THE EFFECTS OF LOCUS OF CONTROL ON THE COMPUTER-ASSISTED LEARNING OF GRAVIMETRIC STOICHIOMETRY

by

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Abstract

This study examined the effects of the locus of two computer-assisted instruction (CAI) control strategies over the sequence of instruction and number of practice examples studied on the accuracy and efficiency in the learning of gravimetric stoichiometry of grade 11 chemistry students. The two locus of control strategies were adaptive learner control (ALC) strategy and adaptive program control (APC) strategy. Effects were examined for CAI strategy, pre-requisite knowledge, metacognitive ability, and gender of student. The group working with CAI strategy of the adaptive program control demonstrated better delayed post-test performance, while requiring fewer number of practice examples and thus considerably less learning time than students in adaptive learner control. The interaction of gender by locus of control strategy was significant, in that male student achieved slightly more under ALC than APC and female subjects did significantly better under APC than ALC.

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I. Research Problem

Statement of the Problem

Instruction is a set of events that is planned to activate and support the learning of an individual in an unique way. Its purpose is to help each person develop as fully as possible, in his/her own individual direction. With this assumption and goal in mind, teachers have long attempted to design their lessons, adjusting both the objectives and the methods of teaching, to match the needs and characteristics of individual learners. Unfortunately, their efforts have been largely frustrated in the past because of the lack of reliable delivery systems designed to adjust instruction to the individuals in a group of twenty-five or more learners.

In recent years, however, comprehensive delivery systems for individualized instruction have surfaced. They attempt to 1) provide a means for assessing the entry skills of pupils; 2) assist in finding the starting point for each pupil in a carefully sequenced series of objectives; 3) provide alternative materials and media for adjustment to varying learning styles of pupils; 4) enable pupils to learn at their own rate;

and 5) provide frequent and convenient progress checks so that pupils do not become "bogged down" with cumulative failures (Gagne & Briggs, 1979). The advancement of high technology and the application of microcomputers to education have made individualization even more feasible in terms of computer-based instruction (CMI) and computer-assisted instruction (CAI). Such electronic delivery systems have set a milestone in the field of education, and educators are now presented with a new medium of instruction, the microcomputer, that adds several dimensions to their repertoire of educational instrumentalities.

Although there is yet no consensus as to the extent to which computer-assisted instruction (CAI) facilitates learning, serious considerations need to be given to the powerful and varied capabilities of CAI for adaptive instruction. Compared to textbooks, CAI is a dynamic medium, capable of instantaneously varying such properties of a lesson as the content selected, modalities featured, sequencing of topics, amount and difficulty level of practice, type of feedback, and so on, all as learner needs dictate. Compared to classroom lectures, the adaptiveness provided can be tailored to the needs of each individual rather than being restricted to the normative characteristics of a class of students. Compared to programmed instruction, adaptive features can be continuously refined as learner needs change over the course of a lesson (Steinberg, 1977; Rothen & Tennyson, 1979; Tennyson & Buttrey, 1980; Ross, 1984).

Owing to the flexibility for individualization that microcomputers display, many adaptive instructional systems such as the Learner-Controlled Education System (LCES) (Jelden & Brown, 1982); the Minnesota Adaptive Instructional System (MAIS) (Tennyson, Christensen & Park, 1984); and the Time-shared, Interactive, Computer-Controlled Information Television (TICCIT) system (Merrill, 1980) have been developed. Numerous studies that compare adaptive strategy with the traditional non-adaptive programs have consistently demonstrated the superiority of adaptive programs over non-adaptive ones. However, questions which often arise in the study of adaptive features of CAI are: Should the locus of control lie with the computer program or with the learner? Should the learner be allowed to exert control over the pacing, number, or sequencing of instructional events? Can such control by learners accommodate their own individual differences more effectively than program control? There seem to be no simple or easy answers to these questions. Control of the amount and sequence of instructional stimuli has been a recurring but as yet unresolved problem in the design of computer-assisted learning environments (Tennyson & Buttrey, 1980). Nevertheless, a widely held belief in many education circles is that learners should be encouraged to make choices for themselves or to exert some personal control.

The present study employs the locus of instructional control strategy as a design variable in the development of an adaptive-interactive CAI program for teaching gravimetric stoichiometry in chemistry. The effects of locus of instructional control are studied under two treatment conditions: (a) adaptive program control (APC) in which the sequence of instruction and the number of practice examples presented are controlled by the program; and (b) adaptive learner control (ALC) in which learners are provided with advice and suggestions but are given control over the sequence of instruction and the number of practice examples. In both treatment conditions, the number of practice examples presented or suggested is based on the subjects' pre-requisite knowledge and on-task performance. Dependent variables of particular interest for this study are: number of practice examples used, total learning time, time spent per practice example, and performance and time spent on immediate and delayed postests. Pre-requisite knowledge scores and metacognitive ability scores are employed as concomitant variables. Furthermore, the presence/absence of interaction effects between gender of the subjects and locus of control strategies for all learning process and outcome variables is also investigated.

Theoretical Background

It is a well accepted belief in the past 50 years that adapting instruction to individual differences among students can improve learning significantly. Educators generally agreed that an instructional system is needed that is designed for mass usage, but which allows for unique environments for the many learner characteristics. Recent work in adaptive designs has generated a number of innovative methods for tailoring instruction to students. In most of the studies, results have shown that adaptive instructional programs are far more superior than non-adaptive programs in facilitating learning. For examples, Tennyson & Rothen (1977) demonstrated that full adaptive strategy is more efficient than partial strategy, which in turn is more efficient than nonadaptive strategy in selecting number of instances needed in a concept learning task. Park & Tennyson (1980) found that the selection of the number of examples according to on-task information is more efficient than the selection according to pretask information; and the students in the response-sensitive condition performed better in the posttest than students in the response-insensitive condition. Ross, Rakow & Bush's (1980) study on strategies for adapting instructional support also showed the advantages of adapting the quantity of examples presented with rules. Ross & Rakow's (1982) subjects learned a series of 10 math rules under full adaptation, partial adaptation, and several forms of standard instruction. Results on a cumulative posttest favored full adaptation over partial adaptation and both adaptive treatments over standard instruction. Ross' (1984) review of other studies that involved the teaching of statistical and mathematical materials consistently demonstrated that adaptive instructional strategy was more effective than conventional supports.

Although researchers and practitioners in recent years have systematically attempted to accommodate individuals with different needs in educational practice, there is still considerable disagreement and confusion regarding exactly what constitutes individualization and how adaptive instruction should be achieved. Holland (1977) defines adaptive instruction as a set of processes for detecting the individual differences in student needs and to prescribe to each student only those learning materials that are necessary to reach the final objectives of the instruction. Park (1982) describes an adaptive instructional system as a program that takes into consideration a given student's learning history and varies the sequence of instruction accordingly. According to Tennyson and his associates (Tennyson, Tennyson, & Rothen, 1980; Tennyson, 1981; Tennyson & Rothen, 1977), an adaptive system is one that prescribes the optimal amount of instruction required to achieve a given objective. Glaser (1982) suggests that an individual's initial competence should be considered for providing alternative environments that will match the different styles of learning. Jonassen (1985) points out that an adaptive tutorial instruction involving the ability of the tutor to select additional, more relevant questions or to explain, prompt, cajole, or do whatever is necessary to assist the tutee in acquiring the knowledge.

The availability of microcomputers for instruction uses in recent years have allowed for greater flexibility in the design of adaptive instructional programs. Computer power is potentially great enough to provide adaptive algorithms at many levels simultaneously. Moreover, adaptive decisions on instructional processes can be left to the student, either in part or in entirety. The term learner control has varied from that allowing the student to make decisions on just one aspect to that of almost complete control of instruction. In a program control environment, on the other hand, instructional variations are selected for students and incorporated in their lessons. The question then becomes which learning decisions should be left up to the student and which should be put under computer control since it is necessary to assign the locus of control of such variables as instructional/learning strategy, sequence of instruction, completion time, amount of practice, level of difficulty, etc. In the present study, focus is centred on the locus of control over the sequence of learning materials and the amount of practice examples selected. The purpose of the study is to compare the effectiveness of the two locus of control strategies, namely, program control and learner control.

Some researchers assume that learner control in CAI would benefit students. They argue that rather than being an advantage to instructional effects, a program control system may be maladaptive, making students system dependent. For example, Merrill (1980) claims that such "spoon fed" students under program control may find that learning from the natural environment is more difficult because the real world is not as adaptive to the individual needs of the student. A learner control system which requires a student to learn to make appropriate strategy choices is different from a system which caters to the student's needs and aptitudes. Merrill argues that a student must learn to recognize his/her own learning needs and not rely on a totally adaptive system which may make decisions on the basis of needs that the student may not even know that s/he has.

On the other hand, advocates for a program control system seek for a maximally adaptive system which could assess a given student's learning style, aptitudes, past achievement, and readiness and then present to the student that content and strategy which are optimally appropriate for him/her to receive at a given moment in time. They maintain that when students control the amount of instruction they receive, they often terminate too early and fail to learn what they should. Learners are often poor judges of how much instruction they need, or in what order (Carrier, 1984).

Recent studies on the effects of the locus of control strategies have yielded various results. Fisher, Blackwell, Garcia & Greene (1975) studied the effects of student control and choice on engagement in a CAI arithmetic task in a low-income elementary school. The study revealed that subjects in the choice condition maintained higher levels of engagement over long periods of time than did subjects in the yoked control condition, but the subjects in the choice condition had the tendency to choose problems that were either too difficult or too easy and thus their performance was worse. Fisher et al. (1975) thus concluded that while choice may be motivating for some children, it can result in poor academic performance. Similar results were obtained in Fry's (1972) study. Subjects who were allowed to select which questions they wanted to answer in order to learn about computers had a more positive attitude than those who were not; however, they learned the least. Results of Fry's study also indicated that high aptitude, high inquiry students did best under student control. High aptitude, low inquiry students performed better in the expert ordered condition than under learner control. Low aptitude, high inquiry students learned best under student control. Low aptitude, low inquiry students achieved so little that the results could not be interpreted.

In their experiment, Judd, Bunderson & Bessent (1970) studied the effects of four levels of student control (total computer management; student control over the sequence of topics; additional student control of the amount of practice; and total learner control) over course flow in a remedial mathematics course for college students. They found that students who were allowed to choose the sequence of topics did worse than those who were under computer control. In particular, students who had done poorly on a pre-test did worst under learner control. However, the study showed that college students were good judges of the amount of practice they needed. Furthermore, learner control did not improve student attitudes.

Tennyson and his associates (Tennyson & Rothen, 1977; 1979; Park & Tennyson, 1980; Tennyson, 1980; Tennyson & Buttrey, 1980) compared different loci of control using computer-based concept lessons. In learner control conditions, the learner decided how many instances of the target concept to review. In adaptive control conditions, the program itself determined the number of instances presented by considering the achievement level, and on-task mastery criterion, and a loss ratio. In learner advisement conditions, the learner had control, but the program provided advice based on information used in the adaptive control system regarding the number of items the individual learner should review. In Tennyson's research, total learner control conditions consistently yielded lower posttest performance than adaptive control, often because subjects in learner control conditions terminated the instruction too early. However, when advisement was introduced in the form of feedback, subjects in the learner control did as well as those under adaptive control conditions. Furthermore, the learner-control-with-advisement condition showed significant decreases in on-task time and amount of instruction.

Ross & Rakow (1981) reported that in a self-paced lesson on math rules in which the number of supporting examples was either adaptive program controlled, learner controlled, or kept constant, the adaptive program control subjects' immediate and delayed test score means were consistently the highest while learner control subjects' means were lowest. Non-adaptive support and lecture treatments produced middle-range outcomes. As for the number of examples received by the subjects under different treatments, Ross & Rakow revealed that the results provided an obvious explanation for performance deficit in learner control. Subjects working under LC condition selected much fewer examples than were prescribed under other three treatments. Furthermore, LC subjects' average study time per rule did not differ from non-adaptive and lecture subjects. The result was an indication that their poor performance was more of failing to use resources wisely than trying to terminate the task early. Interaction patterns also suggested that the advantages of program control over learner control increase both across retention intervals and as subject entry ability decreased.

Goetzfried & Hannafin (1985) examined the effects of the locus of three CAI strategies on the accuracy and efficiency of mathematics rule learning and application by low achieving seventh grade students. In the adaptive control condition, the computer branched students for re-teaching or more examples, depending on the accuracy of responses during the lesson, and the subjects had no control over the pacing or amount of teaching in the lesson. Subjects in the learner control with advisement treatment were continuously advised of their progress and were permitted to determine if re-teaching and/or additional problems were needed. Students using the linear control strategy received the same sequence of instruction and examples but had no advisement and no individual control. The study showed that although achievement differences resulting from the various design strategies were not found, both instructional time and associated learning efficiency were affected significantly. The basic linear design yielded comparable learning coupled with significantly less instructional time and thus resulted in more efficient learning. The findings of this study may be attributable to information and self-evaluation deficiencies of low achievers.

The somewhat inconsistent findings of the above studies suggest that the effects of learner control may vary across the age level and abilities of the subjects, the type of content taught, and the specific nature of the options allowed. Student control of instruction was sometimes motivating. Attitudes were positively affected by learner control, particularly at the elementary level. But improved or even equivalent performance was not necessarily a correlate; sometimes performance was worse. Under specific conditions student did know how to manage their own instruction. When students were allowed to control course flow, some of them achieved as much as students who did not have this option. But this was not true of students who were poor performers in a subject. They used inefficient instructional strategies and learned least under student control. Students were generally poor judges when they selected the difficulty level of problems, the sequence of instruction, or the amount of practice. The poorest decision makers were the students who knew little about the subject or who were performing poorly in it. This finding supports Tobias' work (1976) on the relationship of prior knowledge to instructional support. His research consistently found that the less familiar the students are with the content, the greater their need is for clearly stated objectives, explicit high-lighting of importance, requirements for overt responding, and other guidance devices. Tennyson & Rothen (1979) similarly proposed that high task demands and low student aptitude seem to favor greater use of program or teacher control as a management strategy while learner control seems to be favored for easier subjects requiring minimal prerequisite knowledge. Snow (1980) also argued that with respect to the type of locus of control, learners are different in terms of how well they (1) like self-control over instructional events, (2) will perform under such conditions, and (3) will use their skills in executing such controls. Factors such as age level, familiarity with the learning materials, degree of self-confidence, etc. definitely play an important part.

Tobias's (1976) achievement-treatment interaction approach shifts the focus of adaptation from general traits and aptitudes to task-specific measures of students' prior familiarity with the material to be learned. Tobias (1981) claims that careful classification of aptitude and treatment variables between individual differences in prior achievement and instructional method avoids some of the problems of other approaches, including examining interactions between cognitive processes and instructional method. An interaction is hypothesized such that the higher level of prior achievement, the lower the instructional support needed to accomplish objectives; conversely, the lower the prior achievement level, the higher the support that is needed.

Rationale and Theoretical Hypotheses

The ultimate goal of instructional designers is to identify a set of learning events and the delivery system that would provide an optimal environment in which learners can learn most effectively in order to reach a set of pre-determined objectives. Computer-assisted instruction has generally been shown to be effective in increasing performance, improving learner attitudes, and reducing instructional time (Kulik, Bangert, & Williams, 1983) when principles of teaching and learning are applied in the development of educational coursewares (Gagne, 1982; Jay, 1983). The superiority of adaptive instructional strategies over non-adaptive programs in CAI has been repeatedly demonstrated in various studies (e.g.; Tennyson & Rothen, 1977; Park & Tennyson, 1980; Ross, 1984). It is therefore generally agreed that an adaptive computer-assisted instruction system which is based on sound principles of learning and teaching would be far more superior than the conventional CAI system. However, specific loci of such superiority have not yet been well understood and still need to be discovered.

The present experiment attempted to further the understanding of the effects of the locus of control strategies in computer-assisted instruction. It involves the design and development of an CAI chemistry program which allowed the comparison of the effects of the locus of two CAI control strategies over sequence of instruction and amount of practice examples on the accuracy and efficiency in solving gravimetric stoichiometry problems. The two treatments are an adaptive program control strategy and an adaptive learner control with advisement strategy, which are somewhat similar to the treatments employed in the studies of Tennyson & Buttrey (1980), and Goetzfried & Hannafin (1985). Tennyson & Buttrey revealed that although achievement differences were not found, learner control with advisement strategy was more efficient than program control. However, Goetzfried & Hannafin did not find any differences between the two strategies. The conflicting results obtained may have reflected the differences in age of the subjects (grade 12 vs. grade 7), nature of the task (psychological concepts vs. remedial math), achievement history of the subjects ("regular" vs. remedial), etc. in the two studies.

It is the interest of the present experimenter to find out when it comes to teaching gravimetric stoichiometry in chemistry via CAI, which one of the two control would be more effective, if there is a difference? It is believed that variations in the learners' performance under the two levels of treatment may be attributable to not only the learners' prior achievement in chemistry, as most researchers have claimed, but also the learners' metacognitive ability - the ability to plan strategies for monitoring thought and regulating one's own behaviour according to what a task demands. As Quinto & Weener (1983) pointed out, performance on problem solving is not only determined by pure cognitive knowledge and behaviours but by the knowledge about these cognitions and behaviours. Most metacognitive researchers are concerned with developmental studies on memory (e.g. Flavell & Wellman, 1977) and learning disabilities. In problem solving, studies on metacognitive skills are still quite scarse. However, it is believed that the ability to solve problems, such as stoichiometry problems, could be related to the learners' skills of metacognition. Thus, pre-requisite knowledge and metacognitive ability of the subjects are employed in this study as covariates to reduce any error variance.

In the present experiment, chemistry is viewed as a difficult and unpopular subject for the student population concerned. When this particular lesson is implemented in Chemistry 11, which is the first chemistry course that most of the students ever take, higher instructional support will be needed to accomplish the learning objectives. It is therefore hypothesized that higher level of learning achievement will be obtained under program control than under learner control over sequencing of topics and in selecting number of practice examples.

In the domain of pre-requisite knowledge/metacognitive ability/treatment interaction effects, it was expected that learners with low pre-requisite knowledge or low metacognitive ability would do better under program control for they are less secure and need more guidance. As for learners with high pre-requisite knowledge or metacognitive ability, the two treatment conditions would be similarly effective. However, when pre-requisite knowledge and metacognitive ability factors are considered together, it was expected that learners of low pre-requisite knowledge/low metacognitive ability would benefit most from program control, and learners of high pre-requisite knowledge/high metacognitive ability would find learner control with advisement to be most efficient.

As Brown & DeLoache (1978) proposed, novices are deficient in terms of self-conscious participation and intelligent self-regulation of their actions. The lack of familiarity with the learning materials would lead to a concomitant lack of self-interrogation about the current state of knowledge and to inadequate selection and monitoring of necessary steps between starting levels and desired goals. Therefore it is reasonable to hypothesize that this type of learners would require a more structured approach, which is offered under the program control treatment.

On the other hand, Brown & DeLoache claim that learners who possess high metacognitive skills are able to predict the consequences of an action or event, check the results of their own actions, monitor their ongoing activity, test the reality of their actions, and demonstrate a variety of other behaviours for coordinating and controlling deliberate attempts to learn and solve problems. It was therefore expected that such independent learners who have a high achievement history would be able to control the instructional events effectively and thus their achievement level would be the highest under learner control. As for learners of high pre-requisite knowledge and low metacognitive ability, and learners of low pre-requisite knowledge and high metacognitive ability, it was expected that the two treatment conditions would be similarly effective.

II. METHOD

SUBJECTS AND DESIGN

Participants in this study were student volunteers from three Chemistry 11 classes in a senior secondary school in Burnaby, British Columbia. The subjects were to have completed the unit on Mole, Molar Mass, and Mass relationships and to have mastered the concept of the mole and the implications of chemical formulas and chemical equations. Twenty-eight students (13 males and 15 females) signed up for the study. They were randomly assigned to one of the two locus of control groups in the computer-assisted learning (CAL) of gravimetric stoichiometry. However, two male students, one from each of the two control conditions, withdrew during the middle of their participation. As a result, twenty-six student volunteers (11 males and 15 females) completed the study.

The two locus of control conditions were: (a) adaptive program control (APC) in which the sequence of topics presented was fixed and the number of practice examples presented was controlled by the program and was determined initially by the subject's pre-requisite knowledge scores and subsequently by the subject's on-task performance and; (b) adaptive learner control with suggestions (ALC) in which subjects were given advice as to the sequence of instruction and the number of practice examples needed. The number of examples suggested was based initially on the subject's pre-requisite knowledge score and subsequently on his/her on-task performance. However, subjects under ALC were given total control as to whether or not follow the suggestions.

Subjects were told that they would receive a book certificate at the conclusion of their involvement in the learning project. This contingency was included to encourage serious participation, especially from subjects in the learner control group who might have the tendency to terminate early.

This study employed a simple completely randomized CR-1 design in which subjects were randomly assigned to one of the two levels of CAI locus of control strategy (APC and ALC). Gender of the subjects is used as a blocking factor. Pre-requisite knowledge and metacognitive ability sub-tests scores served as covariates. Dependent variables included were number of practice examples done, ratio of examples correct, learning time (the time during which the student engaged in learning), time spent per practice example, correct scores and time spent on the immediate and delayed post-tests, and average correct response time. The analysis of variance and analysis of covariance procedures were used to test for differences and interaction effects.

LEARNING PROGRAM AND TASK ANALYSIS

The learning task involved a topic in a British Columbia Chemistry 11 unit dealing with Gravimetric Stoichiometry. The unit reflects the students' first exposure to stoichiometry - the prediction of how much of one substance will react or be produced in a chemical reaction relative to the amount of another substance in the reaction. The study of stoichiometry requires the understanding and application of the Law of Definite Proportion in chemical reaction. Everyday applications of stoichiometry are numerous. For examples:

1. The gasoline to air mixture is regulated in a car or motorcycle by the carburetor. Proper proportions of gasoline and air mixture are necessary for maximum power and gasoline mileage.
2. Since cooking food involves chemical reactions, every recipe suggests the proper proportion of

"chemicals" to produce a complete reaction. For example, if the proper proportions of baking soda and cream of tartar are not used, some of one or the other will be left over (in excess). An excess of one component (reactant) may adversely affect the cooked product.

3. Antacid tablets may be harmful if taken in excess. Each antacid tablet contains a certain amount of chemical which neutralizes stomach acid. If too many tablets are taken, too much stomach acid is destroyed and proper digestion can not occur.

Calculation of the amount of materials used or produced in chemical reactions is required when many natural, laboratory, or industrial chemical transformations are studied. Such calculations seem, at first, to take on many different and confusing forms. They all, however, have an underlying similarity, and if this is appreciated at the outset the entire subject can be easily mastered. To do this, it is essential that all problems be approached in an organized way. The objective of this learning program is to help the students adopt one such approach in stoichiometry calculations.

Gravimetric stoichiometry refers to stoichiometry involving the measurement of gravity or mass as opposed to measurement of solution volume (solution stoichiometry) or gas volume (gas stoichiometry). In gravimetric stoichiometry calculations, the amount of substances may be expressed as number of moles (in moles) or mass (in grams). For example, in the following balanced equation,

$$2\ H_{2(g)} \quad + \quad O_{2(g)} \quad \text{------>} \quad 2\ H_2O_{(g)}$$

two moles (4.04 g) of hydrogen react with one mole (32.0 g) of oxygen to produce two moles (36.04 g) of water vapor. Thus the amount of one of the substances reacted or produced (the required substance) can be calculated if the amount of another substance (the given substance) is known.

Depending on whether the number of moles or the mass of the given substance is known, and whether the amount of the required substance is to be expressed in moles or grams, four types of stoichiometry problems can be derived, namely, (a) mole to mole; (b) mole to mass; (c) mass to mole; and (d) mass to mass stoichiometry as shown in Table 1.

Insert Table 1 about here

Given a balanced chemical equation, the task of solving gravimetric stoichiometry problem is conceived to consist of 5 task components: (1) identify the given and the required substances; (2) express the amount of given substance in moles; (3) identify the coefficients of the given and required substances from the balanced equation; (4) find the amount of the required substance in moles by using the mole ratio; and (5) express the amount of required substance in grams if desired. Figure 1 shows a flow chart of the components and processes involved.

Insert Figure 1 about here

Among the four types of stoichiometry problems, mole-to-mole is considered to be the easiest since it involves a one-step calculation (n_G ---> n_R). Mass-to-mass is most difficult, for it requires a three-step calculation (m_G ---> n_G ---> n_R ---> m_R). Mole-to-mass and mass-to-mole problems are of intermediate difficulty, involving a two-step calculation (n_G ---> n_R ---> m_R or m_G ---> n_G ---> n_R). It is therefore anticipated that the most logical sequence of instruction for the four types of stoichiometry problems is (1) mole-to-mole; (2) mole-to-mass or mass-to-mole; and (3) mass-to-mass.

INSTRUCTIONAL SYSTEM DESIGN

The instructional task selected for this study was a chemistry lesson on gravimetric stoichiometry calculations. It was designed with the assumption that the target learners had not yet been taught the content. The instructional system design for each of the two treatment conditions was the same, consisting of an adaptive, intelligent computer-assisted instruction (ICAI) program. Roberts & Park (1983) describe ICAI systems as tutoring systems that have separated the major components of instructional systems in a way which allows both the student and the program to have a flexibility in the learning environment more closely resembling what actually occurs when student and teacher sit down one-on-one and attempt to teach and learn together. Roberts & Park propose that the operational functions of an ICAI system are determined by three main components which represent the three main components of any instructional system, namely, the content to be taught (the expert module), the inherent teaching or instructional strategy (the tutoring module), and a mechanism for understanding what the student does and does not know (the student module). In the development of the CAI modules, Jay's cognitive approach to computer courseware design (1983) is noteworthy. Jay focuses on some aspects that concern human information processing abilities which, he maintains, must be accounted for in order to develop good courseware. Such abilities may include: (a) memory and attention; (b) language or text characteristics; (c) use of graphics and visual processing; (d) mental computation; (e) cognitive characteristics of a user; and (f) feedback to users.

The system designed for the present study followed Lee's (1983) instructional design model which satisfies the criteria for an ICAI system outlined by Roberts & Park. Lee's learner-based computer system consists of 3 main components or modules: (1) the Evaluator, (2) the Diagnostician, and (3) the Tutor. The functions of these components for the present study are outlined in

Table 2. Figure 2 shows the instructional flowchart of the system.

Insert Table 2 about here

a. Pre-test

A total of 12 items consisting of 3 replications of the 4 stoichiometry problem types were mixed and presented in a random order. Sample of pre-test questions is shown in Appendix A. The pre-test was to ensure that participants had no previous knowledge of solving stoichiometry problems.

Insert Figure 2 about here

b. Diagnostic Test

The pre-requisite knowledge involving mole, mass, molar mass concept, and ratio calculation that is required for solving stoichiometry problems was evaluated. Twelve items consisting of 3 replications of the 4 pre-requisite areas were presented. No feedbacks were given for either correct or incorrect responses. Sample items from the diagnostic tests are shown in Appendix B. Table 3 summarizes the types of pre-requisite knowledge that are required for solving various stoichiometry problems.

Insert Table 3 about here

Score obtained by the students in the pre-requisite knowledge test was used to determine the number of practice examples initially presented/suggested. The number of practice examples initially prescribed/suggested were 0, 1, 2, 3, 4, or 5 for a score of 12, 11, 10, 9, 8, 7 or less, respectively.

c. CAI Module

The CAI module consisted of five sections: 1. Introduction to Gravimetric Stoichiometry; 2) Mole-to-mole stoichiometry; 3) Mole-to-mass stoichiometry; 4) Mass-to-mole stoichiometry; and 5) Mass-to-mass stoichiometry. Under the computer-assisted instruction of each type of stoichiometry, an instructional example was given, followed by 0 to 5 practice examples, depending on the progress and/or choice of the learner. The instructional example illustrated the processes and demonstrated how the answer to the problem could be derived, without active participation on the part of the learner. The practice example(s), on the other hand, required active involvement from the learner. The learner was presented with a problem and was prompted to solve it step-by-step. Feedbacks were given at each step and remedial instructions were provided at any point when required.

Under the APC condition, the sequence of instruction was fixed. After the introduction section, subjects were presented first with the relatively easier mole-to-mole stoichiometry, followed by the more difficult mole-to-mass and mass-to-mole problems. Mass-to-mass stoichiometry, considered to be the most difficult, was given last. In APC, the number of practice examples was controlled by the program and was based initially on the learners' pre-requisite knowledge test score. However, the number of prescribed practice examples was continuously modified, reflecting the performance of the subjects on the immediate post-test of the previous stoichiometry type.

Under the ALC condition, subjects were given suggestions but were granted control over the sequence of instruction and the number of practice examples to be studied. The number of practice examples suggested was based on the subjects' pre-requisite knowledge scores and on-task performance as discussed above.

d. Immediate Post-tests

An immediate post-test was given at the end of each type of stoichiometry lesson. Each immediate post-test consisted of 5 questions which were presented in random order. No feedback was provided during the immediate post-tests. However, subjects were given the score at the end of each test.

f. Final Delayed Post-test

The final post-test was administrated one day after the conclusion of the entire lesson. A total of 12 items consisting of 3 replications of the 4 stoichiometry problem types were randomly chosen and presented.

APPARATUS AND PROCEDURES

The experiment was conducted in the Science Resource Room hosting five IBM PC microcomputer systems each with a RGB color monitor. Pencils, paper, nonprogrammable calculator, and a periodic table of chemical elements were available to each participant.

Each subject attended four to six sessions with approximately 60 minutes to 120 minutes per session. The sessions were conducted outside regular class time, i.e., before school, after school, or when the student had a "free period". During the first session, the subject was assigned to one of the computer stations and was provided with directions on the operation and use of the microcomputers. S/he was then given the pre-test, pre-requisite knowledge test, followed by the metacognitive ability test.

The instruments for assessing metacognitive skills were adopted from Quinto & Weener's study (1983). Quinto and Weener's test was designed to assess more comprehensively the metacognitive skills used in three types of problem solving tasks by using self-report measures and systematic observations in determining the relationships among the outcomes of these methods and the degrees of relationships among the metacognitive measures and actual performance. These instruments were chosen for this study because of the general nature of the questions and problems and their appropriateness for the grade level concerned. More importantly, these instruments were found to have a high test-retest reliability (0.86) and internal consistency reliability (0.70) as claimed by the authors. The test consisted of three parts: 1) Self-report inventory of metacognitive skills in problem solving, a self-rating questionnaire to find out how people perceive their own abilities and performance on problem solving tasks and the nature of the problem solving tasks; 2) A questionnaire on 8 specific problem solving tasks; and 3) Solving the 8 Specific problem tasks presented in 2. Sample questions of the metacognitive ability test are shown in Appendix C. Quinto & Weener's study revealed that college students' self-reported assessments of their ability on a general and specific level were positively correlated with their performance on the problem solving task. On predicted performance, students were more accurate in predicting their performance on math and language tasks. Reliability estimates on the instruments used showed the Self-report inventory of metacognitive skills had a test-retest reliability of .86 and an internal consistency reliability of .70.

In the second session, the learner was randomly assigned to one of the two treatment conditions and began the CAI sessions. During the subsequent sessions, the student was to continue on with the CAI lessons and was allowed to stop the session at the end of each immediate post-test if desired. A timer was built into the CAI program to record the total amount of time the subject spent on the CAI lessons. The learning sessions were held between four to six consecutive days. One day after the subject completed the CAI lessons on the four types of stoichiometry problems, s/he was given the final post-test.

III. RESULTS

Analyses of Prior Learning Test Scores

The data analysis of the prior learning test scores consisted of analysis of variance on pre-test, pre-requisite knowledge test, and metacognitive ability sub-tests scores. The tests for homogeneity of variance of within group and between group linearity were nonsignificant ($p > .05$) and thus no transformation of scores was necessary. Mean scores for various tests are presented in Table 4. Correlations for pre-requisite knowledge test and metacognitive ability sub-tests scores are also shown in Table 5.

Pre-test.

All subjects in both the adaptive learner control (ALC) and adaptive program control (APC) conditions encountered difficulties with the questions in the pre-test. None of them was able to make any score. Thus, no analysis of pre-test scores was necessary.

Pre-requisite knowledge test (PRK).

The pre-requisite knowledge mean correct scores were not significantly different ($p > .05$) for the two locus of control groups. Means for males and females were also not significantly different ($p > .05$).

Interaction between gender of students and locus of control was nonsignificant.

Metacognitive ability test.

The metacognitive ability test consisted of three sub-tests: (1) Overall self-rating inventory; (2) Self-rating on specific problem solving tasks; and (3) Performance on specific problem solving tasks. The scores for overall self-rating inventory (OSR) and self rating on specific problem solving tasks (SRS) were determined by adding the total scores obtained in each category. The maximum and minimum possible scores for OSR and SRS were 207, 39 and 96, 18 respectively. Score for performance on specific problem solving task (STS) was the number of problems correct out of 8 problems. Anova's on OSR, SRS, and STS (Table 4) showed no significant differences for the two control groups (p > .05) or between males and females (p >.05).

Insert Table 4 about here

Interaction effect between gender of student and locus of control were also not significant.

Results of correlation tests (Table 5) performed on pre-requisite knowledge test and metacognitive ability sub-tests indicated that only the correlation between overall self-rating (OSR) and self-rating on specific tasks (SSR) scores was significant, $r = 0.86$, $p < .00$.

Insert Table 5 about here

Analyses of CAI Learning Process Variables

Since all the subjects in the learner control group (ALC) followed the suggestions as to the sequence of instruction, all participants (both in ALC and APC) completed the learning program in exactly the same order. Thus, no analysis involving the sequence of instruction was necessary.

The data analyses for CAI were performed on five learning process variables: (a) number of practice examples suggested/prescribed (EP), (b) number of practice examples done (ED), (c) examples correct ratio (CR), (d) learning time (LT), and (e) time spent per practice example (ET), for each of the four types of stoichiometry. Means for the above are presented in

Table 6. Tests for homogeneity of variance were nonsignificant for all variables ($p > .05$) <u>except</u> for learning time in mole-to-mass, mass-to-mole, mass-to-mass stoichiometry (BLT, CLT, DLT), total learning time (TLT), and overall time spent per practice example (TET). Thus, transformation of these scores to their square root was performed in order to reduce the range

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Insert Table 6 about here

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and stablize the variance (Kirk, 1982). The number of practice examples suggested/prescribed for ALC and APC was not significantly different ($p > .05$) in all types of stoichiometry problems. However, ANOVA results indicated that subjects in the ALC group did significantly more practice examples than their APC counterparts in learning mole-to-mass (BED), mass-to-mole (CED), and mass-to-mass (DED) stoichiometry, Fs $(1,24) = 23.67, 9.41, 8.44$, $MSe = 1.77, 1.64, 1.17$, ps $< .0001, .0053, .0078$ respectively. The total number of examples done (TED) was also significantly higher in ALC than in APC, $F\ (1, 24) = 29.88$, $MSe = 8.24$, $p < .00$. Furthermore, results of analyses also showed that students in ALC group spent significantly more time in learning mole-to-mass (BLT) and mass-to-mole (CLT) stoichiometry, *Fs* (1, 24) = 22.11, 5.86, *MSe* = 72.20, 91.88, $p < .0001$, .023 respectively. ALC subjects also spent significantly more time in the entire learning process (TLT), $F(1, 24) = 15.33$, *MSe* = 550.70, $p < .0031$. No significant difference was observed in the examples correct ratio (CR) and the amount of time spent per practice example (ET) for the two locus of control groups ($p > .05$). Analyses of these learning process variables also revealed no significant difference for males and females. However, study of interaction effects indicated that in learning mass-to-mass stoichiometry, the most difficult of the four types of stoichiometry problems, male students in APC spent significantly more time than their ALC counterparts, and female students in ALC spent significantly more time than their APC counterparts, $F(1, 22) = 6.82$, *MSe* = 71.71, $p < .016$. Similar interaction effect was also noticed for time spent per practice example in mass-to-mass stoichiometry (DET), $F(1, 22) = 7.23$, *MSe* = 8.08, $p < .0130$. Other interaction effects were not significant ($p > .05$).

The tests for parallel slopes for the regression of total examples done (TED), overall ratio of examples correct (TCR), and total learning time (TLT) on prerequisite knowledge and metacognitive ability scores (PRK, OSR, SRS, STS) were performed for the two locus of control groups. No significant difference in the regression slopes was observed _except_ in the regression of TCR on OSR, $\underline{F}$ (1, 22) = 4.60, $\underline{p}$ < .044. However, further analysis of covariance on TCR with OSR indicated no significant interaction effect. The standardized regression coefficients shown in Table 8 indicate that the influence of the prior learning tests scores on the learning process variables was not significant.

Analysis of Learning Outcome Variables

Five learning outcome measures from immediate and delayed post-tests were of interest: immediate post-test scores (IP), immediate post-test time (IT), delayed post-test score (DP), total delayed post-test time (TDT), and average correct response rate (ART). Means of these outcome measures are shown in Table 7. Tests for homogeneity of variance for all variables were not significant ($p > .05$) <u>except</u> for immediate post-test time in mole-to-mass (BIT),

Insert Table 7 about here

mass-to-mass (DIT) stoichiometry, and total immediate post-test time (TIT). Thus, BIT, DIT, and TIT scores were transformed to their square root for analysis.

<u>Immediate post-test</u>.

ANOVA's on both immediate post-test scores (IP) and post-test time (IT) for each and overall stoichiometry type were not significant ($p > .05$) for the two locus of control groups and for males and females. Interaction effects between locus of control and gender of students were also not significant.

Tests for homogeneity of slopes for the regression of immediate post-test scores (IP) and post-test time (IT) on prior learning subtests scores (PRK, OSR, SRS, STS) in ALC and APC revealed no significant difference. Since the effects of pre-requisite knowledge and metacognitive ability on immediate post-test scores and post-test time for the two locus of control groups were not significantly different, no further analysis for interaction effects was necessary. The standardized regression coefficients are shown in Table 8 which indicate that the influence of prior learning subtests scores on IP and IT was not significant.

Delayed post-test.

Analyses of variance on delayed post-test scores (DP) showed that subjects in adaptive program control group (APC) scored significantly higher than students in adaptive learner control group (ALC) in mole-to-mass (BDP) and mass-to-mass (DDP) stoichiometry types, $\underline{F}$s (1, 24) = 4.71, 5.05, $\underline{MS}$e = 0.99, 1.10, $\underline{p}$ < .04, .03 respectively. APC subjects' overall delayed post-test score was also significantly higher than their ALC

Insert Table 8 about here

counterparts, $\underline{F}$ (1, 24) = 4.32, $\underline{MS}$e = 9.12, $\underline{p}$ < .049. Post-test scores were not significantly different for males and females. However, interaction effects between locus of control and gender of the students were significant in which male students in ALC did better than their APC counterparts and female students in APC did better than their ALC counterparts in mole-to-mass delayed post-test (BDP), F (1, 22) = 7.30, MSe = 0.81, $p < .013$, and in total delayed post-test (TDP), F (1, 22) = 6.60, MSe = 7.65, $p < .018$ as shown in Figure 3.

Total time spent on delayed post-test (TDT) and average correct response time (ART) for the two locus of control groups and for males and females were not significantly different ($p > .05$). Interaction effects were also not significant.

Insert Figure 3 about here

Tests of homogeneity of slopes for the regression of all learning outcome variables on prior learning subtests scores (PRK, OSR. SRS, STS) in the two locus of control groups showed no significant differences ($p > .05$). Since the effects of pre-requisite knowledge and metacognitive ability on the learning outcome measures for the two locus of control groups were not significantly different, no other analysis for interaction effects was necessary. Standardized regression coefficients presented in Table 8 show that the influence of prior learning subtests scores on learning outcome scores was not significant.

IV. DISCUSSION AND CONCLUSION

Prior Learning Experience

The relatively high mean pre-requisite knowledge score (71%) and the fact that more than half of the participants obtained a score of 75% or more are good indications that these student volunteers have a better-than-average chemistry background. Their performance on the eight specific problem solving tasks revealed that these students are average problem solvers.

In predicting their problem solving ability, the subjects were quite consistent in judging themselves as was indicated by a high correlation between self-rating of general problem solving ability (OSR) and self-rating of specific problem solving ability (SRS). However, the lack of significant correlation patterns between pre-requisite knowledge scores (PRK), overall self-rating scores (ORS), self-rating on solving specific tasks (SRS), and performance on solving specific tasks (STS) made it impossible to draw any valid conclusion regarding the relationships between the prior learning variables.

Analyses of prior learning tests results also revealed that subjects between the two locus of control groups did not differ significantly in their pre-requisite chemistry knowledge, or in their problem-solving ability. Since none of the subjects scored any points in the pre-test, we can attribute any later gains in the ability to solve stoichiometry problem to the effectiveness of the learning programs, and further any difference in gains between the subjects in the two locus of control groups to the different treatment effects.

Effectiveness of the Chemistry CAI Program

Careful analyses of the results provide clear evidence for the effectiveness of the computer-assisted learning program employed in this study. The overall gains indicated by the immediate post-tests and delayed post-test for all subjects are 68% and 63%, respectively. It should be noted that the average net learning time to achieve these gains was approximately 50 minutes which is considerably less than the seven hours normally spent by classroom teachers to cover the same topics (see Alberta Education Chemistry Curriculum Guide, 1983). These findings are consistent with those of previous research (e.g. Kulik, Bangert, & Williams, 1983) that computer-assisted instruction is generally effective in increasing performance and reducing instruction time. However, it must be point out that participants in this study were likely to be above average achievers in chemistry as mentioned earlier, the average learning time could be somewhat longer for a "normal" chemistry 11 class when all students are involved. The efficiency and effectiveness of this particular CAI program for teaching gravimetric stoichiometry in terms of achievement and instructional time deserves further study.

Effectiveness of Locus of Control Strategies, ALC and APC

Although the total number of practice examples suggested to the learner control (ALC) group (9.85) was not significantly different than that prescribed for the program control (APC) group (8.00), subjects in ALC did significantly more (14.15) examples than their APC counterparts (8.00). Consequently, the total learning time was significantly longer for the ALC group. These findings agree with Fisher, Blackwell, Garcia & Greene's study (1975) which indicated that when students were given a choice on engagement in a CAI arithmetic task, they maintained higher levels of engagement over long periods of time than did subjects who were not given a choice. On the other hand, these results are inconsistent with earlier prediction and with other research findings (e. g. Carrier, 1984; Tennyson, 1980; Ross & Rakow, 1981). Both Carrier and Tennyson argued that when students control the amount of instruction they receive, they often terminate too early and fail to learn what they should. The original prediction also was that subjects in ALC would terminate early especially when they encountered new and unfamiliar learning materials. In the present study, the longer learning time engaged by the ALC subjects could be of two reasons: (1) Participants in this study were student-volunteers. They were asked to take part in this learning task outside their normal class time, i.e. before school, lunch time, after school, or when they have a "free" period. Thus, individuals who were willing to be involved were more likely to be those who had a keen interest in learning chemistry in general, and learning through a computer in particular. As a result, these students tended to be more serious and willing to invest more time; and (2)

None of these participant had previous experience with computer-assisted instruction, and therefore they found such an experience quite interesting and were more motivated to spend more time when given the opportunity to do so.

It is rather interesting to note that although subjects in ALC spent significantly more time in learning, they did not achieve as much as their APC counterparts. Subjects in APC did slightly better than the ALC learners in all the immediate post-tests, and the APC's superiority surfaced significantly in the delayed overall post-test. The study by Blackwell, Garcia & Greene (1975) reported similar results. They found that longer engagement on a CAI task did not necessarily result in better performance. The results in the present study suggest that APC is a considerably more efficient strategy in the computer-assisted learning of gravimetric stoichiometry than ALC since subjects in APC achieved significantly more in a much shorter period of time. The superiority of adaptive program control strategy demonstrated in this study is consistent with our prediction and agrees with previous research findings (e.g. Fisher, Blackwell, Garcia & Greene, 1975; Tennyson & Buttrey, 1980; Ross & Rakow, 1981). However, explanations for the superiority of program control strategy demonstrated in this study are not quite straightforward.

In Ross & Rakow's study, program control produced better performance because LC subjects selected much fewer examples than were prescribed and their average study time per rule did not differ from subjects in other groups. In the present study, the reason seems to be the opposite. Careful analyses of the results show that longer learning time was not conducive to the acquisition of rules for solving gravimetric stoichiometry problems. In fact, when subjects were not given a set number of practice examples to do, they tended to rely on having more and more learning resources and not to concentrate on what they were attending to. Although they did more examples and spent approximately the same amount of time per example as their APC counterparts, they probably let their mind wander with the hope that they could always learn from another example if desired. As a result, subjects in ALC and APC did not differ significantly in immediate posttest performance but subjects in APC were able to retain the learned materials for a longer period of time as reflected by their significantly higher delayed posttest score. It can therefore be concluded that ALC subjects' poor performance was more of failing to use resources wisely than trying to terminate the task early.

Contrary to original predictions and Tobias' achievement-treatment interaction theory (Tobia, 1976), neither the students' pre-requisite knowledge nor their metacognitive ability had any effect on learning outcomes. Pre-requisite knowledge and metacognitive ability were not significant covariates for all learning outcome variables. In other words, the interaction effects between pre-requisite knowledge, metacognitive ability and locus of control were not significant. The absence of interactions may be explained by the fact that the subjects involved in the study were a selective group of students whose prior chemistry knowledge and metacognitive ability did not vary much and thus no clear distinction could be drawn between individuals with high and low ability.

Another possible reason for the absence of interaction between metacognitive ability and locus of control could be attributed to the inappropriateness of the instruments employed in measuring metacognitive ability for this particular group. Although Quinto &

Weener (1983) had claimed a high test-retest reliability and a high internal consistency reliability on the instruments used, the empirical evidence may have only provided the face or content validity of the instruments and not its construct validity. Thus the aptitude-treatment interaction effects hypothesized in this research deserve further study using more sophisticated and reliable instruments.

The reasons for the significant gender by locus of control interaction effect observed in delayed post-test scores are not easy to establish. Although there has been no conclusive evidence in recent researches to show that boys are better independent workers than girls in problem-solving, a widely held believe is that girls generally require more guidance and directions than boys in scientific learning tasks and thus they require a more structured approach. It is obvious that further studies on interaction effects between locus of control and gender need to be conducted before any explanations and generalization can be made. Such studies should involve a more generalizable sample which includes subjects with a wider range of prior learning and metacognitive abilities so that the possible interaction effects for locus of control, gender, and other aptitude measures can be studied in depth.

It is quite clear that this study provides evidence for the superiority of adaptive program control strategy over adaptive learner control strategy in the computer-assisted learning of gravimetric stoichiometry as was predicted. When encountering new and unfamiliar task, as in this learning program, students require more structured instructional support. More practice and more learning time do not necessarily facilitate learning, especially when subjects have the tendency to rely on more learning resource materials and do not concentrate on what they are attending to.

However, before any valid conclusions can be made from this study, a few points must be kept in mind. First , because of the lack of computer facilities, it was not possible to conduct a large scale research that involved every student in all Chemistry 11 classes during regular class time. As a result, volunteers had to be drafted and paid for to attend study sessions outside regular class hours. Since volunteers were solicited for the study, they tended to be of a selected group of students with a small range of ability and this makes generalization somewhat difficult. Second, because the study had to be conducted outside regular class hours, it was difficult to control the amount of time elapsed in between sessions and the possible errors caused by different time of the day. For example, it was noticed that students who came in during lunch hours appeared to be under greater time pressure than those who attended sessions early morning and after school and their performance would likely to be different. Another possible error came from the inconsistency in the length of sessions resulting from an attempt to accommodate every volunteer in the study. Due to scheduling difficulties, the length per session varied from 60 minute to 120 minutes.

Although results of this study provide practical implications for the design of computer-assisted instruction materials, replication of this research is recommended with tighter control over the possible sources of errors described above before these results could be generalized in instruction. It would also be interesting to conduct similar studies using different subject domains to see if similar findings would be replicated.

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Table 1

Four Types of Stoichiometry Problems

		required substance in mole	required substance in mass
given substance	in mole	mole to mole	mole to mass
	in mass	mass to mole	mass to mass

Table 2

Instructional Design for Teaching Gravimetric Stoichiometry Calculations

Sequence	Intended Functions	Component
1. Pre-test (12 items with 3 replications of 4 stoichiometry types)	To assess the learner's pre-learning level of knowledge in stoichiometry calculations: (a) mole-to-mole stoichiometry (b) mole-to-mass stoichiometry (c) mass-to-mole stoichiometry (d) mass-to-mass stoichiometry	Evaluator
2. Diagnostic test (12 items with 3 replications of 4 pre-requisite areas)	(a) To assess the learners' pre-requisite knowledge: i) molar mass (M) calculations ii) mole (n) to mass (m) calculations iii) mass (m) to mole (n) calculations iv) ratio calculations	Diagnostician

(table continues)

Sequence	Intended Functions	Component
	(b) To derive instructional prescriptions	
3. CAI Modules	To provide instructions for solving gravimetric stoichiometry problems. (a) identify the given and required substances (b) express the amount of given substance in moles (c) identify the coefficients of the given and required substances from the balanced equation (d) find the amount of the required substance in moles (e) express the amount of the required in grams if desired	Tutor
4. Post-tests	To assess the effectiveness of CAI program	Evaluator

Table 3

Pre-requisite Knowledge Required for Solving the Four Types of Stoichiometry Problems

	Stoichiometry type			
Pre-requisite knowledge	Mole to mole	Mole to mass	Mass to mole	Mass to mass
Ratio calculations	yes	yes	yes	yes
Molar mass calculations		yes	yes	yes
Mole to mass calculations		yes		yes
Mass to mole calculations			yes	yes

Table 4

Mean Scores of Prior Learning Subtests

	ALC		APC	
	Male (n=4)	Female (n=9)	Male (n=7)	Female (n=6)
PRK (Max. 12) (Min. 0)	9.50	7.89	9.00	7.83
OSR (Max. 207) (Min. 39)	144.00	137.78	142.86	147.17
SRS (Max. 96) (Min. 18)	67.25	62.56	67.86	67.83
STS (Max. 8) (Min. 0)	4.50	3.67	3.86	3.67

Note. ALC = adaptive learner control; APC = adaptive program control; PRK = pre-requisite knowledge test score; OSR = overall self-rating score in metacognitive ability subtest; SRS = self-rating on specific tasks in metacognitive ability subtest; STS = performance on specific tasks in metacognitive ability subtest.

Table 5

Correlations Between Pre-Requisite Knowledge Test and Metacognitive Ability Subtests Scores

	OSR	SRS	STS
PRK	-0.0023	-0.1003	0.1081
OSR	-	0.8633	0.1794
SRS	-	-	0.2867

Note. PRK = Pre-requisite knowledge test; OSR = Overall self-rating score; SRS = self-rating on solving specific tasks; STS = performance on solving specific tasks.

Table 6

Means of Learning Process Variables for the Four Types of Stoichiometry Problems

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Type A:				
AEP	2.50	3.78	3.00	3.50
AED	3.75	4.22	3.00	3.50
ACR	0.81	0.73	0.83	0.83
ALT(min)	9.93	12.04	5.63	8.25
AET(min)	2.64	2.60	2.09	2.08
Type B:				
BEP	2.00	1.67	1.43	1.17
BED	4.00	3.79	1.43	1.17
BCR	0.15	0.40	0.56	0.54
BLT(min)	26.17	19.08	6.23	4.85
BET(min)	6.96	5.03	4.21	4.43

(table continues)

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Type C:				
CEP	2.25	2.78	2.57	1.33
CED	3.25	3.67	2.57	1.33
CCR	0.83	0.61	0.60	0.50
CLT(min)	13.71	19.72	11.15	5.99
CET(min)	3.77	5.32	4.29	5.20
Type D:				
DEP	1.75	2.22	1.43	1.50
DED	2.00	3.00	1.43	1.50
DCR	0.88	0.39	0.40	0.53
DLT(min)	5.47	22.04	10.94	9.41
DET(min)	2.79	7.32	7.62	5.89

(<u>table continues</u>)

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Total:				
TEP	8.50	10.44	8.43	7.50
TED	13.00	14.67	8.43	7.50
TCR	0.63	0.56	0.65	0.70
TLT(min)	55.28	72.88	33.95	28.49
TET(min)	4.15	4.87	3.99	3.71

Note. ALC = adaptive learner control; APC = adaptive program control; M = male; F = female; Type A = mole-to-mole stoichiometry; Type B = mole-to-mass stoichiometry; Type C = mass-to-mole stoichiometry; Type D = mass-to-mass stoichiometry; EP = number of practice examples suggested/prescribed; ED = number of practice examples done; CR = ratio of examples correct; LT = learning time; ET = time spent per practice example.

Table 7

Means of Learning Outcome Variables for the Four Types of Stoichiometry Problems

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Immediate Post-test:				
Type A:				
AIP	3.50	3.67	3.71	4.33
AIT(min)	4.83	6.17	5.79	6.57
Type B:				
BIP	3.00	2.67	2.57	4.33
BIT(min)	8.09	8.66	11.31	9.03
Type C:				
CIP	3.25	2.89	3.57	4.00
CIT(min)	7.00	8.15	8.55	10.79
Type D:				
DIP	2.75	2.89	3.71	4.17
DIT(min)	7.94	12.53	10.70	11.83

(table continues)

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Immediate Post-test				
Total:				
TIP	12.50	12.11	13.57	16.83
TIT(min)	27.85	35.51	36.35	38.49
Delayed Post-test:				
Type A:				
ADP	2.75	2.33	2.29	2.83
Type B:				
BDP	1.75	0.67	1.43	2.33
Type C:				
CDP	2.00	1.22	1.86	2.33
Type D:				
DDP	2.00	1.22	2.00	2.83

(<u>table continues</u>)

	ALC		APC	
	M (n=4)	F (n=9)	M (n=7)	F (n=6)
Delayed Post-test				
Total:				
TDP	8.50	5.44	7.57	10.33
ART (min)	1.92	1.97	2.04	2.32
TDT (min)	23.83	26.77	26.01	28.15

Note. ALC = adaptive learner control; APC = adaptive program control; M = male; F = female; Type A = mole-to-mole stoichiometry; Type B = mole-to-mass stoichiometry; Type C = mass-to-mole stoichiometry; Type D = mass-to-mass stoichiometry; IP = immediate post-test score; IT = immediate post-test time; DP = delayed post-test score; ART = average correct response time; TDT = total delayed post-test time.

Table 8

Standardized Regression Coefficients for the Regression of Learning Process and Learning Outcome Variables On Prior Learning Subtests Scores In Locus of Control Groups, ALC and APC

	PRK	OSR	SRS	STS
Learning Process Variables:				
TED	-0.4981	-0.1264	-0.1173	-0.3606
TCR	0.2984	0.1192	0.0269	0.3111
TLT	-0.4574	-0.1203	-0.0233	-0.2783
Learning Outcome Variables:				
Immediate Post Test:				
TIP	0.0805	0.2506	0.2417	0.5160
TIT	-0.1621	-0.0016	-0.1095	0.1010

(table continues)

	PRK	OSR	SRS	STS
Learning Outcome Variables				
Delayed Post Test:				
TDP	0.0116	0.2149	0.0852	0.2157
ART	-0.1212	0.2151	0.1488	0.0968
TDT	-0.0280	0.0719	0.1536	0.2770

Note. ALC = adaptive learner control; APC = adaptive program control; M = male; F = female; PRK = pre-requisite knowledge test score; OSR = overall self rating score in metacognitive ability subtest; SRS = self-rating on specific tasks in metacognitive ability subtest; STS = performance on specific tasks in metacognitive ability subtest; TED = total practice examples done; TCR = total examples correct ratio; TLT = total learning time; TIP = total immediate post-test score; TIT = total immediate post-test time; TDP = total delayed post-test score; ART = average correct response time; TDT = total delayed post-test time.

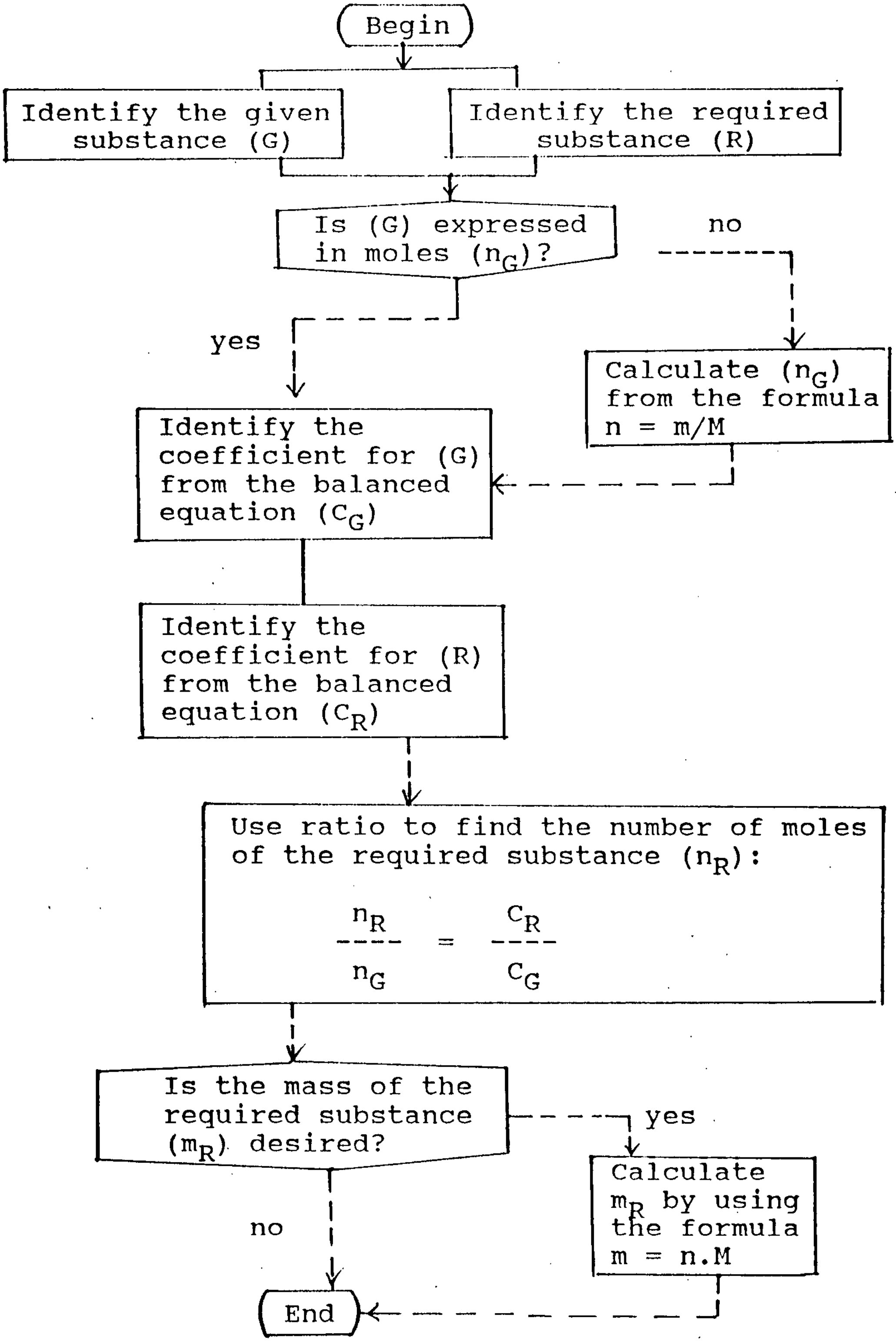


Figure 1. Task components and processes for solving gravimetric stoichiometry problems

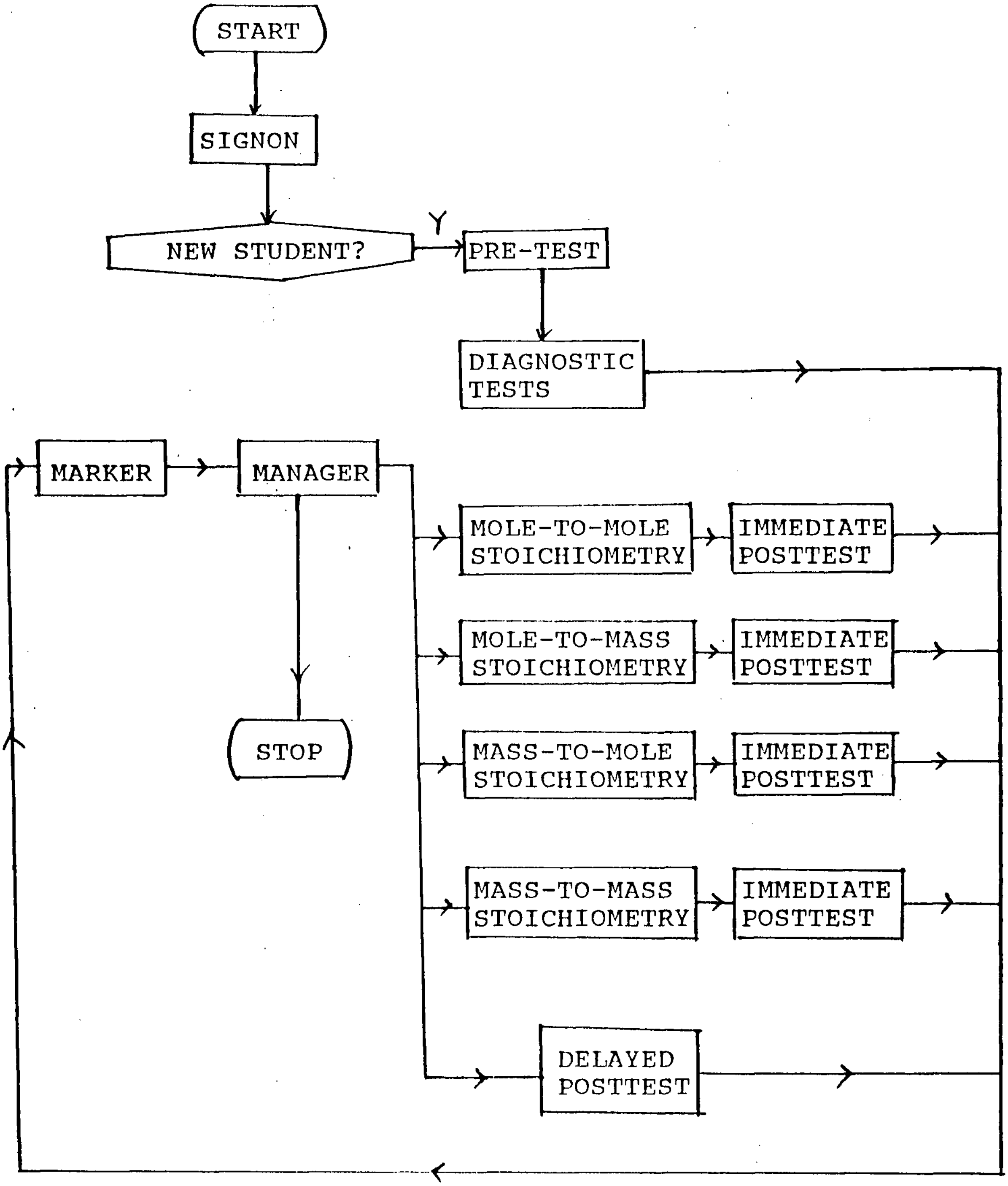


Figure 2. Instructional flowchart
for Learning Gravimetric Stoichiometry.

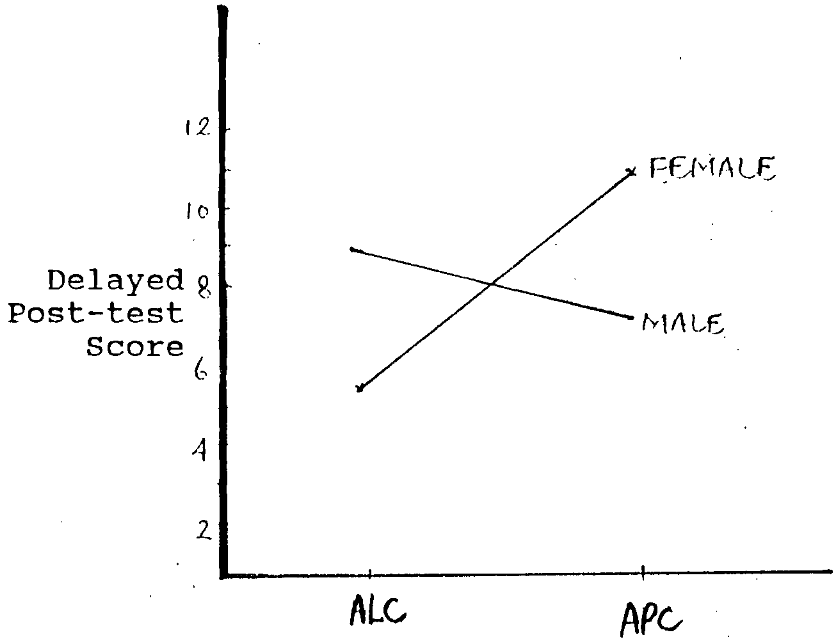


Figure 3. Interaction between gender of students and locus of control

APPENDIX A

Pre-test and Post-test Sample Questions

1. How many moles of oxygen would be required to produce 43.5 mol of carbon dioxide?

$$C_{25}H_{52(s)} + 38\ O_{2(g)} \text{ -----> } 25\ CO_{2(g)} + 26\ H_2O_{(g)}$$

2. 568.2 g of iron would produce how many moles of iron [III] oxide?

$$4\ Fe_{(s)} + 3\ O_{2(g)} \text{ -----> } 2\ Fe_2O_{3(s)}$$

3. What mass of silver would produce 26.84 mol of silver sulfide?

$$16\ Ag_{(s)} + S_{8(s)} \text{ -----> } 8\ Ag_2S_{(s)}$$

4. Find the mass of sodium hydrogen carbonate required to produce 89.62 g of carbon dioxide.

$$2\ NaHCO_{3(s)} \text{ -----> } Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$$

APPENDIX B

Pre-requisite Knowledge Sample Questions

A. Find the molar mass of $(NH_4)_2SO_4$.

B. Determine the number of moles in 745.3 g of CCl_4.

C. Calculate the mass in 5.92 moles of C_2H_5OH.

D. Solve for x:

$$\frac{x}{0.85} = \frac{25}{52}$$

APPENDIX C

Metacognitive Ability Test Sample Questions

General Instruction:

The statements in this inventory are used to find out how people perceive their own abilities and performance on problem solving tasks and the nature of the problem solving tasks. Answer Them according to what you actually think and do and do not answer them according to what you think you should do. Respond as accurately as you can.

SUBTEST 1.

Self-Report Inventory of General Metacognitive Skills.

A. On a scale of 1-7 (from poor to excellent) rate yourself in solving three different types of problem solving tasks. Type the number you choose to rate youself. Time limit: 60 seconds per response.

1. Mathematical Problems - These may involve problems such as adding, subtracting, multiplying, and dividing numbers. Converting meters to kilometers, finding the right number in a series (3, 6, 12, 24 ....) or classifying data.

1	2	3	4	5	6	7
Very Poor	Poor	Fair	Good	Very Good	Superior	Excellent

B. Rate youself on the following items by typing the appropriate number. Time limit: 60 seconds per response.

1. I find it difficult to grasp visual/spatial problems like using a visual diagram to put together a home appliance or visualizing how a room will look after the furnishings have been changed.

1	2	3	4	5
Always	Often	Sometimes	Seldom	Never

2. I can estimate quite accurately how I do on exam.

1	2	3	4	5
Always	Often	Sometimes	Seldom	Never

3. When taking exam, I usually work on easy items first and then go on to the more difficult ones rather than just taking them in the order they are presented.

1	2	3	4	5
Always	Often	Sometimes	Seldom	Never

SUBTEST 2.

A questionnaire on Specific Problem Solving Tasks.

Direction: Type the number you choose to rate yourself. Give your best guess if you are uncertain about how to respond. Time limit: 60 seconds per response.

1. Three fathers -- Pete, John, and Nick -- have between them a total of 15 children of which 9 are boys. Pete has 3 girls and John has the same number of boys. John has 1 more child than Pete, who has 4 children. Nick has 4 more boys than girls and the same number of girls as Pete has boys. How many boys each do Nick and Pete have.

a. How well can you solve this problem?

1	2	3	4
Very Well	Good	Fair	Poor

b. How confident are you in your estimate of your performance.

1	2	3	4
Very Well	Good	Fair	Poor

c. In a scale of 1 to 4 (4 as very difficult) how difficult is this problem for you?

1	2	3	4
Very Well	Good	Fair	Poor

2. On a certain day I ate lunch at Tommy's, took out two books from the library, visited the museum, and had a cavity filled. Tommy's is closed on Wednesday, the library is closed on Staurday and Sunday, the museum is only open Wednesday, Monday, and Friday, and my dentist has office hours Tuesday, Friday, and Saturday. On which day of the week did I do all these thing?

a. How well can you solve this problem?

1	2	3	4
Very Well	Good	Fair	Poor

b. How confident are you in your estimate of your performance.

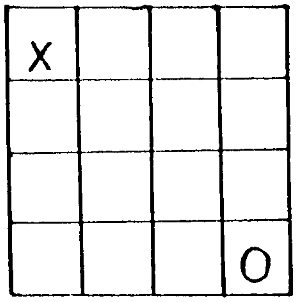
1	2	3	4
Very Well	Good	Fair	Poor

c. In a scale of 1 to 4 (4 as very difficult) how difficult is this problem for you?

1	2	3	4
Very Well	Good	Fair	Poor

3. Below is a diagram showing the arrangement of cells in a state prison. One day the prisoner in the cell marked with an "X" went berserk and was overcome with the urge to kill. So he broke through the wall which separated his cell from the one next to it, and murdered the inmate there. This just intensified his madness, so he proceeded to break into each cell and kill the prisoner there. After each was dead, he dropped the body and went on to the next. He would never go back into a cell containing a dead body. Every cell contained a prisoner; he never went through a cell without murdering anyone he found there; and he never broke through an outside wall or a corner.

When the authorities finally arrived, he was just killing the last inmate in the cell marked with an "O". Show the diagram below with a path he might have taken to arrive at that cell last.



a. How well can you solve this problem?

1	2	3	4
Very Well	Good	Fair	Poor

b. How confident are you in your estimate of your performance.

1	2	3	4
Very Well	Good	Fair	Poor

c. In a scale of 1 to 4 (4 as very difficult) how difficult is this problem for you?

1	2	3	4
Very Well	Good	Fair	Poor

SUBTEST 3.

Solve each of the problems presented in SUBTEST 2.
Time Limit: 5 minutes per question.