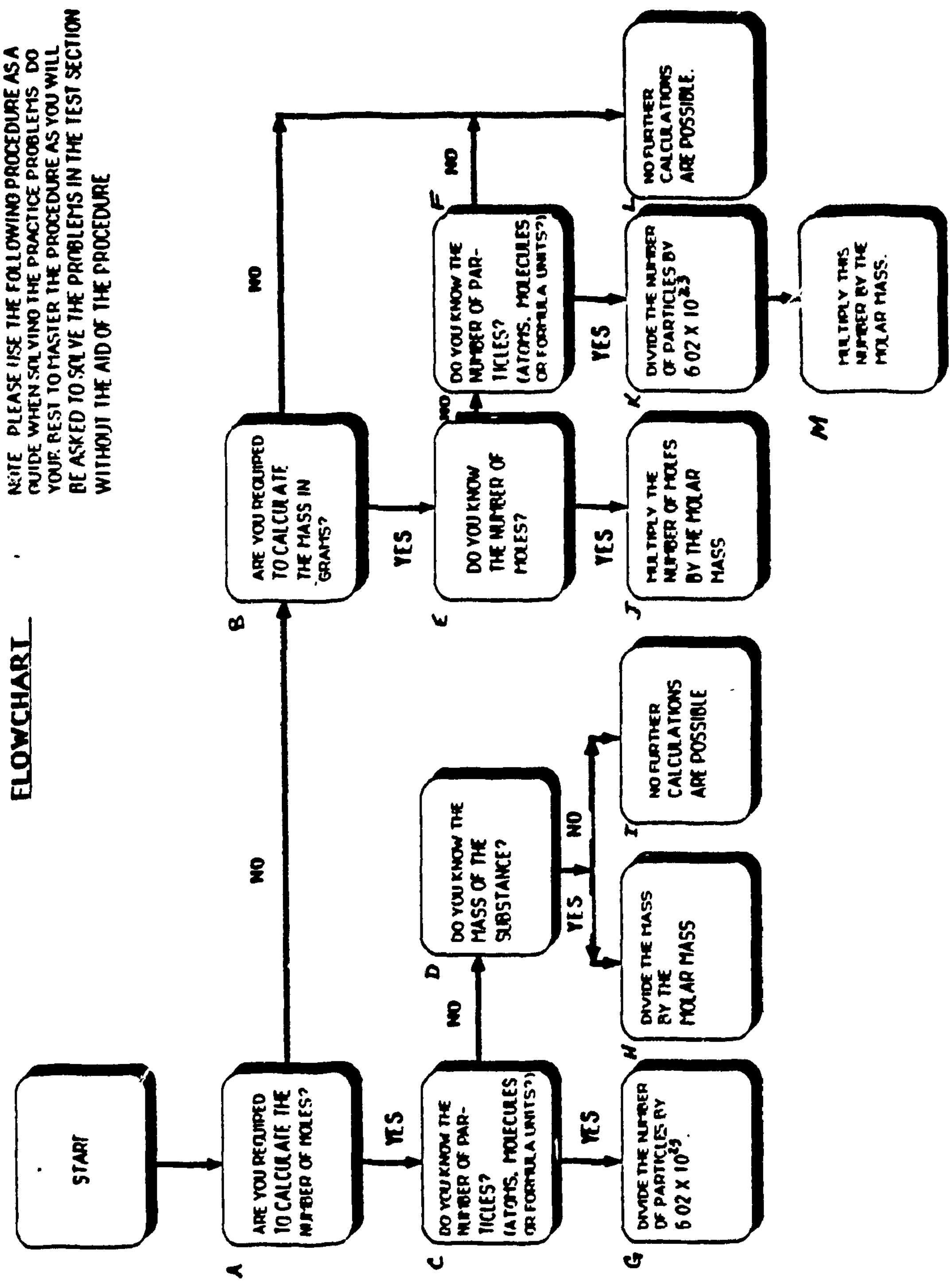
Description of the Algorithm

The terms used to describe algorithms are well laid out by Schmid and Gerlach (1986). The five terms they describe and define refer to both the physical characteristics and the processing characteristics of the algorithm. The first term described is the "depth" of an algorithm. "The depth is the number of levels presented. A level is formed at each new serial step in a branch, so the depth is determined by the longest branch" (p.164). Using the algorithm developed for this study as an example, the depth is illustrated in Figure 2. The longest branch in this algorithm is B - F - K - M, thus the depth of this algorithm is four.

The second term described is the "width" of an algorithm. "The width of an algorithm is associated with how many parallel processes can be recognized at a particular level. The width always refers to the widest level" (p.165). In figure 2 then, the fourth level is the widest, with six independent operators present.

The other terms refer to the processing characteristics of algorithms and specify the relation among the units of the algorithm, depending on how the user is to address them. Serial processing refers to the influence of either the routing procedure and/or by the use of the actual output as an input. For example, in Figure 2, to answer unit C, you have to answer "YES" to unit A. Unit C is influenced by the output of unit A and is therefore considered a serial process. Where there is no inter-dependence between units, the process is called parallel processing. Finally, the term branching describes tasks that contain both serial and parallel components.

Figure 2. Chemistry Algorithm - The Use of The Mole



Issues/Algorithms in Instruction

The major aim of this study was to explore, in a classroom setting the use of different modes of representations using algorithms. Thus, the absolute value of using algorithms in instruction is not in question here; rather, the use of the algorithmic approach in terms of the instructional method chosen is what is of concern. The way an algorithm is presented to the learner will affect whether the approach is deemed effective. As with any instructional innovation, if misapplied in the formative stages, it can lead to a premature death of an otherwise effective procedure. Instructional designers are continually in search of problem-solving procedures that are easy-to-use, effective and efficient and above all, communicable.

What constitutes the most appropriate representation of a given algorithm involves determination of what is most efficient given the subject matter, task type and relevant learner population. "Algorithms may be represented as : 1) prose text, 2) numbered steps, 3) question lists, 4) branching booklets, 5) flowcharts, 6) directed graphics, etc." (Merrill, 1977 p.107).

Some researchers argue that prose descriptions are often ambiguous and difficult to interpret while others argue that flowcharts are laborious to draw and difficult to alter. It is up to the instructional designer to choose that form which he/she deems most efficient for his/her purposes. This study chose a flowchart to establish whether chemistry content is better learned graphically than when it is presented in prose version. It was felt the former would prove to be more efficient after careful consideration of the relevant subject and learner population.

Therefore, the two forms of representation chosen for this study were standard prose and flowchart forms of algorithms. While standard prose has been used in many instructional situations over the years and has proven to be useful in certain subject areas, there was question as to whether it was the most appropriate for the subject matter of this study (chemistry). Thus, the question was, "What method of algorithmic representation, prose or flowchart, best serves the subject matter of chemistry?". It was felt that the flowchart would be of most use to the learners because it provides the minimum sequence of decisions to the learner, routing them graphically to the next relevant solution. The standard prose on the other hand, leaves the learner to decide for themselves whether the next step is indeed relevant to the proper solution to the problem. Davies (1970) argues, "that continual prose inadequately expresses the complex logical interrelationships involved in rules and ... [and that] ... diagramming such algorithms through the use of flowchart symbols has proven to be very valuable in improving communication" (Davies, in Merrill, 1986, p.105).

One point of controversy is whether the use of an algorithm simply takes the onus off the student to make the effort to create his/her own strategy for the solution to the problem. Thus, the criticism is that the algorithm soon becomes a crutch for the student. Indeed, such results have been noted in some studies. Schmid and Gerlach (1986) found that performance by students who were allowed to continue working with the algorithm over an extended period of time actually did decline. However, it was also noted that students in the algorithmic treatment worked more efficiently than those in the prose treatment because the instruction directed them immediately to the resulting strategy. "Only after the prose group had adopted and learned the proper strategy could it work as efficiently" (Schmid & Gerlach, 1986, p.171). The best instructional combination in this study appeared to be the high effort practice on a serial segmentation approach. Thus, what emerges here is a guideline on the use of algorithmic representation during problem solving:

> ...it appears reasonable to remove the algorithm's representation as early as possible, both to increase learner effort during learning and to wean the learner from any dependance upon an easily mastered procedure. Removing the representation may also encourage the learner to create his or her own algorithm representation (overt or covert), thus further enhancing accommodation. (p.171)

The extent of retention is also an issue which this study addresses. Whether learners rely on the physical presence of the algorithm in order to solve the given problems is something that few studies have addressed. Schmid and Gerlach's (1977) study using the Capital Gains Tax algorithm revealed that performance after a one week delay decreased only one percentage point even though 1/4 of the subjects were not allowed to view the tax algorithm after the initial practice session. However, performance of those who were given the algorithm during the test sections was significantly better than those who did not have access to it. Also, in a study conducted in 1978 (Schmid and Gerlach, 1978) this finding was replicated. There was a significant decrease in performance when the flowchart was withheld. Whether or not it is possible to enhance learning, notwithstanding speed and accuracy with an algorithm, without having the learner become dependent upon the physical presence of it, is still questionable.

Field-Dependence/Field-Independence

Field-dependence/field-independence is an aptitude which may influence students' ability to use structured algorithms. Field-dependence and field-independence is described by Witkin (1977) as a global versus articulated cognitive style. This suggests that people have different cognitive functionings and that they impose different degrees of organization on a "field". According to Witkin (1977), if unstructured subject matter is presented, there is a distinct difference in performance between field-dependent and field-independent students. If the subject matter is highly structured or well organized so that students do not have to impose structuring, no influence of field-dependence/ field-independence will be found. Witkin, Moore, Goodenough and Cox (1977), report an investigation in which teachers saw their more field-dependent students as more able to benefit from being provided with a well-structured plan for their actions.

This distinction between field-dependent/field-independent students has also been used in research dealing with programmed instruction. "In teaching programs with large steps (low-structuring), field-dependence/field-independence had a strong influence on achievement. In the small-step programs (more structure) no influence of this cognitive style variable was found" (De Leeuw, 1983, p.7).

The Embedded Figures Test assesses, among other things, the extent to which the organization of the prevailing field dominates perceptions of any of its parts. A learner who performs in a field-dependent fashion adheres to the structure or organization of the field as it is presented, whereas a learner who is relatively field-independent will overcome the organization of the field and will impose his/her own structure with the result that their percepts are organized and definite.

This connection between analytical and structuring abilities has been labelled the global-articulated dimension of the cognitive functioning. The cognitive style involved can be described as follows:

> At one extreme, when the field is structured, there is a tendency for its organization, as given to dictate the manner in which both the field as a whole and its parts are experienced; when the field lacks structure, experience tends to be global and diffuse. At the other extreme there is a tendency for experience to be delineated and structured, even when the material lacks inherent organization; parts of a field are experienced as discrete and the field as a whole organized. To these opposite poles of the cognitive style we applied the labels "global" and "articulated. (Witkin, et al., 1977, p.7)

Evidence of the fact that the field-dependence/ independence construct extended across both perceptual and intellectual activities became more apparent. People who were more field-independent were discovered to be more analytical than their more field-dependent counterparts. Analyses and structuring are considered complementary aspects of articulation.

The field-dependent/independent cognitive style is one of numerous cognitive styles discussed in the literature, each suggesting specific effects on learner processing. Information derived from the work on cognitive styles over the past two decades is being applied to research on problems within education at an ever increasing rate. "Among the cognitive styles identified to date, the field dependence-independence dimension has had the widest application to educational problems" (Witkin, et al., 1977, p.1).

The earliest work in field-dependence/independence dates back to 1949 and was concerned with how people located "true uprightness". By separating the visual and bodily standards, experiments were conducted to determine their roles in perception of the "upright". The Rod and Frame Test (RFT) was the instrument used, or a smaller, more portable form (PRFT). A luminous square frame was presented to the participant in a room void of light. The frame could be rotated about its center and pivoted. At the same time a luminous rod was presented to the learner which could also be pivoted, independently of the luminous frame. The participant's task was to adjust the rod to a position where he/she perceived it as upright while the frame around it remained in its initial position of tilt.

Individual differences in the manner in which participants performed the adjustment were noted. Those who adjusted the rod according to its position within the luminous frame were thought to be field-dependent - that is, dependent on the visual field as their referent to "true uprightness". Those who positioned the rod independent of the frame, were labelled 'field-independent' - independent of the visual cues in perceiving "true uprightness". Other, similar tests that were used to study perceptions of uprightness included the Body-Adjustment Test (BAT) and the

Rotating Room Test (RRT).

Although the *Embedded Figures Test* (EFT) was developed to see if these tendencies would carry over to other areas of perception and does not involve perception of the upright or the body, it is similar to the RFT and BAT in its essential perceptual structure. A participant is asked to look at a certain simple figure with the directive to locate the simple figure in a corresponding complex figure. Again, the participant is asked to locate an object, this time a geometrical figure, and to extract it from the surrounding visual framework within a prescribed amount of time. People at one extreme had no difficulty locating the simple figure and were considered field independent whereas people at the other extreme were unable to locate the simple figure in the time allocated.

Because scores from the *EFT* form a continuous distribution, "...these labels reflect a tendency, in varying degrees of strength, toward one mode of perception or the other. There is no implication that there exists two distinct types of human beings" (Witkin, et al., 1977, p.7). The field-dependence/independence dimension has a bipolar characteristic; it is not more advantageous to be at one pole or the other.

These tests are now available in simpler forms - even group forms - and are applicable in many cases to the entire age span, from kindergarten on. People tend to remain stable in their propensity for perceiving after mid-adolescence (Witkin & Goodenough, 1981). Consistent age related changes have been noted though. Developmental curves for the EFT, RFT and BAT, covering the 8-to-24 year period, show a marked, continuous increase in field-independence, although in this period the rate of change slows down with increasing age (Witkin, Goodenough & Karp, 1977). Nonetheless, learners tend to hold the position relative to peers their own age in the field-dependence dimension as they grow up, while as a group they move toward greater field-independence.

These stylistic tendencies are not isolated to people's perception of immediate stimuli but also appear in congruent form in his/her dealings with symbolic functionings. In a study conducted by Stasz, (1976), structuring of curricular content by learners and their teachers was examined in a social studies course. In the area of social science, much of the structuring of concepts is left to the individual. In order to test for field-dependence tendencies, students were asked to rate ten general anthropological concepts in terms of similarity. It was found that "both before and after the mini-course instruction field-dependent teachers and students made fewer distinctions among concepts..."(p.9) and they clustered them in large, loosely organized groups. Field-independent students on the other hand, clustered the general concepts into smaller groups with less overlap across groups.

Further evidence of the articulated/global dimension is revealed in studies of organizational factors in learning. In a study by Koran, Snow, and Macdonald (1971) teachers were tested on their ability to acquire teaching skills from either written or video-modelling procedures. Differential effects were found for field-dependent and field-independent teachers. Field-dependent teachers were found to benefit more from the video and field-independent teachers were found to benefit from both the written and video versions of the instruction. It was suggested then, that the more field-dependent teachers could not generate the concrete, explicit presentation found in the video, when utilizing the written version of the instruction.

Another study that varied the amount of structure provided to the learners was a study which used programmed instruction. In this study, (Schwen, 1970), the number of generalizations and examples given before an active response from the learner, was varied. In treatment 1, participants worked in large steps, (i.e.) low structure. Participants were given all generalizations dealing with an 'imaginary science' and all examples before they were asked to respond. If they answered incorrectly, they were provided with corrective feedback immediately. In treatment 2, the instruction was highly structured, so that only one generalization and example was presented to the learner at a time and he/she was required to answer after each generalization before moving on to the next (Schwen, 1970).

In the highly structured version of instruction, no relation between field-dependence/field-independence and retention three weeks later was found. In the low-structured version however, greater field-independence was associated with greater retention.

As this present study examined high and low structuring of content in chemistry, it was expected that the results would be similar. That is, that the field-dependent students would show greater achievement with the highly structured flowchart version of the chemistry problem than with the low-structured prose version both immediately after instruction and two weeks later.

Other dimensions studied in terms of field-dependence/ field-independence include social functioning and interpersonal relationships. Field-independent individuals tend to be less socially-oriented than their field-dependent counterparts and seem to prefer less personal contact. In career differentiation then, field-dependent persons tend to choose areas such as social work or education. Field-independent persons tend to choose areas that are task oriented, such as mathematics, engineering, physics, chemistry, etc.. The tendency then, is for field-dependent people to choose educational/vocational areas in which involvement with others is a major feature. Field-independent people tend to choose work which are more solitary. It has been found repeatedly that, "In contrast with the preponderant interest of field-independent persons in the analytical· impersonal domains, field-dependent persons express interest in interpersonal domains that particularly require social skills" (Witkin, et al., 1977, p.41).

This study used a high school chemistry class - an area that would seem to attract the more field-independent type of learner. However, students at the senior academic level are required to sign up for at least one science course, so that whether or not these students signed up for pleasure or because of necessity remains unanswered.

Regarding the reading skills of field-dependent and independent learners, it is suggested that field-dependent people have more difficulty learning concepts from prose material than field-independent people. Again, those who have difficulty disembedding, independent of the organized field (i.e. field-dependent) show less ability in learning material given in prose version, while their field-independent counterparts can identify the concepts by imposing their own structure on the written material.

Studies which support this finding deal with cue salience. "It is clear that in the formation of hypotheses about the nature of the concepts to be learned, noticeable cues are, in general, more likely to be used than cues that are not very noticeable" (Witkin, et al., 1977, p.25). Field-dependent persons who rely particularly on the field for dominant organization would benefit from the effects of cue salience. Field-dependent subjects are dominated by the salient attributes of a stimulus and tend to ignore non-salient cues and are therefore less successful at concept attainment than a field-independent learner who attends to all cues, whether salient or non-salient.

It seems necessary then, for instructional designers to consider these differences when designing material that would be effective for field-dependent persons as well as for field-independent people. This study was interested in examining the effects of structured material (flowchart) against low-structured material (standard prose). With the research on structure and reading skills of field dependent/independent persons, it was expected that the flowchart treatment would be more efficient for the field-dependent and that the field-independent would do as well in either treatment.

In a study conducted by De Leeuw (1983), it was predicted that field-dependence/ field-independence was a relevant moderator variable in the effect of an algorithmic treatment or a heuristic treatment. That is, field-dependent students would perform better after algorithmic than after heuristic training and that field-independent students would perform better with the heuristic training than with the algorithmic training. The task involved in the study required the learner to extrapolate number series and to evaluate syllogisms. The results of the experiment indicated that field-dependence/independence, as measured by the EFT was a significant predictor of the degree of horizontal and non-specific transfer. That is, the degree of transfer was greater for the more field independent students and the field-independent were less "set-prone" than the more field-dependent students.

As stated earlier, the field-dependent/independent dimension is measured by tests which require the participants to overcome embeddedness. One criticism of the EFT is that it fails to control for intelligence and general ability (Rosenberg, Mintz & Clark, 1977). The EFT requires the participant to extract a simple figure from a more complex geometrical figure. In the preceding study, for the EFT to be considered a unique predictor of the ability to transfer, the mental ability variable had to be partialled out. For this reason, IQ was included in De Leeuw's study (1983).

Goodenough and Karp (1961) state that certain subtests of intelligence tests also involve the capacity to overcome embeddedness. Subtests such as the WISC Block Design, Object Assembly and Picture Completion require the learner to overcome embeddedness and therefore a field-independent learner would score better on an I.Q.test. Elitcher in Witkin et al., (1971) "...obtained significant correlations between CEFT scores and a composite of the three WISC subtests for both boys ($\underline{r}$ = .32) and girls ($\underline{r}$ = .36)" (Witkin, Oltman, Raskin & Karp, 1971, p.26). However, test scores reported by

Witkin have shown little relation to grade point average or to overall achievement. Dickstein (1968) found that concept attainment performance is more closely related to field-independence than general intelligence. It must be noted that cognitive styles are concerned with the form rather than the content of cognitive activity. "They refer to individual differences in how we perceive, think, solve problems, learn, relate to others, etc." (Witkin, et al., 1977, p.15). As such, it is also important to reiterate that to be field-independent or field-dependent does not determine intelligence, as is the case with intelligence tests.

The participants in this study were not tested in terms of intelligence. It was felt that they would all have a similar background because of the fact that they come from the area elementary schools and are virtually all at the same grade level, and therefore, would be of average intelligence. Also, a range of scores on the Embedded Figures Test was expected. It was not confirmed whether these students had signed up for chemistry because of a liking of it or whether they were simply fulfilling the requirements of a science credit. Therefore, no speculation as to whether there would be more field-independent people (i.e., because of their propensity for the sciences) than field-dependent people was made.

The test used in this study was the Group Embedded Figures Test (GEFT) which was designed to provide an adaptation of the original individually administered EFT which would allow for group testing. It contains 18 complex figures, 17 of which were taken from the EFT and has a time limit of five minutes per section. In terms of estimating reliability and validity of the GEFT, one method is to look for a correlation between parallel forms of test with identical time limits. "Correlations computed and corrected by the Spearman Brown Prophecy formula, produced a reliability estimate of .82 for both males and females. These reliability estimates compare favorably with those of the EFT" (Witkin, Oltman, Raskin & Karp 1971, p.28). Studies conducted by Jackson, Messick and Myers (1964) revealed that of the types of embedded figures tests that were included in their study (the GEFT being one of them), all types were substantially correlated. Witkin, Oltman, Raskin and Karp (1971), state that "the combined evidence suggests that the GEFT may prove to be a useful substitute for the EFT when individual testing is impractical" (p.29).

Summary

This study explored in an introductory chemistry course, the effect of different modes of representation on immediate and delayed field-dependent/field-independent student achievement as well as the amount of time required to complete the problems and the accuracy with which these were executed. Hopefully, the results of this experiment will replicate the findings of Lewis, et al., (1967) and Schmid and Gerlach (1977) and will further explore the the issue of whether the approach retains is efficiency and effectiveness over an extended period of time. Also examined was the question as to whether approach effectiveness differs for field-dependent students and field-independent students. Thus, the research questions to be addressed in this study were as follows:

- Will the mode of representation affect the mean amount of time necessary to complete the problem-sets?
- Will the mode of representation affect the number of errors made by students in solving the problem-sets?
- Will the mode of representation affect students' achievement on the immediate posttest?
- Will the mode of representation affect the students retention of instruction on delayed posttest?
- Will field-dependence/independence be a relevant moderator variable in the effect of the flowchart/standard prose treatment?

The design will also allow for a test of interaction among the above variables.

It was hypothesized that students in the high-structure flowchart treatment would do significantly better than students in the low-structure standard prose treatment in terms of both immediate and delayed achievement as well as in terms of speed and accuracy with which they tackle the problem sets. As well, based on the reported relationship between the need for structuring and the cognitive style variable it was hypothesized that field-dependent students would perform better in the flowchart treatment than in the standard prose treatment.

Method

Design

This study used a two-between, one-within subject randomized block design.

The independent variables were as follows:

- Mode of Content Representation:
  - High-Structure Algorithmic Representation: Decision tree type representation in which each statement describes only one task and decision points are indicated graphically.
  - Low-Structure Standard Prose: Each statement in the prose can describe more than one task and decision points are not indicated.
- Level of Field-Independence (High, Medium, Low) , and
- Location of Achievement Test (Immediate, Delayed)

The dependent variables were as follows:

- Level of achievement (immediate and delayed)
- Time spent per student on posttests (efficiency in problem-solving as a result of instruction).

Analyses of variance with repeated measures on the location of the achievement test were employed.

Participants

The participants were 102 grade 11 students at a High

School in Ottawa, Ontario enrolled in an introductory chemistry course Out of 102 participants, 77 students attended all four sessions, i.e,: 1) _Group Embedded Figures Test_ and Pre-Test session, 2) Instruction and Immediate Post-Test session, and 3) Delayed Post-Test session. Thus, 25 students were dropped because of failure to attend the GEFT part of the study and 2 students were dropped from the study because of failure to comply with all instructions given - 75 students completed all parts of the study.

Materials

An official version of the _Group Embedded Figures Test_ was distributed to all students in order to rank them in terms of field-dependence and field-independence. The test required the participant to separate embedded items from their background; as such, the test was used to reveal those participants who are influenced by the total field an have difficulty overcoming embeddedness and those who are not influenced by the total field. According to their score the _GEFT_, participants were ranked as either high, medium or low in terms of field-independency and then were randomly assigned to one of two treatments: 1) Representation using a flowchart; and 2) Representation using standard prose (See Table 1)

All materials and instructional tasks were developed by the author. In consultation with three subject matter experts, the content chosen was a section on the "mole".

Table 1

Research Design

		Mode of Representation	
		High Structure Flowchart	Low Structure Standard Prose
Field Independent	High	n = 12	n = 12
	Medium	n = 12	n = 12
Field Dependent	Low	n = 12	n = 12

Students would learn how to use the mole to count atoms and how the number of moles of a substance is related to the mass of the substance. It was felt that these particular concepts were somewhat difficult for the students to grasp using conventional standard prose and usually took up to two class periods to teach.

Thus, the task consisted of generating the solution to chemistry problems involving:

- the calculation of the number of moles present in a particular substance, given:
  - the number of particles (ions, molecules, atoms or formula units) or
  - the mass of the substance; and
- the calculation of the mass in grams of a particular substance given:
  - the number of moles present in the substance or
  - the number of particles (ions, molecules, atoms or formula units).

Depending upon the information presented to the participant, one of five possible computational outputs was appropriate. Students were not required to perform the actual calculations, but were asked to write the appropriate steps involved in carrying out the solution.

A pool of forty-five problems was developed by the author. In consultation with a subject matter expert twenty problems were chosen from the possible forty-five. Four examples of each solution were chosen and four sets of problems were randomly generated. These problem sets were randomly assigned to the practice, pretest, post-test and delayed posttest sections of the study.

A short, two-page introduction was developed and presented to the subjects. (See Appendix B) Both modes of representation made use of the same printed introductory material which informed the students as to the nature of the task and the procedure, and covered the same content. The instructions specific to each treatment followed containing the appropriate representation and an explanation of the type of problems to be solved. (See Appendices C & D)

Following this, the instructional material was presented in two forms:

1) a highly structured algorithmic mode of representation (flowchart) was utilized in which each statement described only one task and decision points were indicated, and
2) a low-structured standard prose representation in which more than one task was described at once and decision points were not indicated.

Both the flowchart and the standard prose versions of the chemistry concepts incorporated the exact same content. According to the specific information provided, participants were required to write down the appropriate solution required in order to calculate the number of moles in a substance or the mass of the substance in grams. (See Appendices E & F)

The highly structured algorithm was designed according to the guidelines set out by Schmid and Gerlach (1986). The depth (i.e. the longest branch) of the algorithm is four and the width of the algorithm (i.e. the widest level) is six. According to Schmid and Gerlach (1986) the width of an algorithm should not exceed seven because of limitations on memory load.

The standard prose representation followed an if/then format. These modes of representation were included in the instructional packages as insertion sheets. They were presented on blue sheets so as to allow for easy access and to assure that each student realized the blue sheet was the "procedure" to be followed.

The practice section of the exercise consisted of five problems, each problem being an example of one of the possible routes the participant could take using the procedure. (See Appendix G) After completing all the practice problems, students were asked to raise thei. hand. Students were then given an answer sheet in order to check their answers and to correct any mistakes. Instructions were included and feedback as to the nature of the answers was included on the answer sheet. The answer sheet was presented on pink paper. (See Appendix H)

The post-test consisted of five randomly ordered problems testing the exact same concepts as those in the practice section of the exercise.(See Appendix I) The instructions were included at the top of the page and a space was provided on the test for the participants to enter their finishing times. Starting time was held constant. The delayed post-test also consisted of five randomly ordered problems and a space for participants to enter their finishing times. (See Appendix J)

Procedure

The experiment ran over 3 weeks. Students were given an official version of the Group Embedded Figures Test during week one. This test, an adaptation of the original individually administered Embedded Figures Test which allows for group testing was chosen because of the fact that scores for many individuals could be collected in a single 20 minute session. Participants gathered in the cafeteria at 9:00 o'clock in the morning, directly after morning announcements. The GEFT booklets and pencils were placed four to a table before the participants arrived. The booklets were all face down.

As soon as all participants were seated, they were asked over a loud speaker to fill out the identifying information on the front of the booklet. They were instructed to use their names as opposed to numbers because the author had no way of knowing what class period would correspond with what number. Students were then instructed to begin reading the directions which included two practice problems to complete and then to stop and wait for further directions.

The directions were then reviewed aloud and participants were permitted to ask questions at this time. Participants were then instructed to turn the page and begin the first section and were told they had two minutes to complete the section. After two minutes, all participants were asked to stop. Sections two and three were conducted in the same fashion except that time allocation for these sections was five minutes each. Three proctors circulated in the room, making sure all students were working on the appropriate section and replacing pencils as required.

Once this test was completed, all booklets were picked up by the proctors and the pre-test was handed out face down. The instructions and task orientation for the pre-test were explained to participants over a loud-speaker. All questions were answered and the participants were instructed to turn the test over, write their name, and begin. When the test was completed, they were instructed to raise their hand. The proctors picked up the tests and the students were told to proceed to their respective classrooms which were already in session. No time limit was to be imposed as it was hoped that students would proceed at their own pace. However, some students felt if they took long enough they would miss their entire first class. After fifteen minutes, all remaining test were picked up.

According to the participants scores on the GEFT, participants were ranked as either high, medium or low in terms of field-independency. On the basis of this cognitive style, students were blocked, with equal numbers of field-dependent and field-independent students being randomly assigned to treatment 1 - highly structure flowchart mode of representation and equals numbers being assigned to treatment 2 - low-structured standard prose mode of representation.

The instruction and immediate posttest session was run in the participants' respective chemistry class periods the next day. Thus, subjects were run in four groups ranging from 17 to 25 subjects in their normal classroom.

The material for all treatments was handed out in the same fashion. All students receiving the highly structured flowchart presentation mode were called by name and a proctor brought them the appropriate package. All students receiving the standard prose version were then called by name. The introduction was read aloud and students followed silently. All questions were answered at this point. Students were asked to proceed at their own pace and to refer to the blue procedure page. However, they were reminded to do their best to remember the procedure as they would not have access to it during the test portion of the exercise. They were asked to raise their hand after the practice section of the exercise so that a proctor could bring them the answer sheet. Once they corrected their practice work students were told to raise their hand and to review the material until everyone had finished. All students were given 20 minutes to complete the instruction. Participants who finished early were asked to read material provided to them beforehand by their respective chemistry teachers. Finally, all instructional material was picked up and the immediate post-test was distributed face down. Participants were asked to record their finishing time after they had completed the entire test. All questions were answered and the participants were instructed to turn the test over, read the instructions and begin. The starting time was marked on the board but students were reminded that it was not a race and that it was in their best interest to work at an appropriate pace. Tests were then collected and the students went to their next class.

The delayed posttest was administered nine days later. Once again, all students gathered in the cafeteria, directly after morning announcements. This test was administered in exactly the same fashion as the immediate post-test. Again, students were reminded to record their finishing time in the space provided. The subjects worked through the problems, recorded their finishing time. When they were finished they were asked to raise their hand and a proctor picked up the test. Participants were thanked and debriefed.

Results

Scoring Procedure

All test questions were scored for number correct, with 2 points being given for the correct answer. Half marks were awarded for only one question on each test, in which students were required to remember more information. Omissions on the test items were recorded as errors. Means and standard deviations appear in Table 2. Missing values were awarded the grand mean in order to maintain a balanced design. There were 8 missing values in all.

Performance level on the pretest was negligible; therefore the use of the pretest as a covariate was abandoned.

Achievement Data

An analysis of variance was performed with mode of representation (flowchart, standard prose) and level of field-dependence as between group factors and location of achievement test (immediate, delayed) as the within group factor.

A significant interaction was found between mode of representation and location of achievement test F (1,66) = 10.27, $p < .01$. Means and standard deviations are presented in Table 3. The Source Table of Comparisons is found in Table 4. Figure 3 illustrates the interaction.

Table 2

Means and Standard Deviations for Scores on the Two Posttests

Mode of Representation

		Standard Prose Imm.	Standard Prose Del.	Flowchart Imm.	Flowchart Del.
Field Dependent	Low	X=4.58 SD=2.31 *=0	X=4.70 SD=2.46 *=2	X=7.83 SD=1.27 *=0	X=4.92 SD=2.68 *=1
	Med.	X=7.51 SD=1.93 *=1	X=6.24 SD=2.70 *=2	X=8.00 SD=1.48 *=0	X=6.12 SD=1.81 *=1
Field Independent	High	X=6.42 SD=1.83 *=0	X=5.54 SD=1.83 *=1	X=8.33 SD=1.72 *=0	X=5.17 SD=2.13 *=0

Location of Achievement Test

Note - *=missing values awarded the grand mean

Table 3

Means and Standard Deviations Indicating Mode of Representation x Location of Achievement Test Interaction from the Repeated Measures ANOVA.

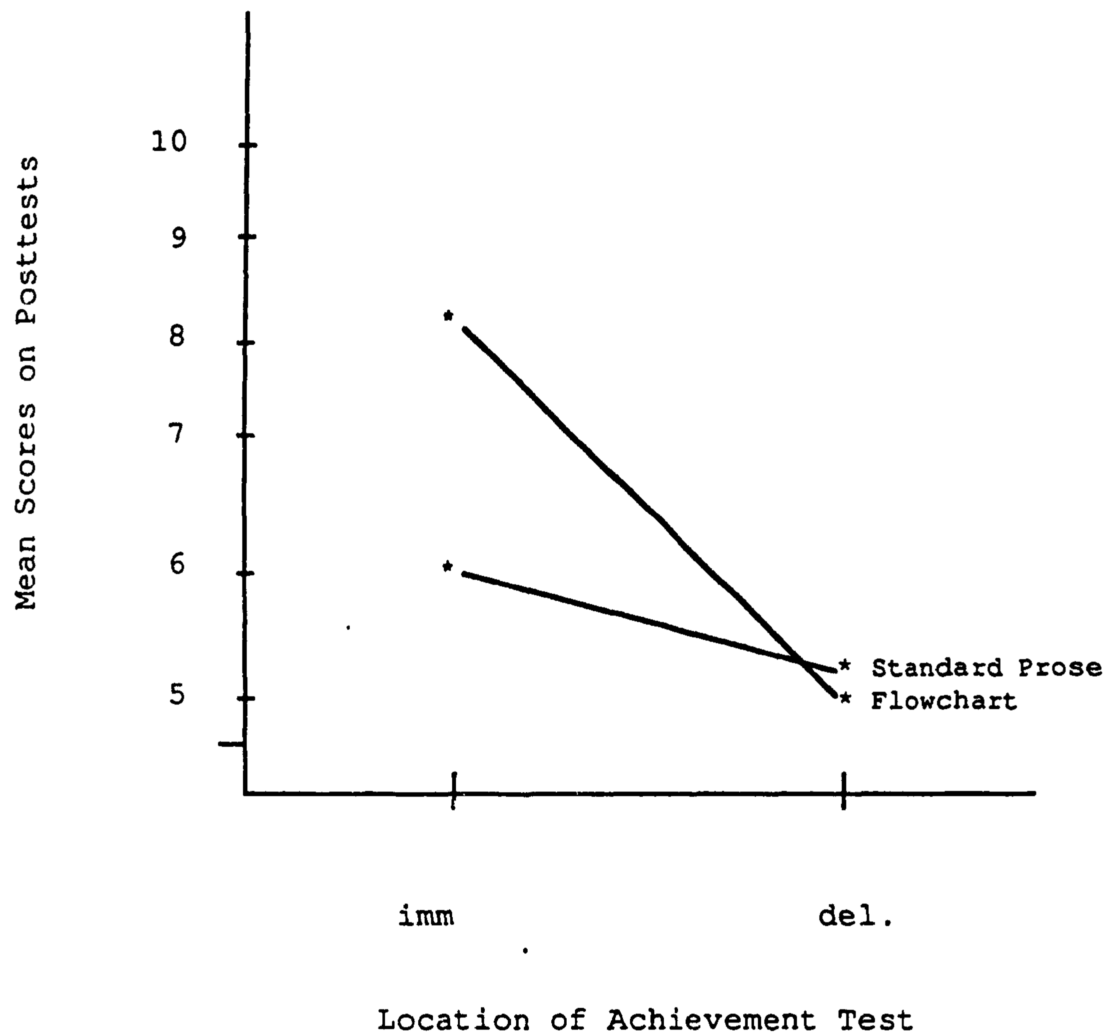
Mode of Representation	Location of Achievement Test: Immediate	Delayed	Totals
Flowchart	n=36 X=8.06 SD=1.47	n=36 X=5.40 SD=2.59	72 X=6.73 SD=1.88
Standard Prose	n=36 X=6.17 SD=2.33	n=36 X=5.49 SD=2.23	72 X=5.83 SD=2.48
Totals	72 X=7.11 SD=2.15	72 X=5.45 SD=2.42	144 X=6.28 SD=2.43

Table 4

Source Table of Comparisons - Repeated Measures ANOVA

Source	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Recode of EFT (A)	2	51.715	25.857	4.525	.0144
Type (B)	1	29.031	29.031	5.08	.0275
AB	2	14.712	7.356	1.287	.2829
subjects w. groups	66	377.155	5.714		
Repeated Measure (C)	1	99.983	99.983	29.23	1.0E-4
AC	2	2.465	1.232	.36	.6989
BC	1	35.123	35.123	10.268	.0021
ABC	2	9.201	4.6	1.345	.2676
C x subjects w. groups	66	225.759	3.421		

<u>Figure 3</u> Mode of representation x location of achievement Test Interaction



The Tukey test was then performed on all pairwise comparisons. Tukey revealed that those students who received the flowchart mode of representation performed significantly better on the immediate posttest than those students who received the standard prose mode of representation, q (4,66) = 6.118, p < .01. This performance was illustrated only on the immediate posttest.

A significant difference was also found for those students who received the flowchart instruction on the immediate and delayed achievement test. It was revealed that students using the flowchart performed significantly better on the immediate test than they did on the delayed achievement test, q (4,66) = 8.613, p <.01. No significant differences were found between the immediate and delayed achievement tests for those students who utilized the standard prose version of instruction.

Significant main effects were found for field-dependency, F (2,66) = 4.53, p < .05 Post hoc analyses performed on the marginal means for field-dependency revealed that students who scored low on field-independency (i.e. the more field-dependent) scored significantly lower in terms of achievement than their medium field-dependency category counterparts, F_{comp} (1,66) = 8.99, p < .05. However, no significant differences were found when the low field-dependency category was compared to the high-field-dependency category.There were no other effects among the variables.

Time Data

Time data were generated by having students record the exact time (i.e. number in minutes) it took them to complete the tests. Means and standard deviations appear in Table 4.

Missing values were awarded the grand mean in order to maintain the balance of the design. As there were numerous missing values (22 in all), the time data results should be reviewed with caution.

Again, an analysis of variance with a repeated measure was performed. A significant main effect was found on the repeated measure (location of achievement test) $F(1,66) = 9.41$, $p < .01$. Students required significantly less time to complete the immediate posttest - more time was needed in order to complete the delayed posttest.

Table 5

Means and Standard Deviations - Time Data

Mode of Representation

		Standard Prose		Flowchart	
		Imm.	Del.	Imm.	Del.
Field Dependent	Low	X=8.75 SD=2.56 *=0	X=8.99 SD=1.24 *=4	X=8.50 SD=2.75 *=0	X=10.06 SD=2.32 *=2
	Med.	X=8.71 SD=2.83 *=1	X=9.53 SD=3.67 *=3	X=7.92 SD=3.03 *=0	X=10.72 SD=1.57 *=2
Field Independent	High	X=8.52 SD=3.18 *=3	X=10.21 SD=2.84 *=2	X=8.63 SD=2.10 *=2	X=9.16 SD=0.99 *=3

Location of Achievement Test

Note - *=missing values awarded the grand mean

Discussion

The results of this investigation largely replicate the findings of earlier studies conducted by Lewis, et al.,(1967) and Schmid and Gerlach (1977).

The hypothesis that students in the highly-structured algorithmic treatment would perform significantly better than students in the low-structured algorithm treatment was supported by the data immediately following instruction - thus, the flowchart was the more effective mode of representation in terms of facilitating initial learning.

However, the prediction that this performance would be maintained after a nine-day delay was not supported. Performance of those students who received the flowchart actually decreased significantly on the delayed test whereas no such decrease was apparent for those students who received the standard prose. It appears then, that while the flowchart initially facilitates learning, this effect is not maintained over time.

It may be that the standard prose group retained the content better due to increased effort during instruction. Indeed, this loss in terms of retention was noted by Schmid and Gerlach (1977) in their study of three forms of algorithmic representation. Perhaps the more highly-structured the algorithm is, the less effort students are required to make during learning. However, students using the flowchart averaged 81% accuracy on the immediate posttest whereas students using the standard prose averaged only 62% accuracy. Both groups averaged approximately 54% accuracy on the delayed test. Although the loss was significant for the flowchart mode of representation, its initial effectiveness must be noted. Whether students should be permitted to continue using the flowchart for a longer period of time following instruction to further enhance accommodation remains questionable. Schmid and Gerlach (1977) note that, "...although learners can indeed memorize the content of an algorithm for later use, enabling them to continue using the procedure is significantly more effective" (p.22).

Notwithstanding the loss of effectiveness of the flowchart, the results indicate that diagramming the logical interrelationships in these types of chemistry problems is, in point of fact, effective.

With regard to field-dependency being a relevant moderator variable in the effect of the flowchart/standard prose treatments, some interesting results emerge. Contrary to what was expected, there was no evidence to suggest that those students on the more field-dependent end of the continuum performed better with the highly-structured flowchart than with the low-structured standard prose mode of representation. Rather, it was revealed that the more field-dependent students (low) scored significantly lower in terms of achievement than participants in the medium category - but not significantly lower than students who were labelled as (high) field-independent.

There was evidence to support the hypothesis that students who were considered field-independent would perform equally well, regardless of their treatment assignment. No significant differences were noted for the (high) field-dependency group in terms of which treatment they received. This result supports other research in which the amount of structure incorporated in instruction was varied (Schwen, 1970; De Leeuw, 1983). Scores on the Group Embedded Field-Dependency Test in this study ranged from 0 to 18 (out of a possible 18), the mean score being 12.4. The participants in this study were slightly skewed toward the field-independent end of the continuum. Thus, the failure to find performance differences for medium and high level learners may be attributable to the non-discriminating powers of the GEFT when scores are clustered at the high end.

Time Data

No differences were noted between the two instructional techniques with respect to speed with which the participants tackled the problems sets. Thus, the hypothesis that students using the flowchart would perform with more efficiency than those using the standard prose was rejected. The results did show however, that the time needed to complete the immediate posttest was significantly lower than the time required to complete the delayed test.

Any conclusions drawn from the results of the time data in this study must be qualified. First, the fact that many students forgot to enter their finishing times on the tests (moreso on the delayed test) resulted in too many missing values being awarded the grand mean. Secondly, participants were asked to record their times using a common timer located at the front of each classroom. However, many students relied on their own watches, even though it was repeatedly mentioned not to do so. Also, some students were quite meticulous in recording time in seconds whereas other students approximated by rounding out their time in minutes. Finally, some students took exorbitant amounts of time to finish so they wouldn't have to proceed to their next class! Future research should stress a more accurate way to record finishing times.

Perhaps the time data would have been more reliable had students been asked to record the time after <u>each</u> test question, rather than at the end of the test. In any event, a general assessment of efficiency should note that the time required to complete the first set of problems was approximately 8 1/2 minutes with only a short period of instruction required (15 min.). The time required to complete the delayed test was approximately 10 minutes. The slight time increase seems reasonable after a nine day delay.

Summary

While any recommendations to instructional designers must be qualified, the effectiveness of the highly structured algorithmic mode of representation as demonstrated by the results of this study suggests that the best instructional technique for performance would be to supply learners with the flowchart and to allow them to continue using it for a longer period of time. How long they should be allowed to have the representation available as reference is something that future studies may wish to investigate more closely.

The subject matter of chemistry seems particularly well-suited to the use of algorithms as much of the content involves complex interrelationships among variables. It is possible that other forms of algorithmic representation may even further enhance learning other than the two forms studied in this investigation. In terms of efficiency, an overall assessment illustrates not only the small amount of time required for instruction, but also the efficiency with which the tests were completed (approximately 8 1/2 minutes). Although one mode of representation was not shown to be more efficient than the other in terms of time required, future studies which both examine study time and test the time variable more closely may demonstrate otherwise. Examples are studies using different time data gathering techniques conducted by Lewis,et al.,(1967) as well as Schmid and Gerlach (1977). Both studies found the flowchart mode of representation to be significantly more efficient.

The cognitive style variable in this study warrants further investigation. While field-dependent learners performed more poorly, as expected, they did not find the highly structured mode of representation more beneficial. Little can be said here except to speculate that the tight, logical structure of chemistry concepts such as the one studied here already provide the separation of order and meaning found difficult by field-dependent learners. The application of these techniques are likely bound not only by learners' cognitive style, but the nature of the content under study. As suggested by Clark (1983), it is only by identifying these complex interrelationships of learner and strategy that educational technology will be able to generate replicable results.

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Appendix A- Pretest

NAME: ______________________

PRETEST

The following test is designed to see if you have any prior knowledge about the concepts involved. No calculations are required - just write down, in words what calculations you would perform to arrive at a correct solution.

Example answer: I am asked to calculate the number of grams and I know the number of moles, therefore I would multiply....

Problem #1:

How would you calculate the number of grams contained in .5 moles of
Sodium Chloride (NaCL)?

Answer:

Problem #2:

If you are given 2 bottles of Ammonia (NH_3), what calculations would you perform to find out a) how many grams of Ammonia are in each container b) how many moles these bottles contain?

Answer:

Problem #3:

If you were asked to calculate the number of moles represented by

x 10^{24} Sulphuric Acid formula units (H_2SO_4), what calculations would you perform?

Answer:

Problem #4:

How would you calculate the number of grams of 3.01 x 10^{23} NaF formula units (Sodium Floride)?

Answer:

Problem #5:

How would you calculate the number of moles present in the following compound ?

55.5g H2s04 (Sulphuric Acid)

Answer:

Appendix B-Introduction

Name:____________________

INTRODUCTION

The following exercise has been designed to teach you the procedure for calculating the mass of a substance (measured in grams) or the number of moles present in a given substance.

There are two sections:
a practice section, and
a test section.

The practice section will allow you to go through the material and will show you how to solve the problems using the procedure.
The test section will allow us to see how well you have learned the procedure.

The problems you will encounter in the practice and test sections do not require you to perform any actual calculations but they do require you to learn the procedure which must be followed.

Using the procedure provided on the blue page, carefully work through the practice section. When you have completed all the problems in this section, go to the sheet marked "ANSWER SHEET" (the pink sheet) and check your answers.

*** It is important that you read ALL instructions given and that you make the effort to do your best. Also, please keep your eyes on your own work as your neighbour is likely working on slightly modified materials.**

*** Please do NOT refer to the answer sheet until AFTER you have completed the practice problems.**

PLEASE DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

Appendix C - Flowchart Instructions

FLOWCHART INSTRUCTIONS

When a chemist tries to determine the formula of a substance like water or sucrose, he must determine how many atoms of each element combine together. It has been determined, for instance that water is made up of H_2O (2 parts hydrogen, 1 part Oxygen) and sucrose is $C_{12}H_{22}O_{11}$. Because atoms are so small that we can't count them, chemists have come up with a concept called the **mole** which is used to count atoms. The mole is defined as an amount of matter that contains 6.02×10^{23} particles. Therefore, 1 mol of any substance contains 6.02×10^{23} particles (particles can be atoms, molecules or formula units.)

The **mass of 1 mol** of a substance is known as the **molar mass** of a substance. Using these concepts, one can determine the mass (in grams) of a substance or the number of moles present in a given substance, if one is given the following data:

the number of particles (atoms, molecules or formula units), or
the mass of the substance, or
the number of moles in the substance or,
the molar mass of the substance.

The flowchart on the inserted page (blue page) is a representation of the procedures used to calculate the mass of a given substance in grams or the number of moles present in a given substance.

PLEASE READ THROUGH THE FLOWCHART CAREFULLY AS YOU WILL USE IT AS A GUIDE DURING THE PRACTICE SECTION OF THE EXERCISE. DO YOUR BEST TO MEMORIZE THE PROCEDURE AS YOU WILL NOT HAVE ACCESS TO IT DURING THE TEST PORTION OF THE EXERCISE.

<u>PLEASE PROCEED AS FOLLOWS:</u>

Read through the flowchart (the blue sheet).
Solve the practice problems using the procedure on the blue sheet.as reference.
Check your answers using the pink "Answer Sheet".

TURN TO THE NEXT PAGE NOW AND BEGIN.

Appendix D - Standard Prose Instructions

Instructions

When a chemist tries to determine the formula of a substance like water or sucrose, he must determine how many atoms of each element combine together. It has been determined, for instance that water is made up of H_2O (2 parts hydrogen, 1 part Oxygen) and sucrose is $C_{12}H_{22}O_{11}$. Because atoms are so small that we can't count them, chemists have come up with a concept called the **mole** which is used to count atoms. The mole is defined as an amount of matter that contains 6.02×10^{23} particles. Therefore, 1 mol of any substance contains 6.02×10^{23} particles (particles can be atoms, molecules or formula units.)

The **mass of 1 mol** of a substance is known as the **molar mass** of a substance. Using these concepts, one can determine the mass (in grams) of a substance or the number of moles present in a given substance, if one is given the following data:

the number of particles (atoms, molecules or formula units), or
the mass of the substance, or
the number of moles in the substance or,
the molar mass of the substance.

The material on the inserted page (blue page) is a representation of the procedures used to calculate the mass of a given substance in grams or the number of moles present in a given substance.

PLEASE READ THROUGH THE MATERIAL CAREFULLY AS YOU WILL USE IT AS A GUIDE DURING THE PRACTICE SECTION OF THE EXERCISE. DO YOUR BEST TO MEMORIZE THE MATERIAL AS YOU WILL NOT HAVE ACCESS TO IT DURING THE TEST PORTION OF THE EXERCISE.

PLEASE PROCEED AS FOLLOWS:

Read through the MATERIAL (the blue sheet).

Solve the practice problems using the procedures on the blue sheet as reference.

Check your answers using the pink "Answer Sheet".

TURN TO THE NEXT PAGE NOW AND BEGIN.

Appendix E - Procedure

Procedure

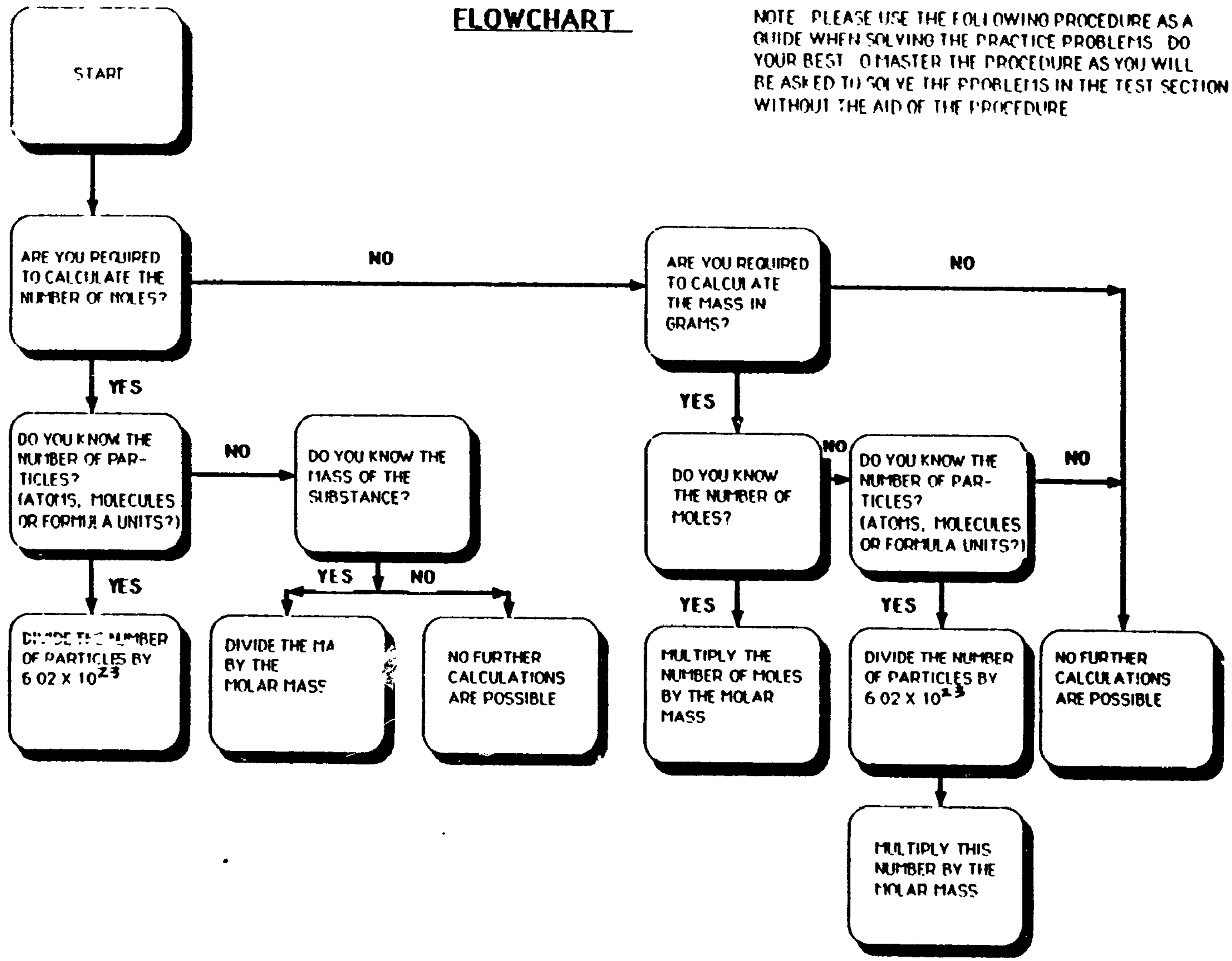
If you are asked to calculate the number of moles in a substance you must look to see if you are given the number of particles (atoms, molecules or formula units) or the mass of the substance. If you are given the number of particles, then divide this number by 6.02×10^{23}. If you you are given the mass of the substance, then divide the mass by the molar mass. If you are not given either the number of particles or the mass of the substance then no further calculations are required. Look to see if you are asked to calculate the mass in grams of the substance.

If you are asked to calculate the mass in grams you must look to see it you are given the number of moles or the number of particles. If you are given the number of moles, then multiply the number of moles by the molar mass. If you are given the number of particles (atoms, molecules of formula units) then divide the number of particles by 6.02×10^{23} and multiply by the molar mass. If you are not given either the number of moles or the number of particles then no further calculations are required.

Appendix F - Flowchart Procedure

FLOWCHART

NOTE PLEASE USE THE FOLLOWING PROCEDURE AS A GUIDE WHEN SOLVING THE PRACTICE PROBLEMS DO YOUR BEST TO MASTER THE PROCEDURE AS YOU WILL BE ASKED TO SOLVE THE PROBLEMS IN THE TEST SECTION WITHOUT THE AID OF THE PROCEDURE



Appendix G - Practice Problems

Practice Problems

The following problems are designed to help you practice all the procedures
you have just read. Please refer to the PROCEDURE on the blue sheet at any time and REMEMBER you are NOT required to PERFORM any calculations - just write down in words the procedure to be followed.

EXAMPLE:
What calculations would you perform to determine the number of moles present in 90g of Water (H20)?

Answer:

I am asked calculate the number of moles and I know the mass (in grams) of water - so I would divide the mass (90g) by the molar mass._ : 90g/ molar mass

Problem #1:

If you are given 2.709×10^{23} ammonia molecules (NH_3), how would you calculate the number of moles present?

Answer:

Problem #2:

If the molar mass of Barium Oxide (Ba0) is 153.3 g/per mole, how would you calculate the number of grams contained in .0025 moles of the substance?

Answer:

Problem #3:

If you are given 1.505×10^{21} Oxygen molecules (O_2), how would you
calculate the number of grams present?

Answer:

Problem #4:

How would you calculate the number of moles present if you were given 3.01×10^{24} Aluminum Atoms (AL)?

Answer:

Problem #5:

Hydrochloric acid (HCL) is a common concrete cleaner. IF you have three bottles of the cleaner, and one of these bottles is half full, what calculations would you perform to find out a) how much cleaner you have, and b) how many moles each of these bottles contain?

Answer:

Now check your answers with the pink "ANSWER SHEET".

PLEASE RAISE YOUR HAND WHEN YOU HAVE FINISHED THIS SECTION.

Appendix H - Answer Sheet

ANSWER SHEET

The answer to each of the practice problems is listed below with an explanation as to the correct answer. Please check your work carefully and refer the procedure on the blue sheet while reading the explanation for further clarification.

Practice Problem #1:

You are asked to **calculate the number of moles** present in a certain amount of Ammonia.

You are given the **number of particles** (Ammonia molecules 2.709×10^{23}). Remember, 1 mol of any substance contains 6.02×10^{23} particles.

Therefore you would **divide** the number of particles (i.e. 2.709×10^{23}) by 6.02×10^{23} in order to calculate the number of moles present.

$$\frac{\text{The number of particles}}{\text{The amount of matter in 1 mol}} = \frac{2.709 \times 10^{23}}{6.02 \times 10^{23}}$$

Problem #2:

You are asked to **calculate the mass (in grams)** and you are **given the number of moles** (i.e. .0025 moles).

You are also given the **molar mass** (153.3 g/per mol).

Remember, the mass of 1 mol of a substance is known as the molar mass.

With this information, you would **multiply** the number of moles by the molar mass to arrive at the mass in grams of Barium Oxide.

The number of moles (.0025) x the molar mass (the mass of 1 mol of Barium Oxide (153.3 g/per mole).

Problem #3:

You are asked to **calculate the number of grams** of Oxygen and you are told that there are 1.505 x 1021 molecules. You know the **number of particles**.

Therefore you would **divide** the number of particles (i.e molecules) by 6.02×10^{23} and then **multiply** this number by the molar mass.

$$\frac{\text{The number of particles}}{\text{The amount of matter in 1 mol}} = \frac{1.505 \times 10^{21}}{6.02 \times 10^{23}} = N, \text{ then } N \times \text{molar mass.}$$

Problem #4:

You are asked to **calculate the number of moles** of Aluminum present and you are told that there are 3.01×10^{24} aluminum atoms (i.e. **particles**). With this information you would **divide** the number of particles by $\mathbf{6.02 \times 10^{23}}$.

$$\frac{\text{The number of particles}}{\text{The amount of matter in 1 mol}} = \frac{3.01 \times 10^{24}}{6.02 \times 10^{23}}$$

Problem #5:

You are told you have three bottles of Hydrochloric acid and you are asked how much of the cleaner you have (in grams) - but **you do not know the number of moles that are present or the number of particles** and therefore **no calculations are possible**. You are also required to calculate how many moles each of these bottles contain. **Again, you are not given the number of particles or the mass of the substance - therefore, no calculations are possible.**

Appendix I - Introduction and Instructions to Posttest

(Immediate)

Instructions

You are now ready to see how well you learned the material presented in the practice section. This test consists of 5 questions similar to those in the practice section, which require you to indicate the correct procedure for calculation.

PLEASE MAKE YOUR BEST EFFORT TO ANSWER ALL THE QUESTIONS.

WHEN YOU HAVE FINISHED, MARK YOUR FINISHING TIME IN THE SPACE PROVIDED.

CHECK TO SEE IF YOU HAVE MARKED YOUR NAME ON THE TEST.

RAISE YOUR HAND WHEN YOU HAVE FINISHED.

* Thank-you for your cooperation!!

NOW TURN THE PAGE AND BEGIN.

Appendix J - Posttest (Immediate)

Name:____________________

POSTTEST

Please write down the procedure you would follow to find the solution to the following problems. No actual calculations are required.

Problem #1:

If you are given 1.2×10^{24} Neon atoms (Ne), how would you calculate the number of grams present?

Answer:

Problem #2:

If the molar mass of H_2O is 18 g/per mole, how would you calculate the number of grams contained in 5 moles of the substance?

Answer:

Problem #3:

If you are given 2.53×10^{23} Magnesium ions (Mg), how would you calculate the number of moles present?

Answer:

Problem #4:

If you are given 6 cups of water (H_20), what calculations would you perform to calculate a) how many grams of water are in each cup b) how many moles each of these cups contain?

Answer:

Problem #5:

How would you calculate the number of moles present if you were given 10.625g of Ammonia (NH_3)?

Answer:

FINISHING TIME: ___________

Appendix J - Posttest (Delayed)

Name:____________________

POSTTEST (D)

Please write down the procedure you would follow to find the solution to the following problems. No actual calculations are required. Please mark your finishing time in the space provided when you have completed the test.

Problem #1:

If you are given 6.02×10^{24} Water molecules (H_20), how would calculate the number of moles present?

Answer:

Problem #2:

If you are given 3.01×10^{23} NaF formula units (Sodium Fluoride)
how would you calculate the number of grams present?

Answer:

Problem #3

If the molar mass of NH_3 (Ammonia) is 17.0 g/per mole, how would you calculate the number of grams contained in 1.5 moles of the substance?

Answer:

Problem #4:

How would you calculate the number of moles present if you were given
kg of C_3H_8 (Propane)?

Answer:

Problem #5:

If you are given 2 containers of Sulphuric Acid (H_2SO_4) , what calculations would you perform to calculate a) how many grams of Sulphuric Acid are in each container b) how many moles of Sulphuric Acid are in each of these containers?

Answer:

FINISHING TIME: ____________