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ABSTRACT

Attempting to define the optimal use of educational resources for large numbers of students, a research group at the University of Texas at Austin has adopted a system approach to curriculum development consisting of the following components: content, teacher, student, machine, and media. The first procedural step in the system is to define the objectives and tasks of the course in terms of related sets of behavioral objectives. Then, using information about teaching style, learning style, and available resources, a complete multimedia course can be designed that is tailored to the individual needs of the student. In one chemistry course, the technique was used to generate remedial modules to assist the student having difficulties with exam questions. Results indicate that computer based techniques relieve the burden on the instructor, and they have a positive effect on student achievement and attitudes. The appendixes include the flow diagram for the system design, a list of the tutorial modules used in the chemistry course, and cost data. (EMH)

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Project C-BE

GRANT GY-9340

COMPUTER-BASED SCIENCE AND ENGINEERING EDUCATION

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THE IMPACT OF COMPUTERS ON UNDERGRADUATE CHEMICAL EDUCATION

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Introduction

Many of the procedures and techniques employed by instructors at large universities are controlled and necessitated by logistical considerations: large numbers of students, low numbers of instructors, classroom space, and record keeping. There have been and are several projects which attempt to use the computer to optimize the educational process. These projects have generally had as their emphasis either the development of a large, powerful delivery system, with little regard for the development of curriculum software or the philosophy for developing curriculum, or they have concentrated on producing complete, self-contained teaching systems in which the computer "controls" the whole course. Other projects have as their central thrust using the computer only as a problem solving tool, while still others employ the computer to "supplement" the teacher in some fashion.

There have recently been numerous attempts to return control of the educational process to the instructor and student: the Keller Method[1] (PSI) audio-tutorial tapes, CAI (computer assisted instructed), CGRE (computer generated, repeatable exams), CMI (computer managed instruction) and

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CAL[2] (computer augmented lecture), to mention a few. Unfortunately, many of these efforts seem to lack a generalized approach to curriculum design which includes the total curriculum and teaching/learning system. We have attempted to combine many of the computer-based and PSI techniques, in light of a generalized approach to curriculum development, to the first course in chemistry. This paper presents our approach to curriculum design, the computer techniques employed, the results we have obtained, and the changes and adaptions which we think will be useful. Even though we use a specific course as an example, it should be clear that the techniques and approach are applicable to any discipline.

Strategy

The governing philosophy in the use of any form of technology in the educational process is to augment the teacher and to optimize his effectiveness, not to replace him. The application of technology should free the teacher from non-instructional tasks and help students learn. Using this philosophy, we adopted a systems approach to curriculum development in which we viewed the teaching/learning process in our course as a system consisting of the components: content, teacher, student, machine, and media (including software). This system is schematically represented in Figure 1.

The techniques we have employed are a combination of CMI, CAI, PSI, contingency management[3], and self-paced, individualized instruction. In combining these techniques and designing the course, we have made the following assumptions: (1) the optimum conditions for learning are unique for each student; each student can learn more effectively when the sequence of instructional material, the pace and mode of presentation and the style of instruction are tailored to his individual needs and capabilities. (2) An integrated system of human, hardware and software components presents the only viable method to offer large numbers of students highly individualized instruction. Planning[4] the utilization process for human components of a system must be completely integrated with the planning of machine and software utilization. The hardware/software functions are to present instructional material, collect data, analyze data, reduce data, and provide reports. The human functions include designing teaching strategies, interpreting data, counseling students, bridging the gap between existing software and current research, and obtaining behavioral objectives in the affective domain (i.e., influencing attitudes, motivating and inspiring students).

The system of curriculum development is shown schematically in Figure 2. The first step is a course analysis which consists of the following tasks: 1. List global objectives of and concepts in the course; 2. Perform a task analysis; that is, determine the specific tasks students will have to perform to successfully master the concepts and complete the course; 3. Prepare a hierarchical grouping of concepts and tasks; that is, group and sequence the concepts and tasks in the order in which they should be encountered by determining which concepts and tasks are necessary pre-skills for other tasks; and 4. Write behavioral objectives.

The next step is to group the behavioral objectives into small, closely related sets which will form the basis for the course modules, each set becoming a module. It is necessary to realize that there is no one best method for helping students attain the desired objectives. There are four principle variables which determine the "best" method:

1. The nature of the objectives themselves. Some information is most efficiently conveyed by lecture, some by the written word, some graphically. Some skills, manipulative in nature, must be performed and practiced in a real setting, the laboratory; some skills may be practiced and learned through simulations or problem solving sets (excellent computer applications).
2. The student. The optimum condition of learning for each student appears to be unique. This implies the necessity of multiple paths leading to the achievement of an objective.
3. The teacher. Just as no two students approach learning in exactly the same manner, no two teachers will use exactly the same teaching methods with equal effectiveness.
4. The availability and cost effectiveness of resources and facilities.

A complete course must be a multi-media course. No one medium -- film, lecture, TV, audio tutorial, computer interactions (CAI, CMI), etc. -- can completely fulfill all objectives. The media used for a module must be tailored to the nature of the objectives, the student, the teacher, and the available resources and facilities. This then, is the next step in the curriculum design system.

From this point on in the diagram each step can apply to a single module, a group of modules or the complete course. The remaining steps are self explanatory and require no further discussion except to note that a consideration of methods of validation and evaluation are beyond the scope of this paper.

It should be pointed out that the use of short, relatively independent modules has many distinct advantages. As Figure 2 illustrates, the development of a course is a continuous loop with the course undergoing constant change and revision due to new knowledge, technological progress, and new human components with different characteristics. The existence of course content in short modules makes revision and change easy. Only the clearly defined modules directly involved need be changed, A second, extremely important advantage in having short, clearly defined and well documented modules is that it makes it possible for other teachers (in the same and/or different institutions) who teach similar or related courses to choose and utilize those modules which meet the needs of his particular situation. This way, other instructors do not have to reinvent any wheels or accept "complete" packages which contain unwanted or undesirable materials. The existence of these modules also makes it possible for different students to have different sequences and content for the same course, which is at it should be in a student centered curriculum.

A student centered curriculum, as indicated in Figure 1, is one which can be specifically tailored to an individual student's needs. The course is self paced within the time constraints of the course. The student's abilities and desires will be a major factor in determining the pace, content, and sequence of modules. However, the decision making process is not completely the student's. The teacher must guide and counsel the student in his decisions to prevent students from being bogged down in modules for which they do not have the necessary pre-skills and to prevent some students from procrastinating until they are too far behind.

Course Description

We have been particularly interested in those parts of the curriculum which can be efficiently and effectively handled by computers. The remainder of discussion will focus on the computer-based application we have implemented.

All too frequently teachers become overly involved in attempting to help students learn in a poor environment, rather than teaching; that is, they have the burden of assigning, grading and giving feedback on homework and tests, helping students with their assignments, and conducting tutorial/remedial drill group interactions. To a large extent the computer can perform these tasks (on an individual basis) as well as, or better, than the instructor. Hence, we have developed a number of CAI type modules which function in the tutorial, drill, simulation and testing modes.

To allow large numbers of students to proceed through a self-paced course, taking different tests and modules at different times requires an automated record keeping system. To meet this requirement we implemented a CMI, contingency management system, which could automatically record computer administered test results, automatically record CAI module results, accept non-computer generated results, and provide student progress reports in the form of individual profiles on demand. This allowed both the instructor and the student to know exactly the student's status at any given time.

In order to understand the implementation of the system, it is necessary to know the structure of the course as taught by one of us (Dr. Lagowski). Figure 3 is the first handout the student receives; it shows the text and chapters used, the work distribution, and the grading schedule. The course consisted of one hour of lecture per week, one hour of small group discussion and one hour of computer interaction per week (the actual computer time varied with the needs and desires of the students). The three major examinations and ten quizzes were instructor generated, administered and graded. However, for each question on each test there was a corresponding test module on the computer which the students could use to make up low scores received on the paper pencil test. The computer test modules used random parameter generation techniques to insure that no two students received exactly the same question and that no student received exactly the same question on repeated trials. The computer administers the test, scores it (immediately giving the student his results) and then records the results in the student's data file.

Figure 4 shows the computer modules (tutorial/drill and simulation) available to the students and their point value. The modules are also keyed to the appropriate chapter in the student's text. The effectiveness of CAI as a teaching tool has been amply demonstrated.[5,6,7,8] Likewise, the rationale behind its development and application in general, and particularly in chemistry, has been well documented.[6,9,10,11] We shall, therefore, only briefly outline the philosophical points underlying our modules: (1) the modules supplement the instructor, not replace him; (2) the modules are designed to help students learn by doing, not necessarily to teach or merely transfer standard information; (3) the computer interactions are modular and independent, facilitating the individualization of student experiences in pace, sequence and content.

A few sample situations will illustrate these points. In the module CHEM1, the gas laws, the module randomly selects the type of problem--whether the student will solve for pressure or volume or temperature using the combined gas law. Then the module randomly generates the numerical value of the parameters to be given to the student. If in the student's first answer he does not convert to absolute temperature, the module is able to diagnose this error and give the appropriate response contingent feedback. On the student's second answer, if he is correct, he is given an appropriate positive response. When the student inputs a series of answers which are incorrect, and the module cannot diagnose a specific type of error, on the first response the student is given a broad clue; on the second response the student receives a more specific hint, and on the third response he is given the solution.

The above situations illustrate a typical tutorial/drill type module; the following situation* illustrates a typical simulation type module. CHEM32 is a kinetics experiment in which the student's task is to collect sufficient

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* Illustrative sample interactions available from the authors.

data to determine (1) the order of reaction, and (2) the reaction rate constant. This module is really a series of decisions the student must make on the basis of his experience and the data he collects. He must decide the experimental conditions: concentration and the wave length at which to follow the reaction. He must decide if his data are satisfactory and how he is to treat the data. After the student has analyzed the data (on or off line), he takes a special module which checks and records his results.

Results

The course utilizing our C-BE methods has been offered twice as a regular section of General Chemistry 302. We evaluated the course by: (1) comparing it to other non-C-BE sections in terms of student achievement; (2) determining costs per student hour; and (3) obtaining student attitudes. We controlled the comparison of sections for differences in entering skills and aptitudes by using chemistry placement test scores and SAT-M and SAT-V test scores as covariables. Comparison data** in terms of grade distributions indicate the classes using C-BE techniques achieved a greater proportion of A's and B's. Figure 5 shows our cost data. It is interesting to note that these costs are based upon experimental charges, not the lower, regular departmental charges. Even at this rate, it is possible to reduce costs by optimizing and improving the system as the drop from $4.05/student hour to $2.07/student hour indicates. We

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** Data available on request.

ERIC Full Text Provided by ERIC

can easily foresee the costs dropping to less than $1.00/student hour when the current department rates are used rather than experimental rates.

At the end of the course an attitude scale consisting of 51 items was administered to the students. The maximum possible positive score was 193. The neutral score was 96.5. The mean score of the 79 responding students was 156.6, which clearly indicates a positive attitude of the student towards C-BE techniques. The alpha coefficient (the coefficient of internal consistency) was .55 and reflects the degree of reliability among the items of a scale in terms of overlapping variance.

Our results indicate that C-BE techniques can efficiently augment the teacher's efforts, and have a positive effect on both student achievement and student attitudes. In light of our results it is not difficult to foresee our general chemistry course becoming not one course but a different individualized course for each student--the content of the course (and hours of credit) to be determined on the basis of a placement test (on minimum core skills) and student desires (for optional units). The sequence and rate of progress of the student will be determined jointly by the teacher and student, so that the course becomes self-paced within the limits agreed upon by student and teacher. The "course" is no longer constrained by the traditional time limits: semesters or quarters and credit hours. In this course, the teacher retains his usual teaching role, but trades the roles of bookkeeper, grader and all around paper shuffler for the roles of counselor and mediator.

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TEACHING/LEARNING SYSTEM

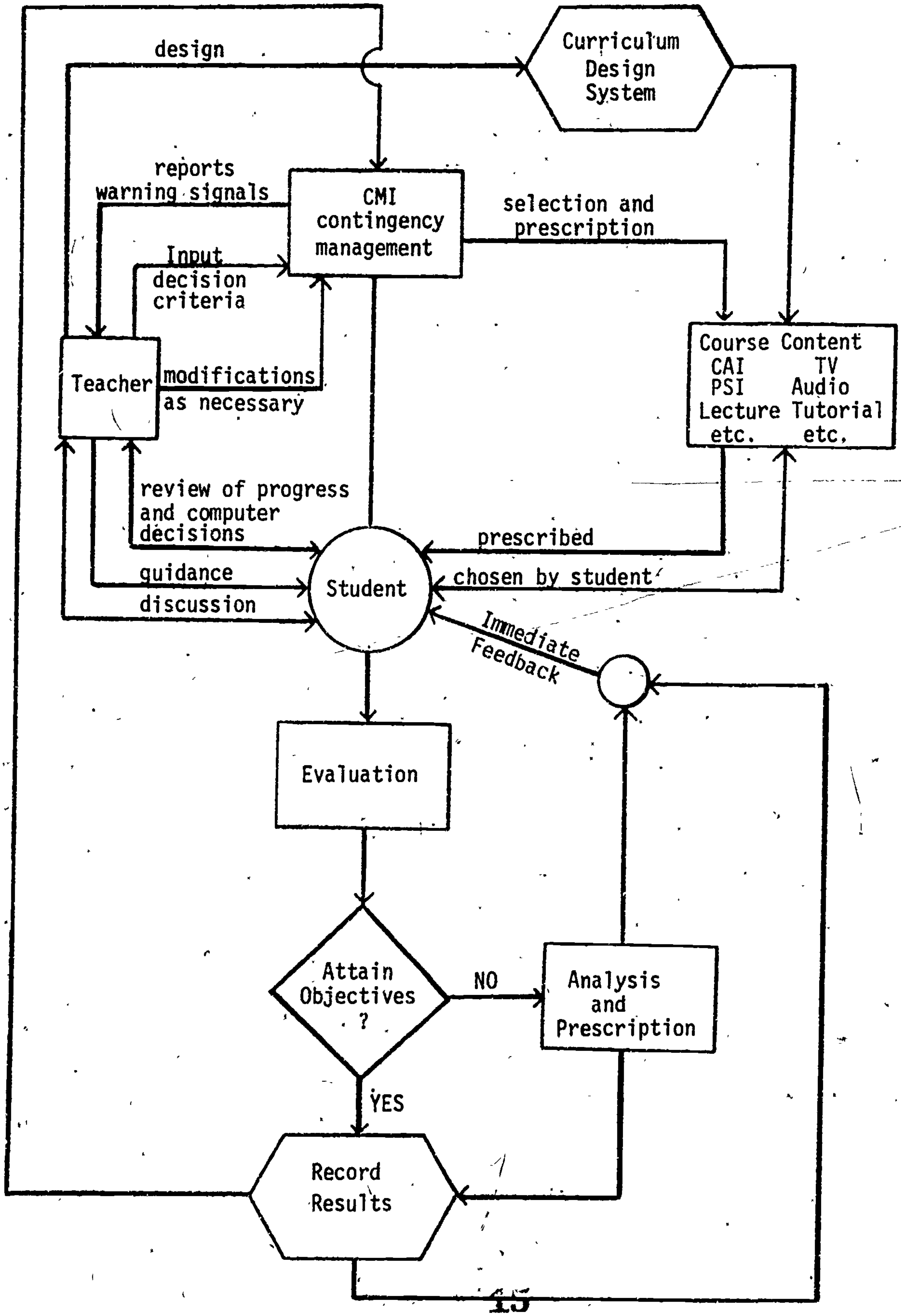

Figure 1

CURRICULUM DESIGN SYSTEM

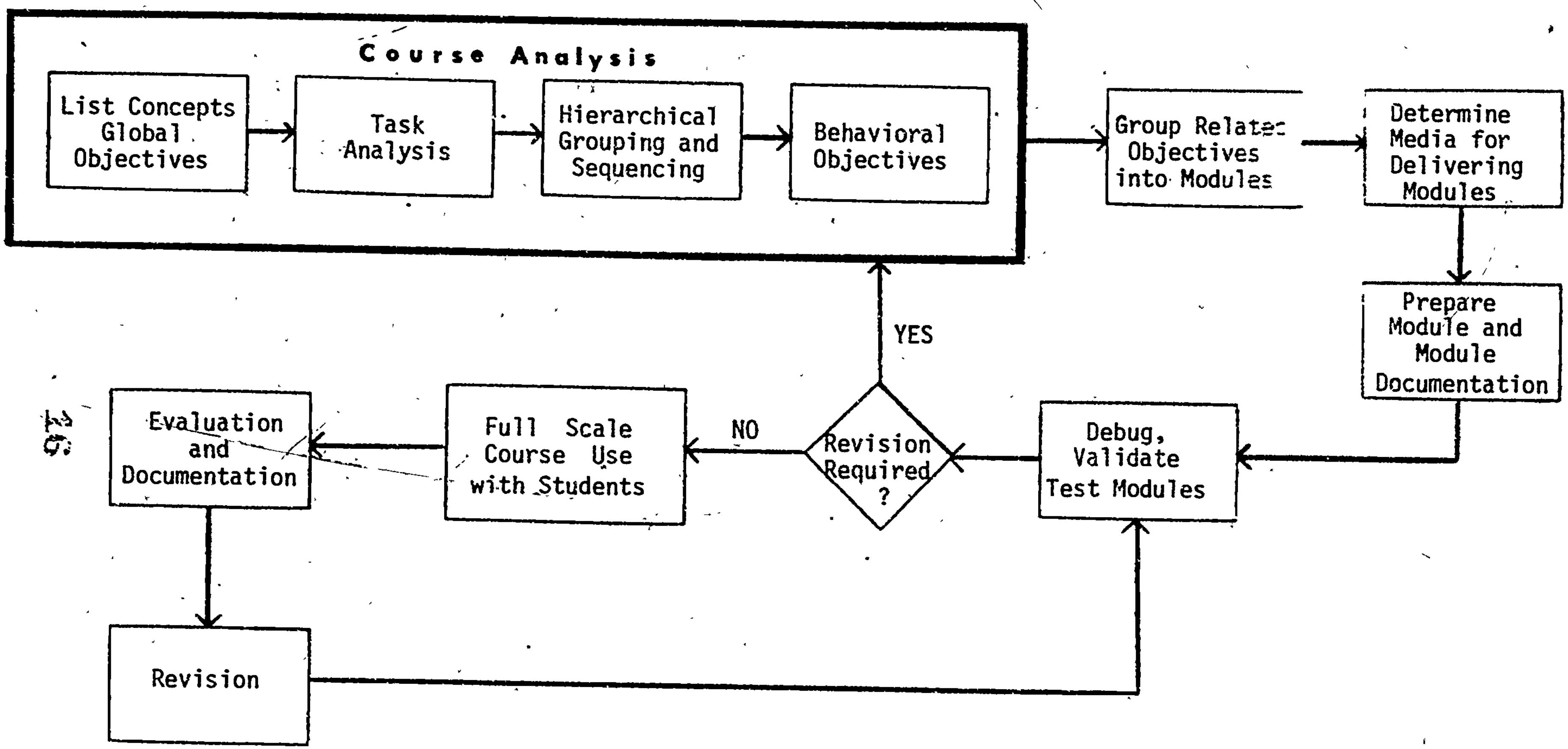

Figure 2

CHEMISTRY 302.12265 - FALL 1972
J. J. Lagowski
TTh 3-4:30
CHE 15

Text: Slabaugh and Parsons, GENERAL CHEMISTRY, Second Edition
Chapters: 7, 8, 9, 10, 11, 12, 13, 14, 15

Work Distribution:

1 Hour lecture every Thursday
1 Discussion period every Tuesday (schedule to be announced).
1 Session/week with computer (to be scheduled at your convenience).

Examinations: 3 October, 8 November, Final Exam Period 21 December, 9-12 am. Exams are scheduled for the evening of these days, 7:30-9:30 pm. In case of a conflict, please see me at least one week before the exam and individual arrangements will be made.

Quizzes: End of each lecture on Thursdays.

Grading Schedule:	Points	Total
3 Major examinations	100 each	300
10 10-minute quizzes	10 each	100
12 Attendance at discussion periods	3 each	36
12 Attendance at lectures	3 each	36
14 Tutorial Modules	See list	150
7 Simulated Experiments	See list	160

A = 100 - 90%
B = 89 - 90%
C = 79 - 70%
D = 69 - 60%
F = 59% and below

Figure 3

CHEMISTRY 302.12265 - FALL 1972
J. J. Lagowski

TUTORIAL MODULES

CHAPTER	CODE	DESCRIPTION	POINTS
7	CHEM 1	The Gas Laws	15
9	CHEM 114	Henry's and Raoult's Law	10
9	CHEM 60	Heat of Vaporization	10
9	CHEM 61	Kinetic Molecular Theory Applications	10
10	CHEM 116	Colligative Properties	10
10	CHEM 113	Solution Concentration	10
10	CHEM 2	Solution Stoichiometry	10
11	CHEM 119	Equilibrium	15
13 (thru 13.5)	CHEM 107	pH, H^+, pOH OH^-	10
13 (thru 13.9)	CHEM 124	Common Ion Effect	10
13 (thru 13.9)	CHEM 126	K_{sp}	10
14	CHEM 36	Redox Equations	10
15	CHEM 109	Elementary Thermochemistry	10
15	CHEM 139	Thermochemistry	15

SIMULATED EXPERIMENTS

CHAPTER	CODE	DESCRIPTION	POINTS
7	CHEM 3	Molar Volume of N_2	25
10	CHEM 115	Colligative Properties	20
11	CHEM 32	Reaction Kinetics	25
13 (thru 13.5)	CHEM 122	pH and K_I Determination	25
13 (thru 13.9)	CHEM 19	Titration	20
14	CHEM 127	Faraday's Law	20
15	CHEM 41	Calorimetry	25

REVIEW MODULES*

CHEM 20	Interpreting Formulas
CHEM 26	Balancing Reactions
CHEM 27	% Composition
CHEM 29	Interpreting Formulas
CHEM 30	Formula Writing
CHEM 36	Balancing Reactions
CHEM 105	Formula Writing
CHEM 43	Formula Weight
CHEM 44	Mole Ratio
CHEM 45	Mole Concept
CHEM 46	Wt/Wt Relations
CHEM 47	MW of Gases
CHEM 48	Volume-Volume Relations
CHEM 49	Wt-Volume Relations
CHEM 42	Mole Concept

* These modules can be used for review in the subject indicated if you think you need it. No credit is given for working with these modules since they contain information which you should be familiar with.

Figure 4

STUDENT USE COSTS

	# JOBS	TM HRS*	COMPUTER COSTS	LINE COSTS	STUDENT HRS.
Fall 1971	2291	18.944	$ 4925.48	1613.57	1613.57
Fall 1972	7440	24.63			

	COST/ STUDENT HR	RATIO STUDENT HR/TM HR	COST/ ACCESS	AVERAGE TIME/ ACCESS
Fall 1971	4.05	85/1	--	--
Fall 1972	2.07	147/1	$ 0.92	40.9 min

*TM HRS = CPU HOURS + PERIPHERAL OPERATIONS TIME FACTOR

COMPUTER COST FIGURES ON THE BASIS OF $256/TM HR

Figure 5